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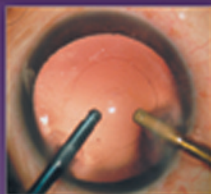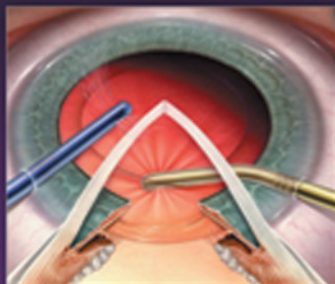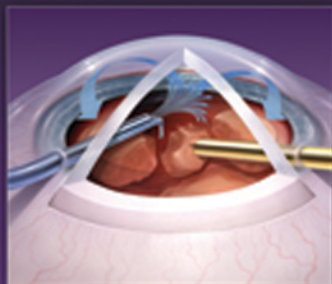
Mastering the Phakonit/MICS Technique

AMAR AGARWAL, MS, FRCS, FRCOphth

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SLACK
INCORPORATED

DEDICATION

This book is dedicated to my parents, Dr. J Agarwal and Dr. T. Agarwal, who created Dr. Agarwal's Group of Eye Hospitals.

And to all the Indian ophthalmologists—Phakonit is India's gift to the world.

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Section Two: Instrumentation and Machines

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Acknowledgments

When Phakonit was started in 1998, I did not realize it would become so popular so fast. I wish I could say it was a brilliant invention of mine, but I cannot. The reason is that this invention (as do all inventions and discoveries) came as a message to me from the Almighty, and so the invention is HIS and only HIS.

About the Editor

Amar Agarwal, MS, FRCS, FRCOphth is the pioneer of Phakonit—Phako with Needle Incision Technology. This technique became popularized as bimanual phaco, microincision cataract surgery (MICS), or microphaco. He also discovered no anesthesia cataract surgery and FAVIT, a new technique to remove dropped nuclei. The use of an air pump to increase the fluid into the eye in bimanual phaco and co-axial phaco has helped prevent surge and built the basis of various techniques of forced infusion for small incision cataract surgery. He was also the first to use trypan blue for staining epiretinal membranes and published the details in his four volume textbook of ophthalmology. His latest discovery is a new refractive error called Aberropia.

Dr. Agarwal has received many awards for his work done on bimanual phaco, the most significant being the Barraquer Award. He has also written more than 20 books that have been published in various languages—English, Spanish, and Polish.

In his center, he also trains doctors from all over the world in phaco, bimanual phaco, LASIK, and retina surgery. Dr. Amar Agarwal is the director of Dr. Agarwal's Group of Eye Hospitals. He practices at Dr. Agarwal's Eye Hospital in Chennai, India.

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PREFACE

Since time immemorial, man has been trying to better his life. Time stands witness that, from the days of couching, we have indeed come a long way. Perhaps no other field of medicine has been so rapidly revolutionized as that of cataract surgery.

It took us many decades to understand that replacement of the lens is the best way to go about rehabilitating vision for the cataract patient. It took us years of experience to understand we need the help of high-energy sources to remove the clouding from the lens. And now we are on the brink of understanding that along with this, a highly efficient management of fluidics can do the job better, faster, and through a much smaller opening. Many thought that phacoemulsification would become obsolete. Though Charles Kelman was routinely doing phacoemulsification in the 1970s, it was only in the 1990s that phacoemulsification really caught on.

With standard phacoemulsification becoming the norm for cataract surgery, bimanual phaco was accepted much faster, as the prospect of breaking the 1.0-mm incision barrier was an exciting one and the potential benefits it held were tremendous.

"Necessity is the mother of invention." It was sheer luck that I chanced upon the idea of making a smaller incision by using a sleeveless phaco to compensate for not having a fragmatome for my vitrectomies. Only when I successfully completed cataract surgeries for vitrectomies in such a fashion did the full implication of the surgery hit me. With greater instrumentation and newer lenses, we have the opportunity to refine our technique further and further thus fully realizing the potential of a microincision surgery.

For hundreds of years, surgeons have used only one hand to do most of their work, needing mechanical pressure of sharp instruments to carry out their job. With time and evolution, we have understood that surgery carried out with both hands is far defter. Furthermore, surgery carried out with fluids discharged with high pressure can have a positive effect on tissues.

Thus came about the need and concept of bimanual phaco—or phakonit. Here the surgeon needs to be able to operate with both hands, while understanding the flow of fluids and the time and placement of the vibrating high energy of ultrasound. If the hands are inside the eye, the feet are on footswitches that control the whole works. Not just that, the surgeon needs to be operating with trained staff that work as a team inside the operating room, because many more hands have to be aiding his work that may take only 5 to 10 crucial minutes.

In this book, I have made an attempt to describe bimanual phaco in its entirety. Though one cannot master surgery by merely reading a book, this book offers to teach you what to do and how to go about it. In this effort, I have made an exhaustive description of the basis, various techniques employed, complications of bimanual phaco, and the practical ways of dealing with them.

Whether it is the air pump, special intraocular lenses, the irrigating chopper, or the sleeveless phaco probe, every piece of equipment necessary to make this surgery routine with your operating team is described by the experts in a manner that will make you want to perform the surgery once you have equipped your mind and body with the advent of newer technologies.

I have made an honest attempt at making this book useful for the surgeons who are newer entrants in the world of bimanual phaco. I am most appreciative of all those who stood by me through all the trying times.

I have also no words to thank John Bond, Amy McShane, Michelle Gatt, Robert Smentek, and the whole team at SLACK Incorporated who asked me to write this book and bore all my idiosyncrasies when I was writing it.

Most important of all, dear reader, this is just the beginning…

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FOREWORD

Charles Kelman's invention of ultrasonic phacoemulsification in 1967 began an inexorable march toward ever-smaller incisions for cataract surgery. In the 1970s, while phacoemulsification remained a specialized procedure, the concomitant development of irrigation/aspiration technology and techniques stimulated the movement from intracapsular cataract extraction to extracapsular cataract extraction, resulting in the first major reduction in incision size since the introduction of the Graefe knife. Refinement of ultrasonic disassembly of the nucleus led to the second transition from extracapsular cataract extraction (ECCE) to phacoemulsification, a transition that extended over two decades.

In addition to technology, a large part of the stimulus for this transition was a series of innovations in surgical techniques, all of which were designed to reduce the size of the principal incision and stabilize it mechanically. Large limbal scissors incisions closed with multiple interrupted sutures were replaced by shelved incisions and creative suture techniques that induced less astigmatism, which in turn gave way to sutureless clear corneal incisions. These innovations ran in parallel with the successive shift from large rigid PMMA lenses, to smaller profile rigid intraocular lenses (IOLs), to foldable silicone and acrylic IOLs.

Now, with the widespread use of injectors for both silicone and acrylic IOLs, permitting incisions slightly under 3.0 mm, some surgeons feel that the incision is now "small enough." But is it small enough? Even with an incision in the range of 2.5 to 3.0 mm, unpredictable shifts in astigmatism occur. With the increasing patient expectation for excellent uncorrected visual acuity, induction of unpredictable astigmatism of any level is undesirable. Furthermore, surgeons appear to be experiencing higher rates of postoperative endophthalmitis despite the use of the latest high penetration broad spectrum antibiotics. The structural integrity of a clear corneal incision is being questioned.

True microincision phacoemulsification, with incisions smaller than 1.5 mm, is, therefore, a logical goal.

Incisions of this size have been a mainstay of ophthalmic surgery for a century, in the form of a paracentesis. The techniques and technology for microincision cataract surgery are now a reality.

A surgeon might then ask whether there is any need to pursue surgical skills in microincision surgery until an intraocular lens is developed that can be inserted through an unenlarged microincision. I believe the answer is yes, for the following reasons. First, a separate larger keratome incision for the sole purpose of introducing the intraocular lens appears to seal more reliably than a keratome incision that is subject to the manipulations and trauma of the ultrasonic and irrigation/aspiration portions of the cataract surgery. Although not yet proven, one may suspect that the potential for postoperative wound leakage and endophthalmitis may be reduced utilizing microincisions for the cataract surgery and a larger incision only for the IOL insertion. Second, the development of microincision cataract surgery techniques serves as a stimulus for further development of small incision IOLs. Foldable and injectable IOLs would never have been developed in the absence of ultrasonic phacoemulsification. Many surgeons in the 1970s argued that Kelman's phacoemulsification was unnecessary because of the large incision needed for the insertion of a rigid intraocular lens. Third, surgeons

who pursue the development of microincision cataract surgery today have the luxury of learning at their own pace. Case selection can be optimized and judicious, with expansion as a surgeon becomes more comfortable with the new instrumentation. The surgeon's skills will then be refined and comfortable when smaller incision IOLs are available. Finally, surgeons who are experienced with microincision techniques already often state that it is an inherently safer and better operation, with a better control of the intraocular environment during the cataract surgery.

Microincision cataract surgery is the future, but it is also very much here in the present!

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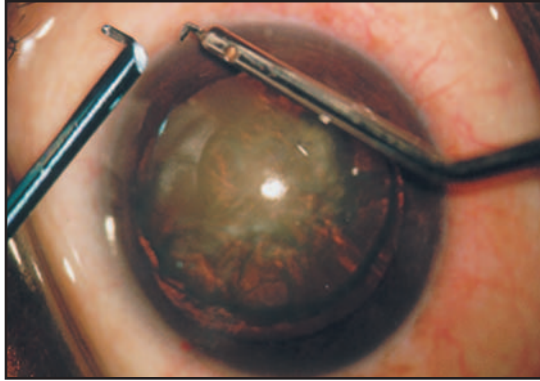
INTRODUCTION AND BASICS

Evolution of Phakonit and Bimanual Phaco

Amar Agarwal, MS, FRCS, FRCOphth

How It All Started

I am basically a vitreoretinal surgeon and used to do all my lensectomies with the phaco handpiece. I did not have a fragmatome (an instrument to remove cataracts by vitreo-retinal surgeons), so I used to remove the infusion sleeve and pass the phaco needle into the lens through the pars plana. Infusion would be performed through the infusion cannula, which is connected in all vitrectomies. This way, I realized I could remove the cataracts in patients in whom I had to continue with vitrectomy for proliferative vitreo-retinopathy or any other posterior segment pathology.

I subsequently began to think about using this system for cataracts for the anterior segment surgeon. The problem was how to have an irrigation system present inside the eye. On August 15, 1998, India's Independence day, the thought of taking a needle, bending it like a chopper and using that for irrigation and chopping occurred to me (Figure 1-1). I also realized that there could be a corneal burn so I thought of irrigating the corneal wound from outside. With this idea in mind, I went to the operation theatre.

In our institute, we have doctors from all over the world training in phacoemulsification (phaco). When I reached the operating theatre, I knew that I could not operate on a patient with a decent soft cataract, since trainee doctors would have to operate on those patients, so I selected for myself a mature cataract. In hindsight, I realize it was a good thing this happened, as it made me understand that this technique could be done in any type of cataract.

When the procedure began, I took out the infusion sleeve from the phaco handpiece and took a 20-gauge needle and connected it to the irrigation bottle. Then I took a needle holder and bent the needle in such a way that it could also be used for chopping. It is easy to understand that a hand bent needle may not come out very well. Another problem with using a needle was that the needles have a bevel; if one pulls out the needle a little bit, the bevel comes out of the eye and the chamber collapses. For the incision, I used the microvitreoretinal blade (MVR blade) which vitreoretinal surgeons use for vitrectomies. While this does not create a perfect valve as the diamond and sapphire knives of today do, it was suitable at that time.

Figure 1-1. Bimanual phaco (Phakonit) done with a bent needle. The needle was bent like a chopper and the first case of Phakonit was done with this instrument. Later on instruments like the refined irrigating choppers were made.
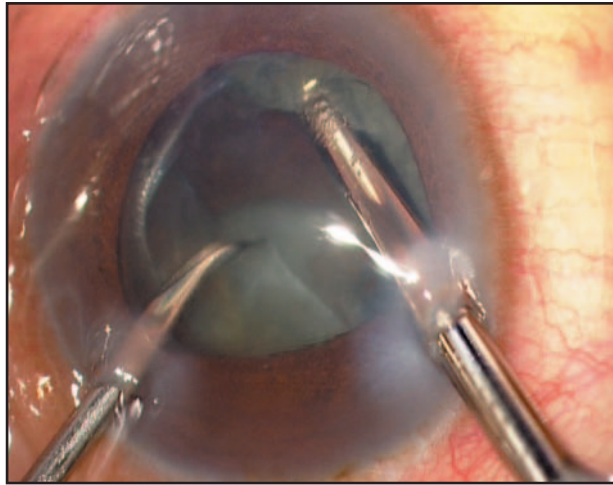
When I had finished the rhexis, I knew hydrodissection was important and tricky. The reason was that the incision size was very small, and therefore, the amount of fluid escaping from the eye would be minimal. So, I was careful to not hydrodissect with a lot of fluid, in order to avoid getting a dropped nucleus during hydrodissection.

When the surgery started, I realized I was having a lot of anterior chamber shallowing. Whenever I would start to remove the nucleus, the chamber would partially collapse. It was obvious that the amount of fluid entering the eye was not enough compared to the amount exiting the eye, so I stopped the surgery and shifted to an 18-gauge needle. To my surprise, everything went well after that. I knew then that the amount of fluid now was balanced with an 18-gauge needle. I could chop the hard cataract (though not as well compared to a chopper), but I knew with more refined instruments this surgical technique would work. Once the surgery was complete, I realized that this could be the next frontier in cataract surgery as the incision was reduced drastically.

Terminology of Phakonit

I wanted to give a name to this surgical technique and started thinking of various names. Some names which came to me at that time were microphaco, miniphaco etc. Then I thought of *Phakonit*—phaco with needle incision technology. The reason I thought of this was because we did phaco using a needle (N) through an incision (I) and with the tip (T) of the phaco needle for the surgery. I used a K (and not a C) in its spelling, as I felt it looked better as PHAKONIT.

Bimanual Phaco

Internationally, the name for Phakonit is *bimanual phaco*. The idea was to separate it from coaxial phaco in which the irrigation is with the phaco handpiece.

In this book we have tried to standardize the terminology and use, by and large, bimanual phaco. It is also known as Phakonit, microphaco, or microincision cataract surgery (MICS). These names are all synonyms of bimanual phaco.

NO ANESTHESIA CATARACT SURGERY

At this stage I would like to digress a bit, and mention another discovery of mine. I was operating on a patient with a posterior polar cataract. Normally in such cases, I used to prefer to do an extracapsular cataract extraction (ECCE). When my fellow rang me up and informed me that the case was a posterior polar cataract, I told her not to block the patient, as I would do ECCE. In those days, I used to do the ECCE under pinpoint anesthesia or subtenons anesthesia, in which I would make a small nick in the conjunctiva and pass a cannula with xylocaine under the conjunctiva and give anesthesia to the patient. This way, the patient does not have an injection and is quite comfortable. When I reached the theatre, I saw the patient and decided to do phaco. When I was in the middle of the case, my fellow came running into the theatre and was very anxious, as she had left before I had started the case. She informed me that she had not put any topical anesthetic drops in the eye as I was going to do subtenons anesthesia for ECCE. She was worried that I would be angry with her. However, I was actually shocked that I was in the middle of the surgery and the patient was not expressing discomfort at all. I told her let us see what happens as this patient obviously did not mind the cataract surgery without anesthesia. When I finished the case, the patient got up shook my hand and thanked me and left the theatre. This set my mind working as I knew this was abnormal.

On June 13, 1998, I was in Ahmedabad, India for a live surgery for a workshop organized by the Indian Intraocular Implant and Refractive society. Although I had discovered that cataract surgery can easily be done without any anesthesia and termed that as *no anesthesia* cataract surgery, I was apprehensive to do it as I felt it was really absurd. In this surgery, no topical anesthetic drops or intracameral anesthesia is used. However, absurd as it may sound, it was true. On June 13, 1998, I decided to do the live surgery without any anesthetic drops. The surgery went very well and there were about 250 eye doctors from all over India watching the surgery. In hindsight, I do not know what made me do the live surgery without anesthesia since I had no way of knowing how successful it would be. When I came back to Chennai (Madras) where I work, I started thinking about it more. At that time, I had a eye doctor from the United States named Dr. Vipul Lakhani training with me. He told me to look at it scientifically and said he would do a double-blind study with me. We took 30 patients that were operated on by my wife (Dr. Athiya Agarwal) and me: 10 were with no anesthesia, 10 with topical, and 10 with topical plus intracameral anesthesia. We did not know which patient we were operating upon. Following the surgery, Dr. Lakhani asked each patient his or her pain factor. At the end, he informed me that his p values showed there was no difference between the three groups. Then I knew no anesthesia surgery was a reality, and since then, have never used topical or intracameral anesthetics. If there is a tough case or an uncooperative patient, I would operate with a peribulbar block. Later, a similar study was done by us with David Apple and Suresh Pandey which was subsequently published in the *Journal of Cataract and Refractive Surgery*.[1,2]

FIRST LIVE PHAKONIT SURGERY

On August 22, 1998, I had to do a live surgery in Pune, India for the Indian Intraocular Implant and Refractive society conference. The organizers asked me what live surgery was I going to perform. I informed them that I was going to perform a new

surgical technique which I had called Phakonit, and would remove cataracts through a 1.0-mm incision. They were very happy and trusted me enough to give me the confidence to proceed.The night before the live surgery, I could not sleep at all. I knew I had to do this new surgery and I had done only five cases at that time. I also knew I had to operate with just a needle, with no refined instruments, and without any anesthesia; this put me under lot of tension. However, the surgery went off very well, and there were about 350 ophthalmologists who watched the live surgery.

PREVIOUS WORK DONE

In 1985, Steve Shearing[14] published a paper on separating the infusion from the phaco handpiece. In 1987, T. Hara from Japan[15] also did the same. I had not heard of any of this work when the concept of Phakonit was started by me. As Phakonit became gradually more popular, work done by these early pioneers was appreciated more and more.

PHACO BOOK

At the time I was writing my first book, *Phacoemulsification, Laser Cataract Surgery, and Foldable IOLs*, which was to be released in September 1998, I immediately contacted the publishers and informed them that I was sending a chapter titled "Phakonit." Although the chapter was quite late and the book was already in press, they agreed and that is how the "Phakonit" chapter came into publication in 1998 itself.[3-13]

IRRIGATING CHOPPERS

I subsequently worked with many companies to make the irrigating chopper and other instruments for Phakonit like the phakonit knife, etc. Various companies now have bimanual phaco instruments designed by various surgeons of the world.

AIR PUMP

One of the main problems in bimanual phaco/Phakonit was the fluidics. As explained earlier, the amount of fluid entering the eye was less than the amount of fluid exiting the eye. My sister, Dr. Sunita Agarwal, understood this problem and started pushing air into the infusion bottle to get more pressurized fluid out of the bottle.[9] When it worked, she then took an aquarium air pump and connected it to the infusion bottle via an IV set. This gave a constant supply of air into the infusion bottle and the amount of fluid coming out of the irrigating chopper was quite enough for us to move from an 18-gauge irrigating chopper to a 20- or 21-gauge irrigating chopper. This was the first time pressurized fluid was used in anterior segment surgeries. The invention of the air pump was made in 1999, and since then we have never looked back. We use the air pump not only in bimanual phaco, but in all our phaco cases.

THREE-PORT BIMANUAL PHACO

Before the air pump I tried to solve the surge problem by fixing an anterior chamber maintainer. This was a three-port bimanual phaco.[2] Once the air pump invention was made by my sister Sunita Agarwal, we realized we did not need the anterior chamber maintainer. The usage of the anterior chamber maintainer made bimanual phaco more cumbersome as three ports were made rather than two.

LIVE SURGERY FROM INDIA: TELECAST TO ASCRS 99

We applied for an instruction course in the ASCRS 99 conference in Seattle; this surgery was to be telecast live via satellite from India to the United States in order to demonstrate Phakonit and no anesthesia cataract surgery. To date, we are very grateful to Dr. Manus Kraff, David Karcher, and the whole ASCRS team for giving us this course. The live surgery went very well, and we took the next flight out to give lectures at the ASCRS meeting, taking advantage of the time difference between the two countries. Many courses were subsequently conducted by us on Phakonit and no anesthesia cataract surgery at the ASCRS, AAO, and ESCRS conferences.

WORK DONE IN 1999

In 1999, P. Crozafon reported the successful use of a sleeveless 21-gauge Teflon-coated tip for minimally invasive bimanual phaco. Crozafon felt that thermal burn could be prevented by coating the phaco tip with Teflon, which has low thermal conductivity.

In 1999, Hiroshi Tseunoka from Japan[16,17] studied the use of ultrasonic phacoemulsification and aspiration for lens extraction through a microincision. Tseunoka used a larger incision as he felt that when the incision size is larger than the phaco tip, the tip gets cooled by the leakage of infusion solution through the incision. The extra space according to him also prevents deformation at the incision site due to tip movement.

MICROINCISION CATARACT SURGERY

Dr. Jorge Alió from Spain[18] coined the term *MICS* or microincision cataract surgery. This meant cataract surgery being done through a 1.5 mm incision or less. This included laser cataract surgery (pioneering work done by Jack Dodick from the United States) and ultrasound.

MICROPHACO

In the fall of 1999, Dr. Randall Olson was the first to create interest in the United States starting by doings studies published in peer review journals to answer the concerns of early critics.[19-22] He helped in developing new equipment that did not restrict inflow. In 2001, Olson reported the feasibility of sleeveless phaco through a 1.0-mm incision using the Sovereign (Advanced Medical Optics [AMO], Santa Ana, Calif) with WhiteStar technology. Olson found that tip heating could be minimized by setting the machine for pulse mode so that ultrasound was generated for extremely short intervals. He coined the term *microphaco.*

HUB OF INFUSION SLEEVE

One problem in bimanual phaco was that there would be a spray of fluid over the cornea whenever it was performed. To solve this problem, one can use the hub of the infusion sleeve. There is no infusion sleeve over the rest of the phaco needle but only over the base of the needle.[3]

SUB-1.0 MM BIMANUAL PHACO SURGERY

Using videos and a special vernier caliper, sub-1.0 mm bimanual phaco surgery was documented and demonstrated. In this case, a 21-gauge irrigating chopper and an 0.8-mm phaco needle were used.[3]

ULTRASMALL INCISION IOLS

Acri.Tec GmbH IOL

Christine Kreiner from Germany made an ultrasmall incision IOL[12] using a special copolymer as the lens material. She founded Acri.Tec GmbH (Berlin, Germany) to manufacture these lenses. Their first lens, the Acri.Smart IOL, was implanted by Kanellopoulos from Greece in 2000.[2] The Acri.Smart was a single piece acrylic IOL which was dehydrated and prerolled.

ThinOptX Rollable IOL

The ThinOptX company (Abingdon, Va), headed by Wayne Callahan, made an ultrathin lens using the Fresnel principles.[8,10] Wayne and Scott Callahan begin developing such a product using an inexpensive lathe, milling machine, and blocking fixture. They then developed a manufacturing process for an extremely thin lens. Most of the work took place in a garage. The first such lens was implanted by Jairo Hoyos from Spain. The second was implanted by Jorge Alió from Spain. They had heard of my work through Kenneth Hoffer (the first President of the ASCRS) and sent me some lenses. I then implanted the lens after bimanual phaco. I realized also that it would be better to have a smaller optic lens, and as a result, designed a special 5.0-mm optic rollable IOL for ThinOptX. They then made this special lens for me and we implanted five such lenses. This was the first 5.0-mm optic ThinOptX rollable IOL implanted. The first smaller sized rollable IOL was implanted on October 2, 2001. These lenses could be rolled, and, hence, the name Rollable IOL—rather than Foldable IOL. The company received a CE Mark in September of 2002, and received approval in the spring of 2004 to start a clinical study in the United States.

SUMMARY

Today, bimanual phaco or Phakonit has taken the ophthalmologic world by storm. This procedure is also known by other names such as MICS or microphaco. The only problem right now is to get more lenses into the market that will pass through sub-1.0 mm incisions, and at the same time not reduce the quality of vision for the patients. These should also have an excellent injector system and should be user friendly. As one will notice many surgeons and pioneers from different parts of the world have made bimanual phaco reach its present status. We have come a long way in cataract surgery but still have a long way to go.

KEY POINTS

✔ Phakonit was started in 1998 using a needle bent like an irrigating chopper and a sleeveless phaco handpiece. Fluid was injected over the clear corneal wound to prevent any corneal burn.

✔ Phakonit is Phaco with Needle Incision Technology.

✔ Other names for Phakonit are bimanual phaco, MICS (Microincision cataract surgery), or microphaco.

✔ No anesthesia cataract surgery was discovered in 1998. This procedure is done without any topical or intracameral anesthetics.

✔ The air pump (first used in 1999) revolutionized bimanual phaco as it pumped air into the infusion bottle, thus allowing more fluid to come out of the irrigating choppers. This was the first time pressurized fluid was used in anterior segment surgeries.

✔ Ultrasmall incision IOLs changed the way the world looked at bimanual phaco. With Acri.Tec GmbH and ThinOptX IOLs in the market, the advantage of the bimanual phaco incision could be utilized.

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TEMPERATURE CONTROL STUDIES

Randall J. Olson, MD and Suresh K. Pandey, MD

INTRODUCTION

We recently showed that incision burns are possible with microphaco (irrigation is separated from aspiration in phacoemulsification) using continuous and pulsed ultrasound at high power.[1] Under similar conditions, incision burn could be produced using micropulse technology (Sovereign WhiteStar, Advanced Medical Optics, Santa Ana, Calif), only if flow and aspiration were occluded.[2] In the cadaver eyes tested with micropulse phaco, the incision temperature did not exceed 32.4°C after 3 minutes of ultrasound energy at 100% power with the aspiration line clamped. This suggests a decreased risk of incision burn with micropulse technology.

Thermistor monitoring of the incision temperature during microphaco using Sovereign WhiteStar micropulse technology in a series of patients using the "divide and conquer" approach also showed no incision temperature elevation above body temperature during ultrasound lens removal.[3] Our conclusion from these studies is that micropulse technology can decrease the risk of incision burn during lens removal.

EYES USED

A fresh, unfrozen, pair of human eyes was obtained (45-years-old at death and only 18 hours from time of death to utilization) for our sleeved ultrasound study to specifically minimize the abnormal incision leakage often associated with frozen human eye bank tissue. For the unsleeved experiments done at the same time we utilized two human eyes frozen for less than 1 week and with less than 24 hours from time of death to enucleation.

MACHINES USED

Legacy with Advantec (L-ADV) (Alcon, Fort Worth, Tex) and Sovereign with WhiteStar (S-WS) (AMO, Santa Ana, Calif) were the phacoemulsification systems used. They were both set at 50% power and used a 20-gauge straight phaco needle with a 30 degree angulated tip and no by-pass hole. L-ADV was set at 15 pulses per second

(pps) and S-WS at duty cycle CF (6 msec on, 12 msec off). Bottle height was at 90.0 cm above the eye measured to the top of the water level in the bottle for sleeved studies and 120.0 cm high for the unsleeved studies.

STUDY WITH A SLEEVED PROBE

A 2.8-mm Storz steel keratome (Bausch & Lomb Surgical, San Dimas, Calif) was used to make a straight in-and-out incision starting at the limbus. A mark was made at the limbus and then 2.0 mm inside the limbus so the entry was at the first mark and the exit into the anterior chamber was at the second mark, making the incision approximately 2.0 mm long. The same blade for the same set of eyes was used throughout the study. A small protractor placed tangential to the wound was used to note a point at the opposite limbus 30 degrees to the right of the incision. This was marked with a methylene blue pen. The BAT 10 microthermistor tip (Physitemp, Clifton, NJ) was placed through the incision into the anterior chamber. After tuning the ultrasound handpiece, the tip with sleeve was also placed through the incision and the microthermistor tip brought back until it was midway into the wound. This was undertaken with the irrigation on to help facilitate this maneuver. The phaco tip was angled so the center of the tip pointed at the limbal marking 30 degrees to the right to increase frictional heat.[4] The microthermistor probe was at the far right side of the incision directly against the sleeve. In this fresh tissue the sleeve easily held the microthermistor probe in place throughout the experiment.

Irrigation and aspiration were used until the temperature was stable. An independent observer noted the temperature and timed the experiment. With the phacoemulsification system foot pedal fully depressed, the temperature was recorded every 5 seconds for 1 minute, while the operator monitored the procedure through an operating microscope. At 10 seconds, the aspiration line was clamped to represent blockage during lens removal. Some leakage was always noted around the sleeve.

At the end of each 1-minute run, a double-bite 10-0 nylon suture was placed in the wound to make sure that it was water tight and then a new incision was made in the eye. The same procedure was carried out, alternating phacoemulsification systems for each run. Seven runs were performed with each system. The high and low runs were discarded.

STUDY WITH A NONSLEEVED PROBE

The same parameters were used for sleeveless phaco. Incisions were made with a 20-gauge steel blade (Microsurgical Technology [MST], Redmond, Wash). Due to the small size of the incision, trying to gauge the length of the wounds was difficult. We therefore simply went straight in parallel to the iris plane. Due to the more edematous nature of these corneas, it was difficult to determine exactly how long the wounds were. However, the process itself was consistent. The same 30-degree mark to the right was made in the same fashion and a second incision was made for the irrigator. We did not make an additional incision for the irrigator for each run; we simply made new incisions for the phaco tip throughout this procedure.

The MST 20-gauge Duet irrigator was placed in the irrigation wound. We had found that the microthermistor was usually damaged when it contacted the phaco tip. We made a small, superficial incision to the right of the phaco wound, approximately 200.0 μm in size and only halfway into the cornea. The microthermistor wire was

Figure 2-1. Comparison of handpiece power at different system power settings and different flow levels for the L-ADV and S-WS systems. Dotted lines indicate the L-ADV system, solid lines the S-WS system. Note that as the load decreases, handpiece power decreases with the L-ADV system and increases with the S-WS system.

placed in this small slit and was held in the tissue approximately one-wire width away (about 100.0 μm) from the ultrasound needle as observed at the highest magnification of our operating microscope. The experiments were then carried out in a fashion analogous to the sleeved experiments. When clamped, leakage was always noted around the ultrasound needle. Only a single-bite 10-0 nylon suture was used to close these small incisions.

To determine how fluid flow affected the operation of the two systems, an independent technical service (Intertek Testing Services) determined the energy utilization for both instruments using 15 pps for the L-ADV and CF for S-WS over the entire power range for operation in fluid, in air, and in air at 1.0 mL/min of flow (Figure 2-1).

With each machine set at 12.0 mL/min the aspiration flow was measured for 3 minutes for 10 runs each. Bottle height was adjusted to 90.0 cm for each run.

Statistical comparison was by Student T-Test. Statistical significance was defined as $P<0.05$.

RESULTS

There was a statistically significant difference in wound temperature between the L-ADV and S-WS systems for sleeved phaco after 10 seconds and for unsleeved phaco after 5 seconds from the time of clamping the aspiration line (Figures 2-2 and 2-3). In all runs, L-ADV ran at a higher temperature than the S-WS after clamping the aspiration line. A clinical wound burn was noted in one L-ADV run of sleeved phaco. There were no wound burns with the S-WS. As each run progressed, particularly with sleeveless phaco (microphaco), the L-ADV system would often substantially decrease ultrasound power. In some instances, ultrasound output ceased. As soon as we noted the decrease or loss of ultrasound power, we stopped the run. This affected the power of our analysis in that we did not have many data points toward the end of our L-ADV experimental runs. This did not happen for the S-WS system.

Energy utilization experiments showed clear differences when the machines functioned in air (no or 1.0 mL/min flow) or a fluid environment (12.0 mL/min fluid flow).
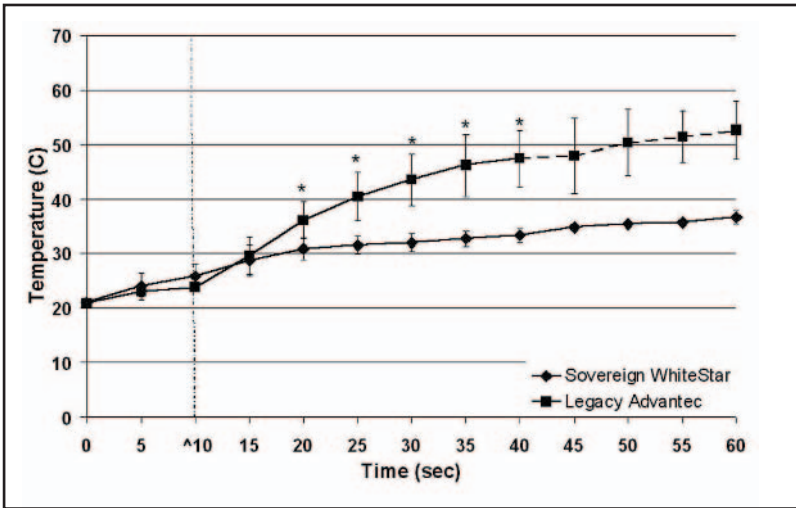
Figure 2-2. Mean temperature scores for L-ADV and S-WS (sleeved experiments). Power was 50%, flow 12 mL/min, and the phaco tip angled at 30 degrees to mimic a possible wound burn situation for all runs. Aspiration line was clamped to stimulate occlusion at 10 seconds. L-ADV was set for 15 pps, S-WS for duty cycle CF, 6 msec on:12 msec off. *Indicates significant difference between the two groups at P≤0.05. †Indicates signs of wound burn. Dotted line indicates times at which the Legacy Advantec handpiece detuned during the run, and was excluded from the analysis.
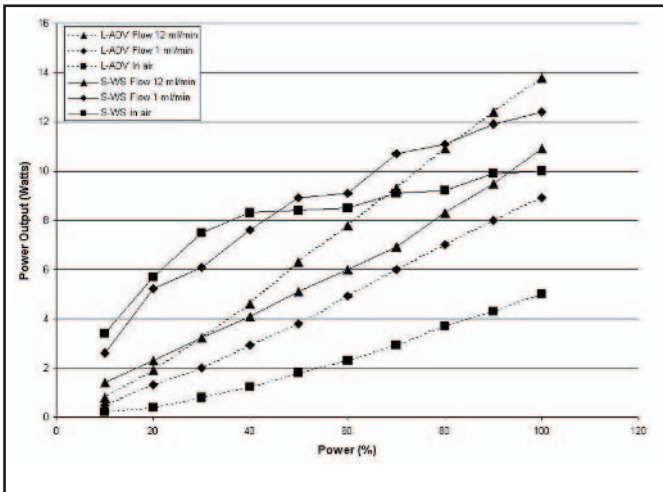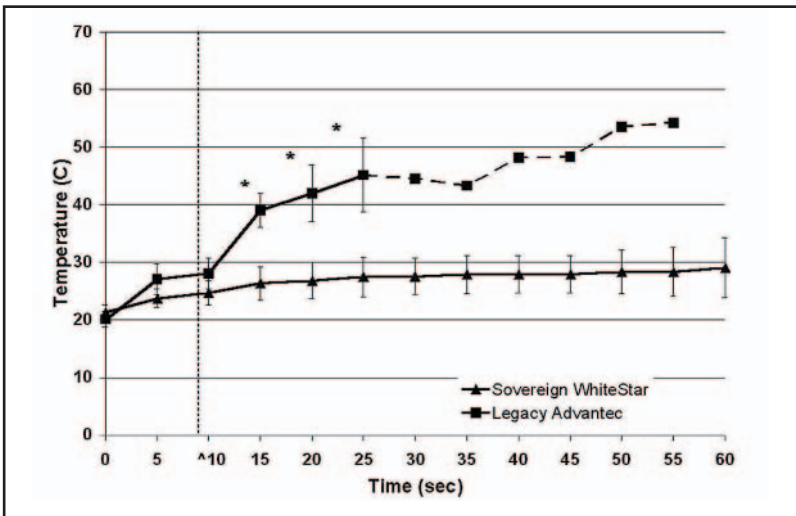

Figure 2-3. Comparison of handpiece power at different system power settings and different flow levels for the L-ADV and S-WS systems. Dotted lines indicate the L-ADV system, solid lines the S-WS system. Note that as the load decreases, handpiece power decreases with the L-ADV system and increases with the S-WS system.

L-ADV sharply decreased energy utilization, particularly in air but also with 1.0 mL/min flow, while S-WS substantially increased energy utilization with the highest energy utilization at 50% power while in air and at 1.0 mL/min flow in air (see Figure 2-1). The L-ADV had significantly more fluid flow than S-WS. (For 3 minutes S-WS 35:4±0.25 mL; L-ADV 38.9±0.24 mL; P<.0001). S-WS was closer to the stated 12.0 mL/min flow (11.8 vs 13.0 mL/min).

DISCUSSION

The laws of thermodynamics are absolute, therefore, all believable results must exist within their framework. If all other parameters are equivalent then equal stroke length must result in equal frictional heat generation, which is the culprit in wound burn. Frequency differences can be counterbalanced by changes in stroke length to again produce equivalence. If all of these factors have then been brought to equivalence, a shorter duty cycle (percent of time on) will always produce less frictional heat than a longer duty cycle over time. Any results contrary to this suggest some other factors must have come into play.

While we have not determined all of the differences, a very important one is how these two machines behave under load. The L-ADV handpiece protects its stroke length so it idles in air and will work increasingly harder with increasing load. The S-WS handpiece protects its power output so except our results show it races in air actually increasing the power and stroke length and under increasing load will have an increasingly shorter stroke length with comparatively less frictional heat generation. So incisional temperature comparisons without a load (ie, in air) will dramatically favor L-ADV, while with increasing load S-WS will come out ahead. These differences are inherent in the machines and have nothing to do with ultrapulse or 15 pps Advantec software.

There are other important potential issues. Fluid flow is very effective in removing frictional heat generation. Parameters, as listed machine to machine and even cassette to cassette, are bound to vary as they did in our case. Although set at 12.0 mL/min, L-ADV pulled an average of 13.0 mL/min of aspiration (statistically more than S-WS) which would lower the L-ADV temperature, all else being equal. This must be considered in any incisional temperature study. Incision leakage is another way of changing fluid flow. Reproducible incision creation is therefore very important. A further example is an ultrasound needle by-pass port that effectively creates a leak under occlusion and will thereby indirectly cool the incision.

Our two Legacy machines, when occluded, would often drop power or cease operation after 15 to 30 seconds in an admittedly torturous situation. This is a laudable safety feature to protect against incision burns, however, when it comes into play, any feature comparison is further rendered meaningless because such events were not noted with the S-WS unit.

To further complicate the picture there are no industry standards, so power at any setting does not necessarily have any equivalence between machines from different manufacturers. Also, there are probably other factors we have not considered which makes any comparison problematic.

Conclusion

So with this information as a background we can conclude:

1. Under the increased frictional load (friction directly increases ultrasound tip work) of our experiments (tight wound and angled tip), a stroke length protected instrument (L-ADV) will always generate more frictional heat than a power protected instrument (S-WS) if stroke length is about equal in an unloaded fluid environment.

2. Air as a medium is both clinically irrelevant and distinctly favors the L-ADV handpiece irrespective of any other handpiece feature.

3. All else being equal, frictional heat from a pulse will be the same no matter who the instrument maker might be.

Key Points

✔ If all other parameters are equivalent then equal stroke length must result in equal frictional heat generation, which is the culprit in wound burn. Frequency differences can be counterbalanced by changes in stroke length to again produce equivalence. If all of these factors have then been brought to equivalence, a shorter duty cycle (percent of time on) will always produce less frictional heat than a longer duty cycle over time.

✔ Ultrapulse ultrasound is significantly cooler with the Sovereign unit than pulsed ultrasound with Legacy Advantec software.

✔ Under the increased frictional load (friction directly increases ultrasound tip work) a stroke length protected instrument like the Legacy will always generate more frictional heat than a power protected instrument like the Sovereign if stroke length is about equal in an unloaded fluid environment.

✔ All else being equal, frictional heat from a pulse will be the same no matter who the instrument maker might be.

✔ Fluid flow is very effective in removing frictional heat generation.

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THERMAL BURN STUDIES IN ANIMAL EYES

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INTRODUCTION

There are two different types of procedures used in emulsification of the nuclei: *nonoccluded emulsification* and *occluded emulsification* (Figure 3-1A and B). In nonoccluded emulsification, the nucleus is emulsified while avoiding complete occlusion of the phaco tip (Figure 3-1A). In occluded emulsification, the phaco tip is completely occluded during part of the phacoemulsification process (see Figure 3-1B). During nonoccluded emulsification, the solution in the eye is aspirated through the phaco tip. The flow of infusion solution around the outside of the tip is approximately equivalent to the aspiration volume. So, the phaco tip is cooled both internally by aspiration flow and externally by the infusion flow. Thermal burn is unlikely to occur. In contrast, during occluded emulsification, no infusion solution moves through the phaco tip. The amount of solution flowing around the outside of the tip is limited to the amount which leaks through the incision. If there is only a little leakage, thermal burn can easily develop.

EXPERIMENTAL THERMAL BURN WITH PHACO IN PORCINE EYES

I experimented in postmortem porcine eyes in order to find out how much the temperature would rise at the incision site during ultrasound operation with complete occlusion in emulsification of the nucleus, when there was no aspiration of infusion solution through the tip. The phacoemulsification machine which I used was Legacy 20000 (Alcon, Fort Worth, Tex) equipped with a 20-gauge phaco tip. To measure temperatures at the corneal incision site, I used a sheathed thermocouple (Figure 3-2) manufactured by Toa Electronics Company LTD (Tokyo, Japan) (Model No. TSC-K0.3) and a temperature recorder manufactured by Chino KK (Japan) (Model No. AR5757-F00).

Figure 3-1. Two types of procedures used in phacoemulsification of the nucleus. A) Nonoccluded emulsification. The nucleus is emulsified while the phaco tip is not completely occluded. Infusion solution is aspirated through the phaco tip during phacoemulsification. B) Occluded emulsification. The nucleus is emulsified while the phaco tip is completely occluded. There is no infusion solution aspirated through the phaco tip during phacoemulsification.
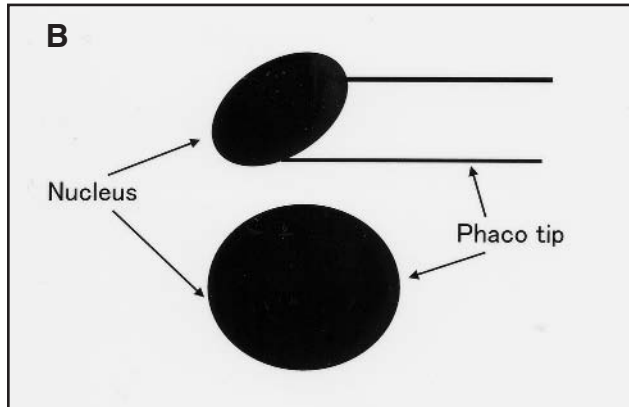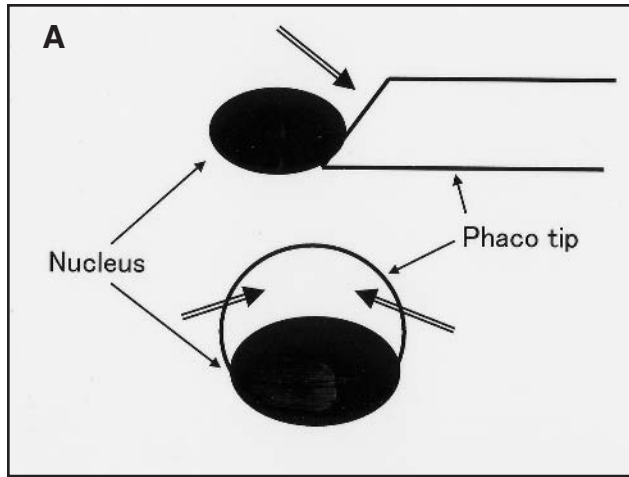
Figure 3-2. Method for measuring temperature at the incision site. The thermocouple is inserted into a tunnel created in the cornea above the incision site, and temperature at the incision site is measured with ultrasound.
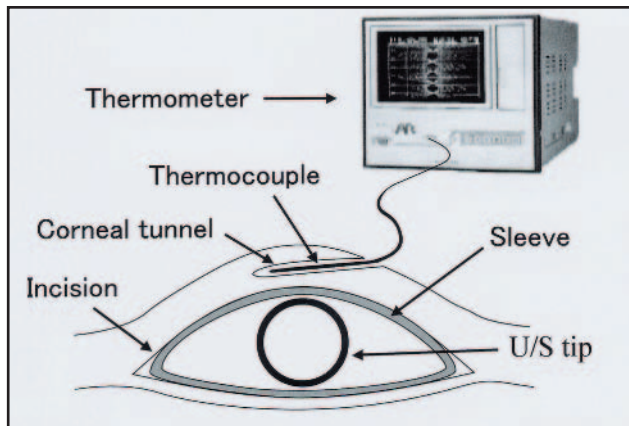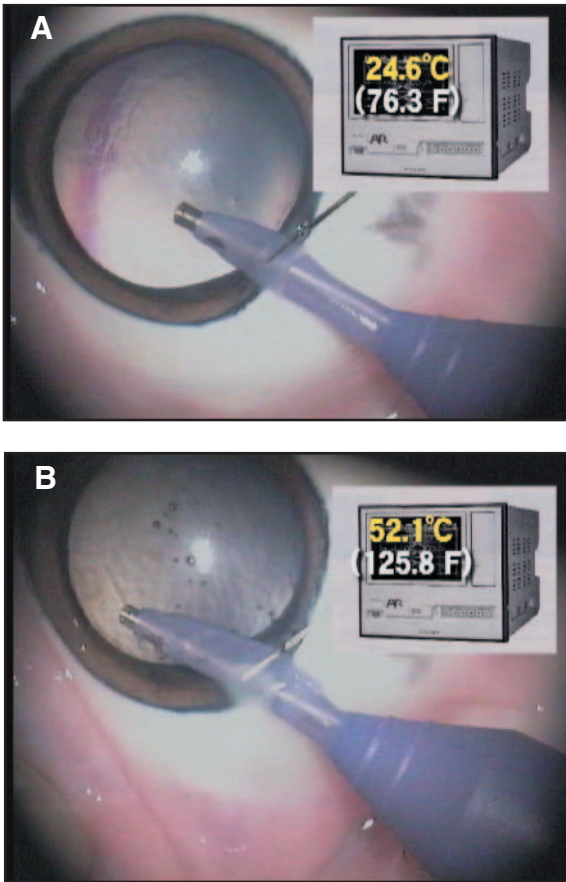
Figure 3-3. Measurement of the temperature at the incision site during conventional phacoemulsification in postmortem porcine eyes using a thermometer.
Phaco machine setting: Aspiration.
Port: Occluded.
U/S power: 80%, continuous mode.
U/S duration: 2.0 min continuous.
A) A 20-gauge phaco tip with the infusion sleeve was inserted through a 3.0 mm incision, and ultrasound were operated. Temperature at the incision site rose only slightly while the tip was kept from pressing on the incision wall.
B) A 20-gauge phaco tip was pressed against the incision wall during ultrasound operation. Once the tip was pressed against the incision wall during ultrasound operation, the temperature at the incision site rose significantly and a thermal burn developed.

I incised the porcine cornea using a 3.0-mm slit knife. I then used the 20-gauge keratome to create a tunnel parallel to the incision site in the upper cornea for insertion of the thermocouple electrode of the thermometer. I measured temperature elevation at the corneal incision three times during each test while performing phacoemulsification with phaco tip occluded (see Figure 3-2). I used a clamp to close the aspiration tube so that aspiration was completely occluded during ultrasonic wave generation. I set the ultrasound power at 80%, turned on the ultrasound, and operated the unit for 2 minutes continuously.

- *Measurement 1*: A 20-gauge phaco tip with an infusion sleeve was inserted into an incision 3.0 mm in width, and precautions were taken to ensure that the tip did not press the incision wall while ultrasound was operating.

  Result 1: Temperature of the cornea at the incision site was elevated by 7.7°C, with no thermal burn developing even after 2 minutes (Figure 3-3A).

- *Measurement 2*: A 20-gauge Kelman phaco tip with sleeve was inserted into an incision 3.0 mm in width, and the tip was allowed to press the incision wall while ultrasound was operating.

  Result 2: Temperature increased progressively over the time course of the test, and thermal burn developed. Mean temperature elevation was 26.3°C (Figure 3-3B).

Figure 3-4. Measurement of the temperature at the incision site during phaco-emulsification with sleeveless phaco tip in postmortem porcine eyes using a thermometer. Phaco machine setting.
Aspiration port: Occluded.
U/S power: 80%, continuous mode.
U/S duration: 2.0 min continuous.
A 20-gauge phaco tip without the infusion sleeve was inserted through a 19-gauge incision, and ultrasound was operated. Temperature did not rise at the incision site even when the tip was pressed against the incision, and no thermal burn developed.

INCISION TEMPERATURE DURING BIMANUAL PHACO IN PORCINE EYES

I believed that if the incision was made slightly wider than the outer diameter of the phaco tip, the sleeveless phaco tip would be satisfactorily cooled by the leakage of infusion solution through the incision, preventing thermal burn at the incision site. To test this hypothesis I measured temperature at the incision site in postmortem porcine eyes during bimanual phaco with sleeveless phaco tips using the same devices and methods mentioned above.

I created a corneal incision in the postmortem porcine eye using a 19-gauge micro-vitreoretinal (MVR) blade (actual incision width is 1.4 mm). I inserted a sleeveless 20-gauge phaco tip through the 19-gauge incision and an infusion cannula through the corneal side-port. Because there was no aspiration through the phaco tip, these conditions were similar to completely occluded emulsification. I performed 3 measurements of temperature elevation at the corneal incision during ultrasound oscillation. The phaco tip was pressed against the incision, and ultrasound waves were generated continuously for 2 minutes at 80% ultrasound power. Our results showed a mean temperature elevation of 8.4°C. At no time during the procedure did the temperature at the incision site exceed 40°C, and no thermal burn was observed (Figure 3-4).

EXPLANATION IN PHACO

During completely occluded emulsification, no infusion solution is aspirated through the phaco tip. This means that infusion around the tip is equivalent to leakage through the incision. The infusion sleeve is soft, so it deforms to match the shape of the incision when the tip is inserted. This reduces leakage through the incision, and therefore also reduces the amount of infusion solution flowing around the outside of the tip (Figure 3-5A).

Under these conditions, if the phaco tip is pressed against the incision wall, then friction will develop between the tip and the sleeve. Because only a little infusion solution flows around the outside of the tip, the heat of friction is not dispersed. Instead, this heat is transmitted to the surrounding tissue, and thermal burn develops. In this experiment, temperature at the incision site rose to 52°C (Figure 3-5B).
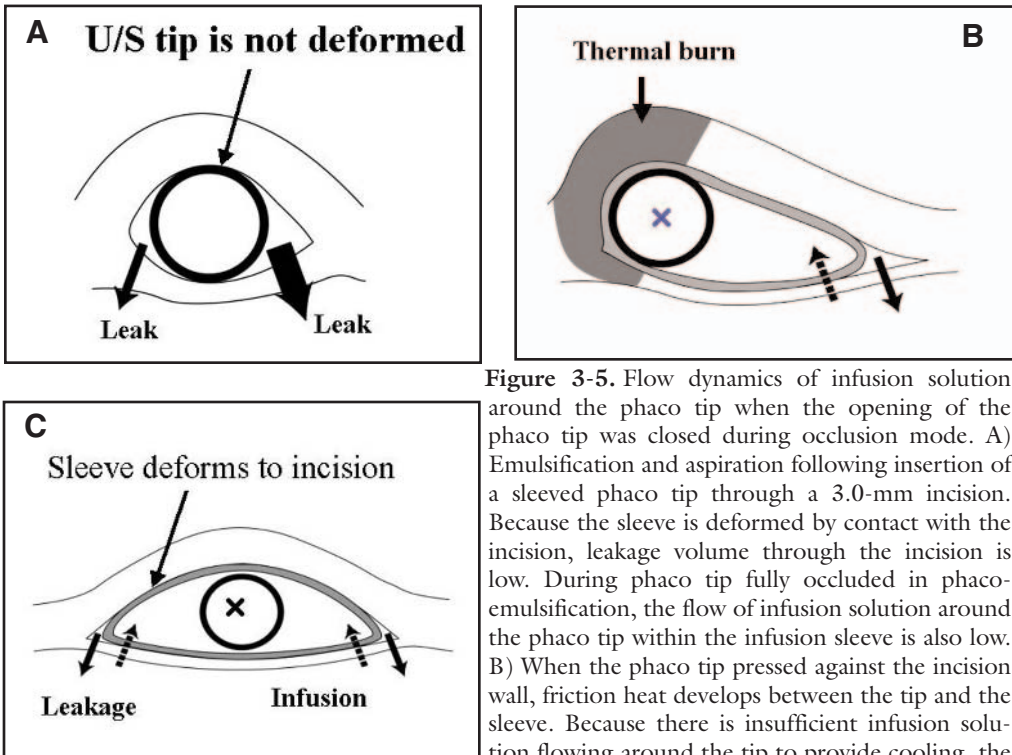
Figure 3-5. Flow dynamics of infusion solution around the phaco tip when the opening of the phaco tip was closed during occlusion mode. A) Emulsification and aspiration following insertion of a sleeved phaco tip through a 3.0-mm incision. Because the sleeve is deformed by contact with the incision, leakage volume through the incision is low. During phaco tip fully occluded in phaco-emulsification, the flow of infusion solution around the phaco tip within the infusion sleeve is also low. B) When the phaco tip pressed against the incision wall, friction heat develops between the tip and the sleeve. Because there is insufficient infusion solution flowing around the tip to provide cooling, the heat is transmitted to tissues at the incision site. Thermal burn develops at the incision. C) Emulsification and aspiration following insertion of a sleeveless 20-gauge phaco tip through a 19-gauge (1.4-mm) incision. Because the phaco tip is hard and not deformed by passage through the incision, there is space between the tip and the incision. Thus the maximum possible volume of infusion solution is available to flow around the tip, providing cooling for any friction between the tip and the incision tissue. No thermal burn develops at the incision site.

EXPLANATION IN BIMANUAL PHACO

When using a phaco tip with the infusion sleeve removed, the tip comes into direct contact with tissue at the incision site. However, because the phaco tip is hard, it does not deform even when inserted into the incision and pressed against the incision wall. This means that there is considerable space between the incision and the phaco tip, which allows ample leakage of infusion solution. The leaked solution keeps the phaco tip cool. As long as adequate leakage flow can be maintained between the incision wall and the tip, even when the phaco tip is completely occluded during ultrasound operation, thermal burn does not occur (Figure 3-5C). Especially in the case of a hard nucleus, this larger incision reduces the elevation of the temperature of the phaco tip, and no thermal burn develops, even when the tip is completely occluded and ultrasound is oscillated long time, because solution leaking through the incision provides sufficient cooling of any friction heat which may develop between the tip and the surrounding tissue. By implementing this technique, thermal burn is less likely to occur when using a sleeveless tip than when using a tip equipped with the infusion sleeve.

Summary

When we perform bimanual phacoemulsification, one of the main points in our surgical technique involves the use of an incision which is 1 gauge larger than the outer diameter of the phaco tip. This means that the incision for a 20-gauge phaco tip is made using a 19-gauge (1.4 mm) MVR, and for a 21-gauge phaco tip I used a 20-gauge (1.2 mm) MVR. The slight space between the phaco tip and the incision wall also prevent deformation and injury at the incision site due to movement of the phaco tip.

Key Points

- ✔ If the incision is made slightly wider than the outer diameter of the phaco tip, the sleeveless phaco tip is satisfactorily cooled by the leakage of infusion solution through the incision, preventing thermal burn at the incision site.
- ✔ When using a phaco tip with the infusion sleeve removed, the tip comes into direct contact with tissue at the incision site. However, because the phaco tip is hard, it does not deform even when inserted into the incision and pressed against the incision wall. This means that there is considerable space between the incision and the phaco tip, which allows ample leakage of infusion solution. The leaked solution keeps the phaco tip cool.
- ✔ As long as adequate leakage flow can be maintained between the incision wall and the tip, even when the phaco tip is completely occluded during ultrasound operation, thermal burn does not occur
- ✔ In the case of a hard nucleus, this larger incision reduces the elevation of the temperature of the phaco tip, and no thermal burn develops, even when the tip is completely occluded and ultrasound is oscillated long time, because solution leaking through the incision provides sufficient cooling of any friction heat which may develop between the tip and the surrounding tissue.
- ✔ By implementing this technique, thermal burn is less likely to occur when using a sleeveless tip than when using a tip equipped with the infusion sleeve.

FLUIDICS IN BIMANUAL PHACO

L. Felipe Vejarano, MD and Alejandro Tello, MD

INTRODUCTION

When performing bimanual phaco or Phakonit surgery, knowledge and management of fluidics are crucial. The issue of destabilization of the anterior chamber in bimanual phaco surgery, mentioned by several authors, like Tsuneoka,[1] is basically due to the fact that more fluid is going out of the eye than the amount that is entering into the anterior chamber in a given moment. This has been a problem for surgeons initiating bimanual phaco, since the irrigation rate in this technique is usually less than in standard phacoemulsification.

FACTORS

The factors that influence fluid balance in bimanual phaco are several:

- The infusion rate of the irrigating instruments. This is determined by the fluidic resistance of the irrigating line and instruments (determined by the inner diameter of tubing and instruments—chopper—and the irrigating port size) and the pressure of the fluid (bottle height, or amount of positive pressure applied to the bottle by any active system).

- The amount of leakage through the incisions, determined by the relation between the outer diameter of the instruments (phaco needle and irrigating chopper) and the incision architecture (size and presence of an inner valve).

- The amount of fluid aspirated through the phaco needle, determined by the fluidic resistance of the aspirating line (determined by the inner diameter of the tubing and needle) and the level of vacuum.

It is necessary to maintain an equilibrium between these factors, in order to achieve a stable anterior chamber, without jeopardizing the intraocular tissues (iris, endothelium, posterior capsule). This is more crucial when dealing with the surge phenomenon. Since the goal of the surgery is not solely to maintain an anterior chamber space, but to permit the emulsification of the nucleus, it is necessary to use high vacuum levels in order to achieve a good purchase of the nucleus and its fragments, and perform an

effective chopping procedure. In this setting, when occluding the phaco tip, the nuclear fragment will cause an aspiration line vacuum build up. At the moment the occlusion is broken, and the fragments are rapidly aspirated, the fluid in the anterior chamber (which has reached a high pressure while the occlusion lasted) tends to rush into the aspiration line through the phaco tip, and the phenomenon of surge may occur. This situation is even more critical in bimanual phaco cases, since the irrigation rate is usually lower than in standard phacoemulsification.

SURGE CONTROL

Surge control has been managed with several approaches by manufacturers. Since the amount of fluid that surges into the aspiration port is a function of the device's compliance, any fluid circuit component which was changed in volume by the high vacuum needs equilibration, for instance decreased tubing volume. If the tubing becomes constricted during the occlusion, it then expands on occlusion break, and this expansion is an additional source of vacuum production. This fluid may not be replaced rapidly enough by infusion to prevent shallowing of the anterior chamber. Thus having tubes reinforced to prevent collapse, with minimal compliance, will help to avert surge. Of course, they should still allow an ergonomic manipulation of the tubing/handpiece, as well as (in peristaltic pumps) allow the adequate functioning of the pump mechanism.

Machines Minimizing Surge

Some machines have additional features designed to diminish the possibility of surge. The Prestige (AMO, Santa Ana, Calif) decreases its pump speed as the actual vacuum approaches the maximum vacuum preset. The microprocessor controls a process akin to programmed rise time. Through a feed-back system, pump speed regulation is related to the prevailing vacuum. Deflection of a flow-sensitive diaphragm on the aspiration side is translated into voltage, which decreases the pump speed when 50% of the targeted vacuum has been reached.[2] When the pressure transducer senses an occlusion break, the pump speed is increased again over a short time rather than abruptly in order to minimize the amount of vacuum which needs equilibration by venting. The Sovereign (AMO) merges the advanced high vacuum fluidics of the AMO Prestige unit with the burst and occlusion mode programmability of the AMO Diplomax. The Sovereign has an on-board fluidic computer that allows the pump to rotate forward and backward, helping surgeons to control the release of vacuum. Microprocessors sample vacuum and flow parameters 50 times a second, creating a "virtual" anterior chamber model. At the moment of surge, the machine's computer senses the increase in flow and instantaneously slows or reverses the pump to stop surge production. The machine has several settings for pre- and postocclusion, four phaco modes, and four memory modes.

The Series 20000 Legacy (Alcon, Fort Worth, Tex) has a pump system called TurboStaltic pump that is a very smooth system, having a floating head so there are no pulsations as the pump speed and vacuum build-up takes place. It has noncompliant fluidic channels to allow for higher vacuum with fewer pulsations. The tubing in the cassette (MaxVac) has been replaced with rigid plastic fluidic channels that are totally noncompliant. It has the option of smaller aspiration tubing lumen, which providing increased fluidic resistance reduces total flow from the eye; that tubing has a thicker

wall to reduce the compliance, and these features help to obtunds surge, even using high vacuum.

The Storz Millennium and the Premiere (Bausch & Lomb Surgical, San Dimas, Calif) also achieve a low system compliance via the use of lower compliance tubing. Moreover, using the Millennium, the dual linear foot pedal can be programmed to separate both the flow and vacuum from power. In this way, flow or vacuum can be lowered before beginning the emulsification of an occluding fragment. The emulsification therefore occurs in the presence of a lower vacuum or flow so that surge is minimized. Separating simultaneous linear control of vacuum and ultrasound into two planes of pedal movement (pitch and yaw) with linear control of vacuum in phaco mode, the surgeon can approach material with safer lower vacuum levels and increase it only after desired material is positively engaged. Most vacuum pumps do not allow attenuation of rapid rise times, although the Storz Millennium and the Premiere machines are exceptions. These pumps allow the surgeon to set a time delay for full commanded vacuum build-up which starts when the surgeon enters foot pedal position 2. However, once this delay has elapsed, any subsequent engagement of material will be exposed to a typically rapid vacuum pump rise time.

Phaco Needles

Other alternatives have been developed to avoid or minimize surge, including changes in phaco needle designs, to make them more safe and effective. The standard 19-gauge phaco needle has an outer diameter of 1.1 mm and an inner diameter of 0.9 mm. It has a good holding power due to its large surface area, especially if beveled. However when the occlusion is broken, there is possibility of surge, since the inner diameter is large. The MicroFlow tip (Bausch & Lomb Surgical) designed by Barrett[3] has an outer diameter of 1.07 mm (similar to a standard phaco needle), and although it has also an inner diameter of 0.9 mm at the tip (again, similar to a standard phaco needle), it has a smaller shaft inner diameter (0.5 mm). This tip has a good holding force, but unlike a standard 1.1 phaco needle, it provides a fluidic resistance due to its smaller shaft inner diameter, avoiding sudden increment in flow levels, after breaking the occlusion, when emulsifying fragments. It reduces this flow by about 40%. Another advantage of this design is that, due to its large diameter just at the tip, more volume of nuclear material can be engaged and aspirated per unit of time of ultrasound power application relative to micro needles, which are effective preventing surge, but are less effective emulsifying the nuclear material. Moreover, since the MicroFlow design, has an internal ring surface within the tip, perpendicular to the long axis of the needle and therefore to the direction of the movement of the tip while applying ultrasonic energy, produces additional cavitation. It is possible, however, that after emulsifying some lens material and returning to position 2 in the foot pedal, the emulsified material plugs the shaft (which is only 0.5 mm in diameter) and aspiration may become compromised. When the surgeon notes that situation, it is necessary to apply a small amount of ultrasound energy (even to the aqueous, if there is not more material to emulsify) just to make the tip vibrate and solve the obstruction.

Other tip designs using a similar principle are the flared tips, like the MicroSeal (Alcon). The difference is that this needle has a smaller outer shaft diameter (0.8 mm vs 1.1 mm) and a larger inner shaft diameter (0.6 mm vs 0.5 mm) than the MicroFlow. It works in a similar way, but for microincision surgery, the disparity between the diameter at the tip (1.1 mm) and the outer shaft diameter (0.8 mm) may cause an excessive leakage through the incision.

Aspiration Bypass System

Other approaches to the issue of surge, has been to design a bypass port on the side of the phaco tip (Aspiration Bypass System—ABS). The ABS tips have 0.175 to 0.230 mm (depending if it is the microtip or standard tip) holes drilled in the shaft of the needle. During occlusion, the hole provides for a continuous alternate fluid flow, yielding 4.0 to 15.0 cc/min, depending in the tip diameter and vacuum level. This will cause dampening of the surge on occlusion break. The ABS port remains inactive as long as the main port is not occluded. This system is used in the Legacy system in its Turbosonics ABS phaco tips (Alcon).

Coiled Tubing

Some manufacturers have designed other special tubing systems to diminish the flow. A coiled tubing may help to slow the flow in the aspiration line, thus keeping the anterior chamber deep and stable. The flow exiting the eye is slowed by the resistance of the curvature of each coil in the tubing. STAAR Surgical (Monrovia, Calif) uses this system (UltraVac V1).

Vacuum Surge Suppressor

Other options to obtund surge include devices designed to be placed in the way of the aspiration line. One of these is the Vacuum Surge Suppressor—VSS (Surgin Inc, Tustin, Calif) (Figure 4-1). It is incorporated in the aspiration line and adjacent to the handpiece, and regulates fluid flow out of the eye (Figure 4-2). As vacuum increases, VSS constricts, thereby limiting fluid outflow and maintaining a deep and stable anterior chamber.

CRUISE CONTROL

Cruise Control is a device developed by STAAR as a filter between the phaco handpiece and aspiration tubing that captures nuclear material. The principle is the same—to reduce flow. It easily attaches to aspiration port on the phaco handpiece, and is compatible with peristaltic or venturi phaco machines. It has a cylindrical filter mesh that retains all cataract material coming from the phaco handpiece. Only clear fluid flows into the aspiration line. Occlusions and stagnation in the tubing are eliminated. Cruise Control limits the flow in a nonlinear manner such that only excessive flows are limited. Regular flow rates, below 50.0 cc/min, are not affected. Cruise Control works regardless of the size and configuration of phaco tips or tubing, and may be more forgiving with bottle height.

ANTERIOR CHAMBER MAINTAINER

During the transition to bimanual phaco a surgeon may resort to an additional source of balanced salt solution (BSS), in order to guarantee a steady anterior chamber. Blumenthal has shown that using an anterior chamber maintainer during standard phacoemulsification reduces both the amplitude and frequency of the anterior chamber depth fluctuation.[7] This may be not so critical in standard phaco, but may be helpful for the surgeon beginning bimanual phaco. The disadvantage of using an Anterior Chamber Maintainer is the necessity of a third incision, but it makes the procedure very safe for the beginning bimanual phaco surgeon, not only because it prevents
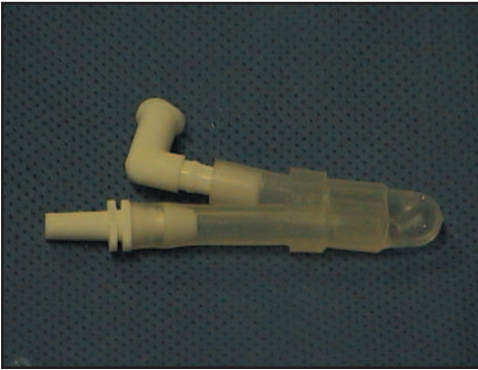
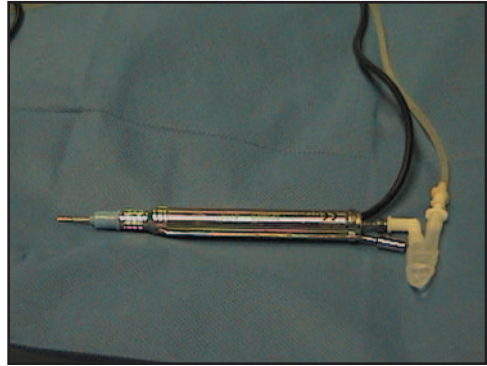**Figure 4-1.** Vacuum Surge Suppressor—VSS (Surgin Inc, Tustin, Calif).

Figure 4-2. The Vacuum Surge Suppressor is incorporated in the aspiration line and adjacent to the handpiece, and regulates fluid flow out of the eye. As vacuum increases, the VSS constricts, thereby limiting fluid outflow and maintaining a deep and stable anterior chamber.

surge, but also because it can maintain the anterior chamber depth in case the surgeon mistakingly retracts the irrigating chopper more than normal thus losing inflow.

Care must be taken with the direction of the inflow tube of the Anterior Chamber Maintainer, because if it is directed too posterior, it could touch the iris or the capsule (causing a variable degree of trauma), and could be cumbersome for the surgeon. Maybe the best way to place the Anterior Chamber Maintainer is like Blumenthal describes,[8] using a 1.5-mm corneal tunnel, parallel to the limbus. The usage of two BSS bottles (one connected to the irrigating chopper, and the other to the Anterior Chamber Maintainer) will increase the flow, but will not increase the IOP in a significant amount.

Of the three parameters mentioned at the beginning of the chapter, the infusion rate and the amount of fluid aspirated through the phaco needle (determined by bottle height, or amount of positive pressure applied to the bottle by any active system, and vacuum level, respectively, and both influenced by the resistance of the lines and instruments) may be changed easily during the procedure, and should be increased and decreased, respectively, when a surgeon first notices modest chamber shallowing immediately following occlusion breaks. Although for phacoemulsification conventional gravity feed has been the standard, it is not the best option in microincision surgery.

AIR PUMP

Agarwal created an ingenious system (the "antichamber collapser") using an aquarium pump to generate a power fluid infusion (see Chapter 7), placing a micropore air filter between the air pump and the infusion bottle.[9] A drawback of the system is that it is difficult to adjust it to different levels of inflow. This kind of forced infusion is available in several phacoemulsification machines. Storz Premiere unit does have a pressurized inflow system (IOP control), that injects air to the infusion bottle, and setting it at a level of 80.0 mmHg we were able to achieve the infusion rate of 42.0 cc/min

Figure 4-3. Flow rate of the Vejarano´s Irrigating Chopper, using gravity at different heights.
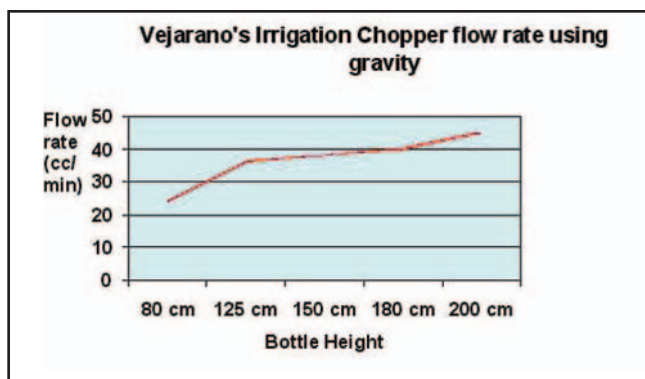
through the Vejarano's Irrigating Chopper (AC7340, Accutome, Malvern, Pa), using it along with standard IV sets. An advantage of this kind of device is that it can be adjusted, increasing or decreasing the air pressure, and thus increasing or decreasing the inflow rate. In some instances this pressurized inflow may be raised up to its maximum (100.0 mmHg). The Accurus machine (Alcon) has also a digitally controlled infusion system for instant access to elevated pressures via the foot switch, utilizing the Anterior Vented Gas Forced Infusion Tubing (VGFI), it can reach the level of 120.0 mmHg.

We measured the flow rate of the Vejarano´s Irrigating Chopper, using gravity (at different heights) and using the IOP-pressurized inflow in the Storz Premiere (at different levels of pressure), our results are shown in Figures 4-3 and 4-4. The wide difference between the two systems is evident. It is crucial when using this kind of instruments, since the inflow rate is lower than using the irrigation sleeve around the phaco tip. Using the BSS bottle at a level of 80.0 cm height, the irrigating chopper achieve a flow rate of 24.0 cc/min, while the phaco needle with the irrigating sleeve on achieves 62.0 cc/min. To achieve an inflow rate of 40.0 cc/min with the irrigating chopper (reached using the IOP pressurized system at 80.0 mmHg) it would be necessary to place the bottle at 180.0 cm height (measured from the middle of the drip chamber), which is cumbersome and not possible in some surgical rooms.

In our cases of bimanual phaco, average time spent in the real phacoemulsification of the nucleus (without taking into account the previous and posterior surgical steps) is 5 minutes, 21 seconds, with an average volume of fluid used of 202.0 cc (ranges from 167.0 to 258.0 cc). Others have reported higher flow rates using different irrigation choppers. Tsuneoka have reported that with his special irrigation chopper (20-gauge outer diameter, but 0.75 mm inner diameter), and elevating the bottle to 110.0 cm, he achieves a flow volume of 50.0 cc/min.[1,4] Prakash reported an infusion rate of 50.0 cc/min.[5] Agarwal mentions an increased irrigation rate using the antichamber collapser.[6] We have found that in our technique, an irrigation rate of 35.0 to 42.0 cc/min, using the Vejarano´s Irrigating Chopper, assures a very steady anterior chamber throughout the procedure. We think that this is another advantage of this instrument, since there are less fluid interchange and turbulence inside the eye.
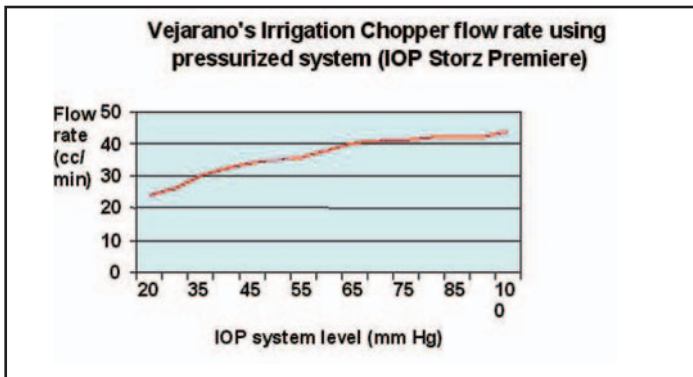
Figure 4-4. Flow rate of the Vejarano´s Irrigating Chopper using the IOP pressurized inflow in the Storz Premiere (at different levels of pressure).

PROBLEMS

No doubt by increasing the irrigation flow, the possibility of a shallow anterior chamber during the procedure is less, but it is necessary to keep in mind that the more fluid entering the anterior chamber, the more turbulence occurs and hence more trauma. For these reasons, it is desirable to minimize as much as possible the amount of fluid going into the eye and the leakage through incisions (but keeping in mind that through the main incision it is necessary to have a certain amount of leakage for cooling). Ideally, the side-port incision must be as watertight as possible when the instrument is in position, without compromising its maneuverability.

INCISIONS

We have found that performing a 1.0-mm side-port lets us use the Vejarano's Irrigating Chopper, 0.9 mm outer diameter, with almost no leakage. To achieve a good architecture we use a 1.0 mm diamond knife (Accutome) to perform the side-port incision, but an alternative is to use vitreoretinal blades. When performing the main incision, we use a 1.5-mm diamond blade (Natural Clear Cornea Vejarano's Microincision Knife [AK6018], Accutome). Inserting the Microflow 1.07-mm outer diameter needle (approximately 19-gauge) through this incision lets a small amount of leakage, influenced also by the presence of the grooves along the tip, and this prevents corneal burn.

CONCLUSION

In conclusion, fluidics balance when performing bimanual phaco is critical. The goal is to create a steady state within the anterior chamber. We have found very good stabilization of the anterior chamber using a 0.9-mm outer diameter irrigating chopper (Vejarano's Irrigating Chopper) through a 1.0-mm side-port, with a snug and almost watertight fitting; the Microflow phaco needle, 1.07 mm diameter and 0.5 mm inner shaft diameter, through a 1.5-mm incision; and the pressurized inflow (IOP control in the Storz Premiere system) at a level of 80.0 mmHg. We think that this combination yields a very good balance of fluidics, and maintains a very stable anterior chamber, without causing an excessive amount of fluid to enter the eye, which could cause more turbulence and trauma. The trend of cataract surgery all over the world in the future undoubtedly will be toward the direction of microincision, and every cataract surgeon who wants to keep himself updated should be ready for the transition.

KEY POINTS

✔ The issue of destabilization of the anterior chamber in bimanual phaco is basically due to the fact that more fluid is going out of the eye than the amount that is entering into the anterior chamber at a given moment. This has been a problem for surgeons initiating bimanual phaco, since the irrigation rate in this technique is usually less than in standard phacoemulsification.

✔ The factors that influence the fluid balance in bimanual microincision phacoemulsification are the infusion rate of the irrigating instruments, the amount of leakage through the incisions and the amount of fluid aspirated through the phaco needle.

✔ At the moment the occlusion is broken, and the fragments are rapidly aspirated, the fluid in the anterior chamber tends to rush into the aspiration line through the phaco tip, and the phenomenon of surge may occur. This situation is even more critical in bimanual phaco cases, since the irrigation rate is usually lower than in standard phacoemulsification.

✔ By increasing the irrigation flow, the possibility of a shallow anterior chamber during the procedure is less, but it is necessary to keep in mind that the more fluid entering the anterior chamber more turbulence occurs and hence more trauma.

✔ The incisions should be very good, otherwise with the air pump, there would be iris prolapse.

✔ Fluidics balance when performing bimanual phaco is critical. The goal is to create a steady state within the anterior chamber.

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Corneal Topography in Cataract Surgery

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Introduction

Topography is defined as the science of describing or representing the features of a particular place in detail. The word *topography* is derived[1,2] from two Greek words: *TOPOS*—meaning place and *GRAPHIEN*—meaning to write.

In corneal topography, the place is the cornea, that is, we describe the features of the cornea in detail.

Cornea

There are basically three refractive elements of the eye, namely: *axial length, lens,* and *cornea*. The cornea is the most important plane or tissue for refraction. This is because it has the highest refractive power (which is about + 45 diopters [D]) and it is easily accessible to the surgeon without entering the eye.

To understand the cornea, one should realize that the cornea is a parabolic curve—its radius of curvature differs from center to periphery. It is steepest in the center and flatter in the periphery. For all practical purposes, the central cornea (ie, the optical zone) is taken into consideration when doing a refractive surgery. A flatter cornea has less refraction power and a steeper cornea has a higher refraction power. If we want to change the refraction, we must make the steeper diameter flatter and the flatter diameter steeper.

Keratometry

The keratometer was invented by Hermann Von Helmholtz and modified by Javal, Schiotz et al. If we place an object in front of a convex mirror, we get a virtual, erect, and minified image (Figure 5-1). A keratometer in relation to the cornea is just like an object in front of a convex reflecting mirror. As in a convex reflecting surface, the image is located posterior to the cornea. The cornea behaves as a convex reflecting mirror and the mires of the keratometer are the objects. The radius of curvature of the cornea's anterior surface determines the size of the image.

Figure 5-1. Physics of a convex mirror. Note the image is virtual, erect, and minified. The cornea acts like the convex mirror and the mire of the keratometer is the object.
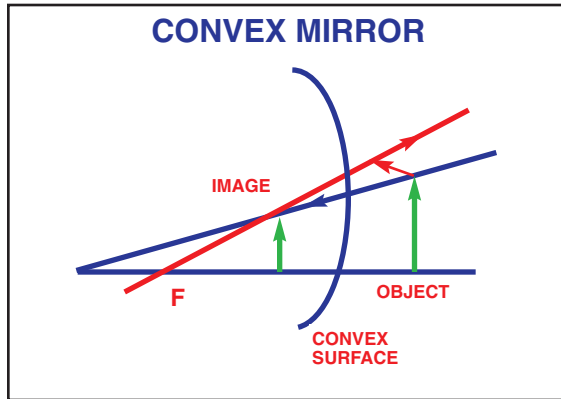
Figure 5-2. Keratometers measure the central 3.0-mm of the cornea, which generally behaves like a sphere or a spherocylinder. This is the reason why keratometers are generally accurate. But in complex situations such as keratoconus or refractive surgery, they become inaccurate.
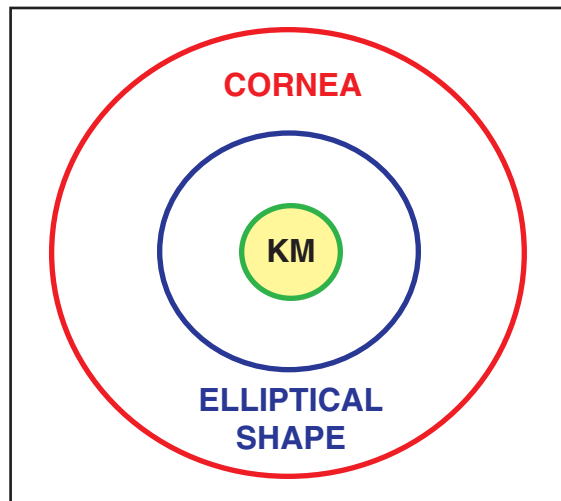
The keratometer projects a single mire on the cornea; the separation of the two points on the mire is used to determine corneal curvature. The zone measured depends upon corneal curvature—the steeper the cornea, the smaller the zone. For example, for a 36-D cornea, the keratometer measures a 4.0-mm zone and for a 50-D cornea, the size of the cone is 2.88 mm.

Keratometers are only accurate when the corneal surface is a sphere or a spherocylinder. Actually, the shape of the anterior surface of the cornea is more than a sphere or a spherocylinder. However, keratometers measure the central 3.0-mm of the cornea, which behaves like a sphere or a spherocylinder. This is the reason why Helmholtz could manage with the keratometer (Figure 5-2). This is also the reason why most ophthalmologists can manage management of cataract surgery with the keratometer. But today, with refractive surgery, the ball game has changed. This is due to the fact that when the cornea has complex central curves like in keratoconus or after refractive surgery, the keratometer cannot give good results and becomes inaccurate. Thus, the advantages of the keratometer like speed, ease of use, low cost, and minimum maintenance is obscured.

Figure 5-3. The Orbscan.

The objects used in the keratometer are referred to as mires. Separation of two points on the mire is used to determine corneal curvature. The object in the keratometer can be rotated with respect to the axis. The disadvantages of the keratometer are that they measure only a small region of the cornea. The peripheral regions are ignored. They also lose accuracy when measuring very steep or flat corneas. As the keratometer assumes the cornea to be symmetrical, it becomes at a disadvantage if the cornea is asymmetrical as after refractive surgery.

KERATOSCOPY

To solve the various problems experienced with keratometers, scientists worked on a system called *keratoscopy*. In this, they projected a beam of concentric rings and observed them over a wide expanse of the corneal surface. However, this was not enough and the next step was to move into computerized videokeratography.

COMPUTERIZED VIDEOKERATOGRAPHY

In this procedure, some form of light (like a placido disk) is projected onto the cornea. The cornea modifies this light and this modification is captured by a video camera. This information is analyzed by computer software and the data is then displayed in a variety of formats. To simplify the results to an ophthalmologist, Klyce, in 1988, created the corneal color maps. The corneal color maps display the estimate of corneal shape in a fashion that is understandable to the ophthalmologist. Each color on the map is assigned a defined range of measurement. The placido type topographic machines do not assess the posterior surface of the cornea. The details of the corneal assessment can be performed only with the Orbscan (Bausch & Lomb, Rochester, NY), which assesses both anterior and posterior surface of the cornea.

Orbscan

The Orbscan corneal topography system (Figure 5-3) uses a scanning optical slit scan that is fundamentally different than the corneal topography which analyzes the reflected images from the anterior corneal surface. The high-resolution video camera captures 40 light slits at a 45-degree angle projected through the cornea similar to what is seen during slit lamp examination. The slits are projected on to the anterior segment

Figure 5-4. Topography of a normal cornea.
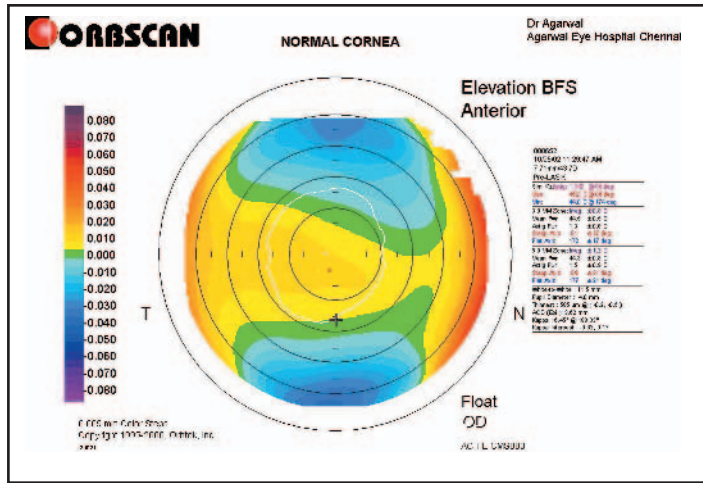
of the eye: the anterior cornea, the posterior cornea, anterior iris, and anterior lens. The data collected from these four surfaces are used to create a topographic map.

NORMAL CORNEA

In a normal cornea (Figure 5-4), the nasal cornea is flatter than the temporal cornea. This is similar to the curvature of the long end of an ellipse. In Figure 5-4, we will notice the values written on the right end of the pictures. These indicate the astigmatic values—Max K is 45 at 84 degrees and Min K is 44 at 174 degrees. This means the astigmatism is +1.0 D at 84 degrees. This is with-the-rule astigmatism, as the astigmatism is "plus" at the 90 degrees axis. If the astigmatism was "plus" at 180 degrees, then it is against-the-rule astigmatism. The normal corneal topography can be round, oval, irregular, symmetric bow tie, or asymmetric bow tie in appearance. Figure 5-5 is a case of astigmatism in which the astigmatism is +4.9 D at 146 degrees. These figures show the curvature of the anterior surface of the cornea. It is important to remember that these are not the keratometric maps. The blue/green colors denote steepening and the red colors denote flattening. If we want the red to denote steepening, then we can invert the colors.

CATARACT SURGERY

Corneal topography is extremely important in cataract surgery. The smaller the size of the incision lessens the astigmatism and earlier stability of refraction will occur. One can reduce the astigmatism or increase the astigmatism of a patient after cataract surgery. The simple rule to follow is that wherever you make an incision will flatten that area and wherever you apply sutures will steepen that area.

Extracapsular Cataract Extraction

One of the problems in extracapsular cataract extraction (ECCE) is the astigmatism created by the incision size (about 10.0 to 12.0 mm). In Figure 5-6, you can see the topographic picture of a patient after ECCE. You can see the picture on the left is the preoperative photo and the picture on the right is postoperative day 1 photo.
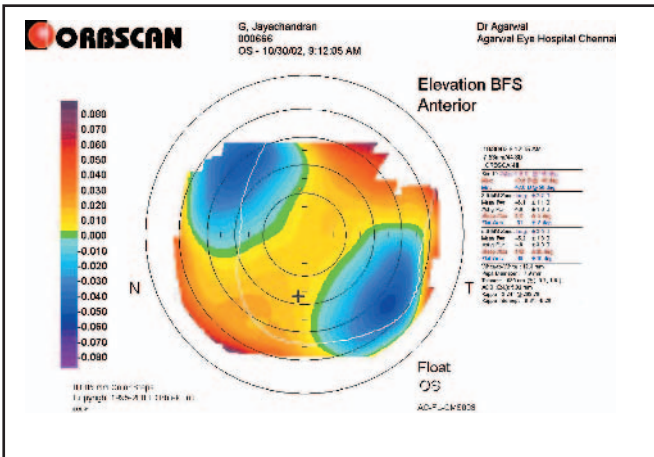
Figure 5-5. Topography showing an astigmatic cornea.
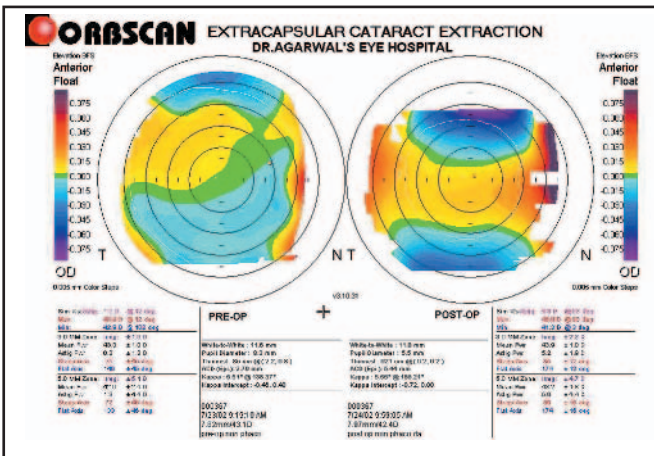
Figure 5-6. Topography after extracapsular cataract extraction (ECCE). The figure on the left shows astigmatism of +1.1 D at 12 degrees preoperatively. The astigmatism has increased to +4.8 D, as seen in the figure on the right.

Preoperatively one will notice the astigmatism is +1.0 D at 12 degrees and postoperatively it is +4.8 D at 93 degrees. In the immediate postoperative period, the astigmatism is high, but will reduce with time. The predictability of astigmatism is poor, which is why smaller incision cataract surgery is more successful.

Nonfoldable Intraocular Lens

Some surgeons perform phaco and implant a nonfoldable intraocular lens (IOL) in an incision of between 5.5 and 6.0 mm. In such cases, the astigmatism is better than in an ECCE. In Figure 5-7, the pictures are of a patient who has had a nonfoldable IOL. Notice in this the preoperative astigmatism is +0.8 D at 166 degrees. This is the left eye of the patient. If we had done a phaco with a foldable IOL, the astigmatism would have been nearly the same or reduced, since our incision would have come in the area of the astigmatism. In this case after phaco, a nonfoldable IOL was implanted. The postoperative astigmatism after 1 week is +1.8 D at 115 degrees. You can notice from the two pictures that the astigmatism has increased.

Figure 5-7. Topography of a nonfoldable IOL implantation.
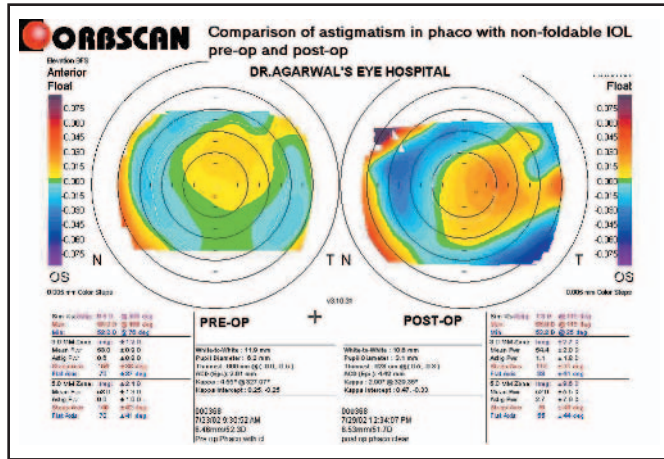
Figure 5-8. Topography of phaco cataract surgery with a foldable IOL implantation.
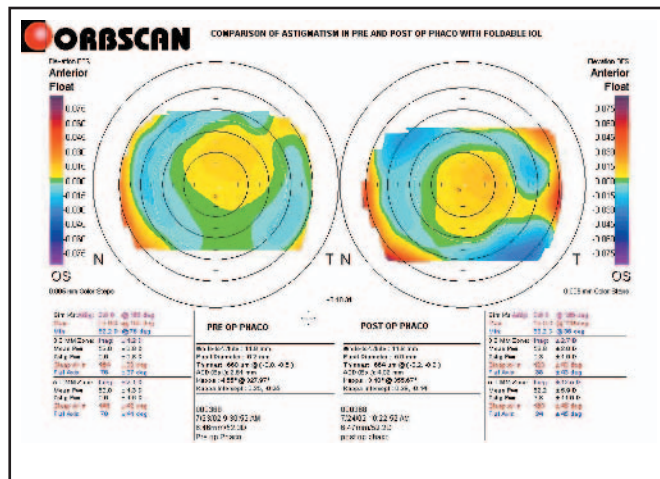
Foldable IOL

In phaco with a foldable IOL, the amount of astigmatism created is much less than with a nonfoldable IOL. Let us look now at Figure 5-8. The patient, as you can see, has negligible astigmatism in the left eye. The picture on the left shows a preoperative astigmatism of +0.8 D at 166 degrees axis. Now, we operate generally with a temporal clear corneal approach, so in the left eye, the incision will be generally at the area of the steepened axis. This will reduce the astigmatism. If we see the postoperative photo of day 1, we will see the astigmatism is only +0.6 D at 126 degrees. This means that after a day, the astigmatism has not changed much and this shows a good result. This patient had a foldable IOL implanted under the no anesthesia cataract surgical technique after a phaco cataract surgery with a 2.8-mm incision.

Astigmatism Increased

If we are not careful in selecting the incision based upon the corneal topography, we can "burn our hands." Figure 5-9 illustrates a case in which astigmatism has increased due to the incision being made in the wrong meridian. The patient had a 2.8-

Figure 5-9. Increase in astigmatism after cataract surgery due to incision being made in the wrong meridian. Topography of a phaco with foldable IOL implantation.

mm incision with a foldable IOL implanted after a phaco cataract surgery peformed with the no anesthesia cataract surgical technique. Both pictures are of the right eye. In Figure 5-9, look at the picture on the left. Here, you can see the patient has an astigmatism of +1.1 D at axis 107 degrees. As this is the right eye, we should have made a superior incision to reduce the preoperative astigmatism, but by mistake we made a temporal clear corneal incision. This has increased the astigmatism. Now if we wanted to flatten this case, we should have made the incision in the steeper meridian. That was at the 105-degrees axis. However, because we were doing routinely temporal clear corneal incisions, we made the incision in the opposite axis. Now look at the picture on the right. The astigmatism has increased from +1.1 D to +1.7 D. This shows a bad result. If we had made the incision superiorly at the 107-degrees axis, we would have flattened that axis and the astigmatism would have been reduced or neutralized.

Basic Rule

The basic rule to follow is to look at the number written in red. The red numbers indicate the plus axis. If the difference in astigmatism is say 3.0 D at 180 degrees, it means the patient has +3.0 D astigmatism at axis 180 degrees. This is against the rule astigmatism. In such cases, make your clear corneal incision at 180 degrees so that you can flatten this steepness This will reduce the astigmatism.

Unique Case

In Figure 5-10, the patient had a temporal clear corneal incision for phaco cataract surgery under no anesthesia with a nonfoldable IOL. Both the pictures are of the left eye. The figure on the left shows the postoperative topographic picture. The postoperative astigmatism was +1.8 D at axis 115 degrees. This patient had three sutures in the site of the incision. These sutures were put as a nonfoldable IOL had been implanted in the eye with a clear corneal incision. When this patient came for a follow up, we removed the sutures. The next day the patient came to us with loss of vision. On examination, we found the astigmatism had increased. We then took another topography. The picture on the right is of the topography after removing the sutures. The astigmatism increased to +5.7 D. So, one should be very careful in analyzing the corneal

Figure 5-11. Unique case. Topographic changes after suture removal.

topography when one does suture removal also. To solve this problem one can do an astigmatic keratotomy.

Bimanual Phaco

The astigmatism induced by a 1.0-mm incision is very little compared to a 2.6-mm phaco incision. Today, with the rollable IOL and the Acri.Tec GmbH IOLs (Berlin, Germany)—which are ultrasmall incision IOLs—one can pass IOLs through sub-1.4 mm incisions. This is seen clearly in Figures 5-11 and 5-12. Figure 5-11 shows the comparison after bimanual phaco with a rollable IOL and Figure 5-123 with an Acri.Tec GmbH IOL. If you compare the preoperative and the postoperative photographs, you will see there is not much difference between the two. In this case, a rollable IOL was implanted. From this picture we will notice that there is not much difference between the preoperative photo and the 1 day postoperative photo.

Summary

Corneal topography is an extremely important tool for the ophthalmologist. It is not only the refractive surgeon who should utilize this instrument but also the cataract surgeon. The most important refractive surgery done in the world is cataract surgery and not laser-in-situ keratomileusis (LASIK) or photorefractive keratectomy (PRK). With more advancements in corneal topography, topographic-assisted LASIK will become available to everyone with an excimer laser. One might also have the corneal topographic machine fixed onto the operating microscope so that one can easily reduce the astigmatism of the patient.
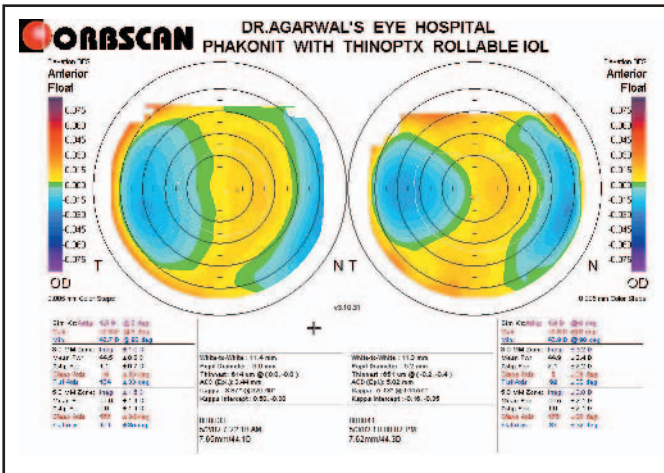
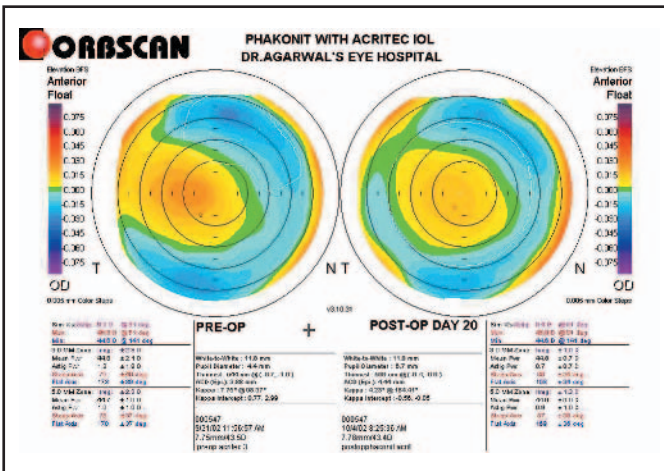**Figure 5-11.** Topography of a bimanual phaco with a rollable IOL.

**Figure 5-12.** Topography of a bimanual phaco with an Acri.Tec GmbH IOL.

KEY POINTS

✔ Keratometers are accurate only when the corneal surface is a sphere or a spherocylinder. To solve the problem of keratometers, scientists worked on a system called keratoscopy. The corneal color maps in a computerized videokeratoscope displays the estimate of corneal shape in a fashion that is understandable to the ophthalmologist.

✔ In a normal cornea, the nasal cornea is flatter than the temporal cornea.

✔ The smaller the size of the incision lesser the astigmatism and earlier stability of the astigmatism will occur. The astigmatism created by a 1.0-mm incision is very little compared to a 2.6-mm phaco incision.

✔ Wherever you make an incision that area will flatten and wherever you apply sutures that area will steepen.

✔ The most important refractive surgery is cataract surgery, and not LASIK or PRK.

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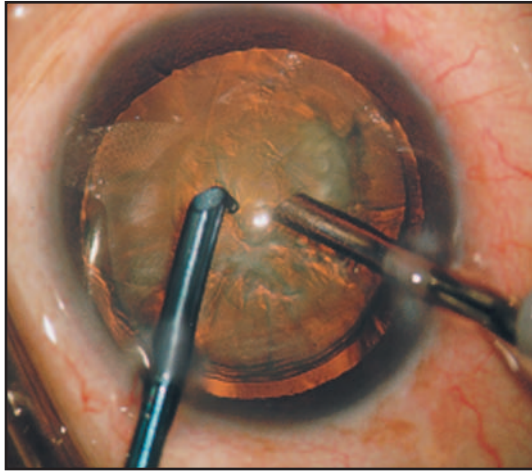
INSTRUMENTATION AND MACHINES

INSTRUMENTS FOR BIMANUAL PHACO

Amar Agarwal, MS, FRCS, FRCOphth

HISTORY

Bimanual phaco (or Phakonit) was basically developed to reduce the size of the incision.[1-5] This was done by removing the sleeve from the phaco needle. In order to introduce fluid into the eye during the procedure, in the beginning in 1998, we took a needle and bent it like an irrigating chopper and started doing bimanual phaco with it. When it succeeded, we realized the potential of this technique. With time, we have devised various instruments working with many companies around the world to make bimanual phaco an easier and safer technique.

INSTRUMENTS TO CREATE THE INCISION

One of the main problems in bimanual phaco was creating the temporal clear corneal incision. When we started the technique, there were no knives for the surgery, so we used a microvitreoretinal (MVR) blade for the purpose. Now many special bimanual phaco knives are available on the market (Figure 6-1).

Note in Figure 6-1 the left hand holds a globe stabilization rod (Geuder, Heidelberg, Germany). This helps to stabilize the eye while creating the clear corneal incision. The special knife is held in the dominant hand. This knife has been designed by Mateen Amin. It creates an incision of either sub-1.0 mm or 1.2 mm depending on which size knife is chosen by the surgeon. If one is using a sub-1.0 mm knife then one should use a 21-gauge irrigating chopper and a 0.8-mm phaco needle.

Knives for bimanual phaco can be either sapphire (Figure 6-2) or stainless steel. The Sapphire Phakonit knife has been made by Huco (Switzerland). It creates a very good 1.2 mm valve. A stainless steel blade has been made by Microsurgical Technology (MST, Redmond, Wash). This creates an incision of 1.2 to 1.4 mm (Figure 6-3). One of the key issues in bimanual phaco is to have a very good valve. If the valve is bad, there will be iris prolapse and the advantage of the microincision in bimanual phaco will be negated.

Figure 6-1. Clear corneal incision made with a special knife (MST, Redmond, Wash). Note the left hand has a globe stabilization rod to stabilize the eye (Geuder, Heidelberg Germany). This knife can create an incision from sub-1.1 mm to 1.2 mm.
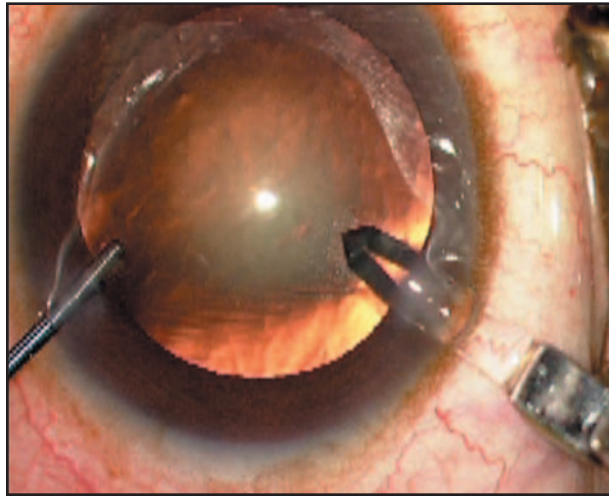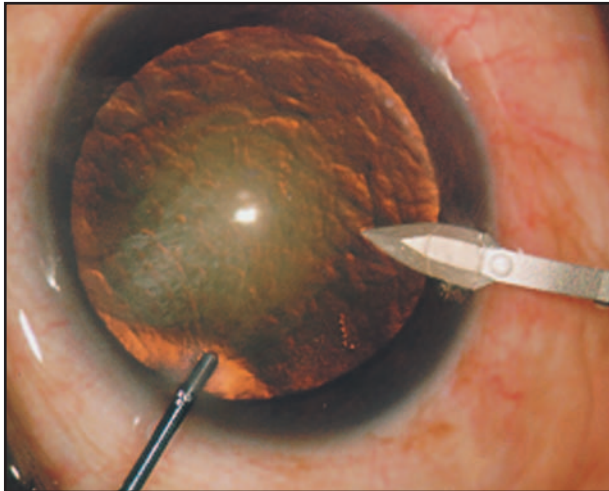

Figure 6-2. Agarwal sapphire Phakonit knife made by Huco (Switzerland).

Figure 6-3. Incision created by the stainless steel knife by MST (Redmond, Wash). This creates an incision of 1.2 to 1.4 mm. Note the globe stabilization rod in the left hand used to stabilize the eye.

Another difficulty faced in bimanual phaco is that we have two incisions of 1.0 mm. In phaco, one does not need to be as careful while creating the side port incision. However, in bimanual phaco one should be very careful even while creating the side port incision to avoid iris prolapse that can occur through the incision if the valve is not well made.
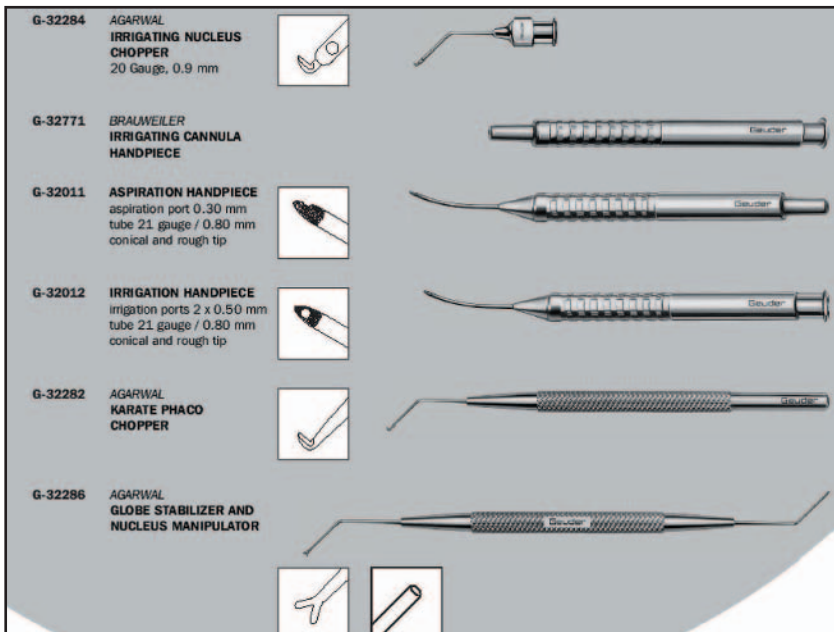
Figure 6-4A. Phakonit instrument set from Geuder (Heidelberg, Germany).

GLOBE STABILIZATION ROD AND NUCLEUS MANIPULATOR

This is an extremely important tool. One end of the rod has a blunt tip which helps to stabilize the eye (see Figures 6-1 and 6-3). The other end of the rod has a fork or a Y (Figure 6-4A). This helps to rotate the nucleus after hydrodissection. This can also be used for retracting the iris in small pupils. Finally, the fork helps to also implant the IOL as it can tuck the IOL into the capsular bag. This instrument is available from Geuder. If one is operating under no anesthesia or topical anesthesia, the globe stabilization rod is very helpful in stabilizing the eye especially if the patient is uncooperative. Figure 6-4B shows the Megatron S3 Phaco/Phakonit machine from Geuder.

RHEXIS INSTRUMENTS

Rhexis can be done with a needle (Figure 6-5). The advantage of this is that every time one can use a new needle and bend it like a cystotome to create the rhexis. One should use a 26-gauge needle connected to a syringe with viscoelastic. If the viscoelastic leaks out from the wound, the viscoelastic can be injected inside the eye. One should use the globe stabilization rod in the nondominant hand while performing the rhexis.

Microsurgical Technology has designed an excellent rhexis forceps for bimanual phaco (Figure 6-6A). This goes through a 1.0-mm incision. Those comfortable with a forceps in phaco can use this special forceps in bimanual (Figure 6-6B). Designed by Larry Laks from the United States, this forceps works very well. One problem in bimanual phaco is that those who are comfortable with a forceps in phaco find it difficult to convert to bimanual, as one has to shift to a needle for rhexis. The advantages of the MST forceps are:

Figure 6-4B. Megatron S3 Phaco/Phakonit Machine from Geuder (Heidelberg, Germany).

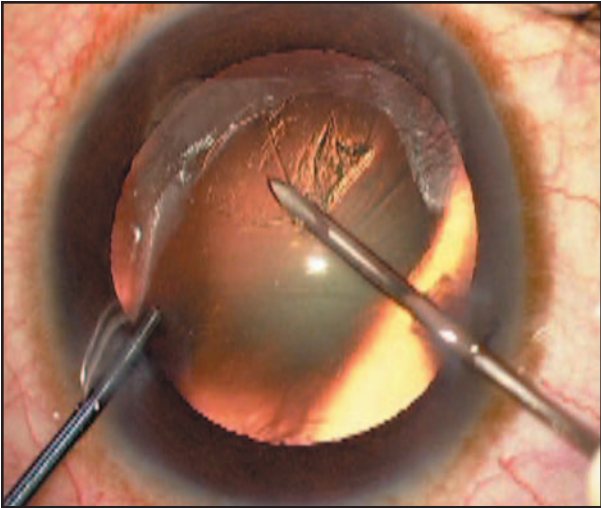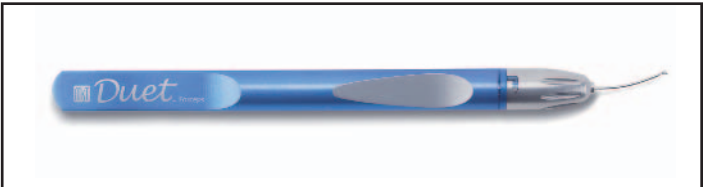**Figure 6-5.** Rhexis done with a needle.

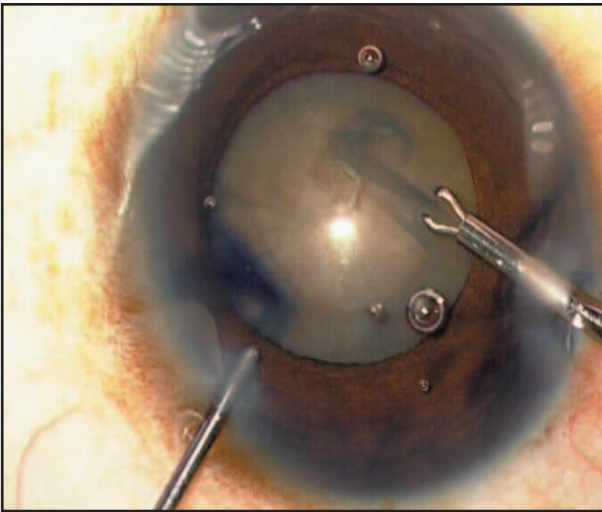**Figure 6-6A.** Rhexis forceps from MST (Redmond, Wash).

Figure 6-6B. MST Rhexis forceps used to perform the rhexis in a mature cataract. Note the Trypan Blue staining the anterior capsule.

Figure 6-7. Two designs of Agarwal irrigating choppers. The one on the left has an end opening for fluid. The one on the right has two openings on the sides.

- The removable head enables easy upgrades.
- There are flat areas in the forceps which are located in the areas where the surgeons fingers should be present. This helps easy handling of the forceps.
- The innovative fine tip lets one hold the tissue easily.

IRRIGATING CHOPPERS

After enlarging the side-port, a 20-gauge irrigating chopper connected to the infusion line of the phaco machine is introduced with foot pedal on position 1. There are various irrigating choppers. In Figure 6-7, you will notice two designs of irrigating choppers which we have designed. On the left is the Agarwal irrigating chopper made by the MST company, which is incorporated in their Duet system. The irrigating chopper on the right is made by Geuder. Notice in the right figure the opening for the fluid is end opening, whereas the one on the left has two openings in the side. Depending on the convenience of the surgeon, the surgeon can decide which design of irrigating chopper they would like to use.

Figure 6-8. Bimanual phaco done. Notice the irrigating chopper with an end opening (courtesy of Larry Laks, MST, USA).
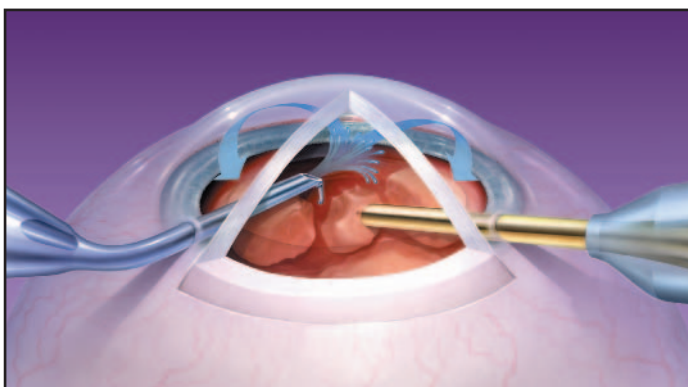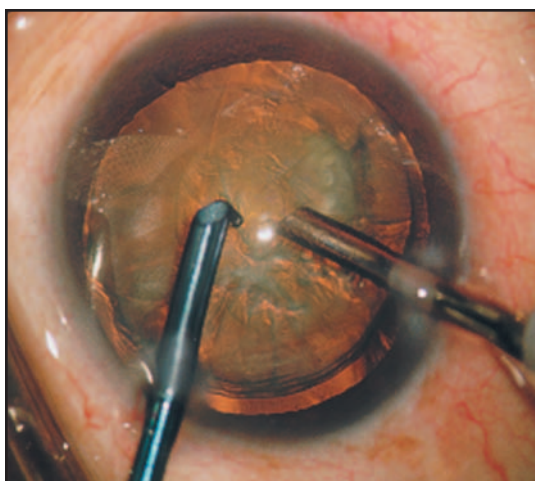

Figure 6-9. Agarwal Phakonit irrigating chopper (MST, Redmond, Wash) and Phako probe without the sleeve inside the eye. This irrigating chopper has a sharp tip and a cutting edge that helps in "karate" chopping or quick chopping.

The phaco probe is connected to the aspiration line and the phaco tip (without an infusion sleeve) is introduced through the clear corneal incision (Figures 6-8 and 6-9). The irrigating chopper we designed is basically a sharp chopper with a sharp cutting edge and helps in karate chopping or quick chopping. It can chop any type of cataract including hard cataracts.

Microsurgical Technology's Duet system has two handles (Figures 6-10 and 6-11). One handle is for irrigation and the other for aspiration. Various irrigating choppers of various surgeons can be interchanged with these handles (Figure 6-12). We have also designed a sharp irrigating chopper for Katena (Denville, NJ).

Air Pump

One of the real concerns in bimanual phaco when it was first started was the problem of destabilization of the anterior chamber during surgery.[3,4] This was solved to a certain extent by using an 18-gauge irrigating chopper. A development made by Sunita Agarwal was to use an air pump that injects air into the infusion bottle (see Chapter 7). This pushes in more fluid into the eye through the irrigating chopper and also prevents
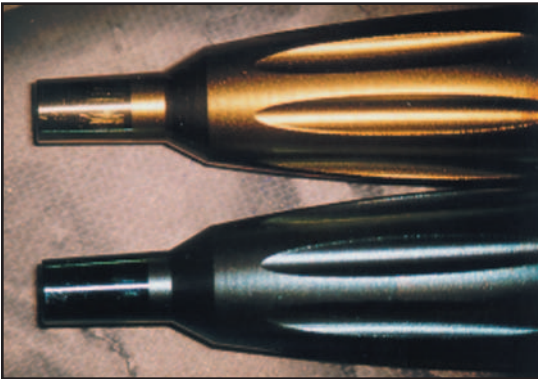
Figure 6-10. Duet handles (MST, Redmond, Wash).

Figure 6-11. Duet handles from MST. The advantage of these handles is that one can change the irrigating chopper tips.

Figure 6-12. Various irrigating chopper tips designed by various surgeons. These can be fixed onto the Duet handles.

surge. Thus, we were not only able to use a 20- or 21-gauge irrigating chopper but also to solve the problem of destabilization of the anterior chamber during surgery. This increases the steady-state pressure of the eye making the anterior chamber deep and well maintained during the entire procedure. This is very essential in bimanual phaco.

BIMANUAL IRRIGATION ASPIRATION SYSTEM

Bimanual irrigation aspiration is then done with the bimanual irrigation aspiration instruments (Figures 6-13 and 6-14). These instruments are designed by Microsurgical Technology and Geuder. MST also designed a soft tip I/A that is very safe for the posterior capsule (Figures 6-15 and 6-16).

MEGATRON S3 MACHINE

This machine from Geuder (see Figure 6-4B) has all the features for performing a phaco or a bimanual phaco procedure.

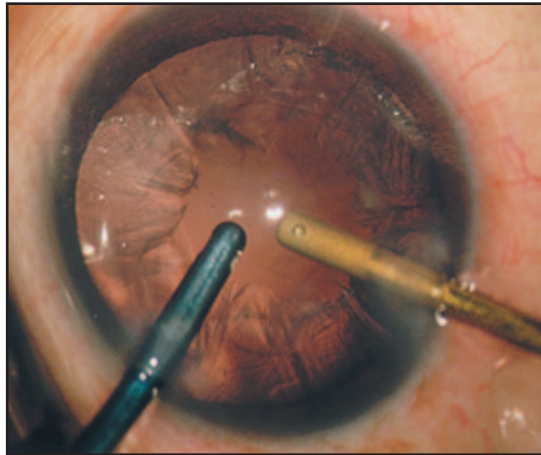**Figure 6-13.** Bimanual irrigation started using the Duet system.

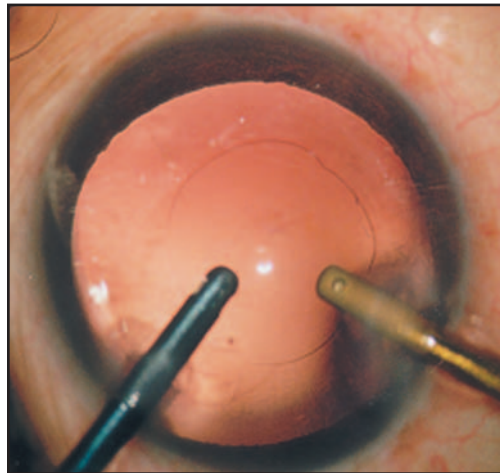**Figure 6-14.** Bimanual irrigation aspiration completed.

Figure 6-15. Soft tip I/A from MST (courtesy of Larry Laks, MST, Redmond, Wash).
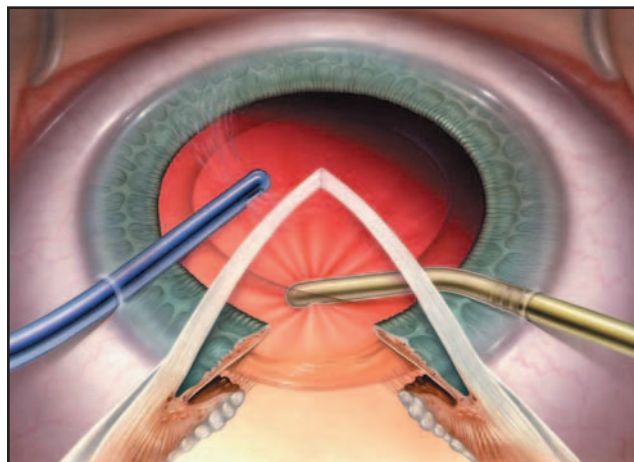
Figure 6-16. Soft tip I/A set from MST.

SUMMARY

With improvements in technology, newer and better instruments will soon come out and make the process of bimanual phaco easier.

KEY POINTS

✔ In phaco, one does not need to be very careful while creating the side-port incision, whereas in bimanual phaco, one should be very careful—even while creating the side-port incision—as there can be iris prolapse through that incision if the valve is not good.

✔ The nondominant hand should hold a globe stabilization rod to stabilize the eye while creating the clear corneal incision.

✔ One problem in bimanual phaco is that those who are comfortable with a forceps in phaco find it difficult to convert to bimanual phaco as one has to shift to a needle for rhexis.

✔ The Agarwal irrigating chopper is basically a sharp chopper which has a sharp cutting edge and helps in karate chopping or quick chopping. It can chop any type of cataract including hard cataracts.

✔ The air pump or some sort of gas forced infusion system is mandatory in bimanual phaco.

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AIR PUMP

Sunita Agarwal, MS, DO

Various methods have been used to combat surge during phacoemulsification. This chapter describes a simple device that can be used with any phacoemulsification machine to minimize surge during phacoemulsification—the air pump. This technique helps in maintaining anterior chamber stability in bimanual phaco. An automated air pump is used to push air into the infusion bottle thus increasing the pressure with which the fluid flows into the eye. This increases the steady-state pressure of the eye making the anterior chamber deep and well maintained during the entire procedure. It makes bimanual phaco (ie, Phakonit, microphaco, or MICS) and phacoemulsification a relatively safe procedure by reducing surge even at high vacuum levels.

HISTORY

The main problem in bimanual phaco is the destabilization of the anterior chamber during surgery. We solved it to a certain extent by using an 18-gauge irrigating chopper. The use of an antichamber collapser, which injects air into the infusion bottle (Figure 7-1) was then suggested. This pushes more fluid into the eye through the irrigating chopper and also prevents surge. Thus, we were able to use a 20-gauge or 21-gauge irrigating chopper as well as solve the problem of destabilization of the anterior chamber during surgery.

INTRODUCTION

Since the introduction of phacoemulsification by Kelman,[1] it has been undergoing revolutionary changes in an attempt to perfect the techniques of extracapsular cataract extraction surgery (ECCE). Although advantageous in many aspects, this technique is not without its complications. A well-maintained anterior chamber without intraocular fluctuations is one of the prerequisites for safe phacoemulsification and bimanual phaco.[2]

When an occluded fragment is held by high vacuum and then abruptly aspirated, fluid rushes into the phaco tip to equilibrate the built up vacuum in the aspiration line, causing surge.[3] This leads to shallowing or collapse of the anterior chamber.

Figure 7-1. Diagrammatic representation of the connection of the air pump to the infusion bottle. Note the air pump is connected to the needle in the irrigating bottle via an IV set.
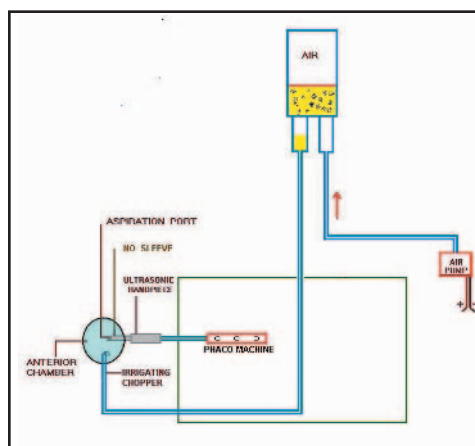
Different machines employ a variety of methods to combat surge. These include usage of noncompliant tubing, small bore aspiration line tubing, microflow tips, aspiration bypass systems, dual linear foot pedal control, and incorporation of sophisticated microprocessors to sense the anterior chamber pressure fluctuations.[4]

The surgeon-dependent variables to counteract surge include good wound construction with minimal leakage,[5] and selection of appropriate machine parameters depending on the stage of the surgery.[6] An anterior chamber maintainer has also been described in literature to prevent surge, but an extra side port makes it an inconvenient procedure.

We herein describe a simple and effective method to prevent anterior chamber collapse during phacoemulsification and bimanual phaco by increasing the velocity of the fluid inflow into the anterior chamber. This is achieved by an automated air pump that pumps atmospheric air through an air filter into the infusion bottle thereby preventing surge. We stumbled upon this idea when we were operating cases with bimanual phaco[7] where we wanted more fluid entering the eye, but now use it in all our phaco cases.

TECHNIQUE

A locally manufactured automated device, used in fish tanks (aquariums) to supply oxygen, is utilized to forcefully pump air into the irrigation bottle. This pump is easily available in aquarium shops. It has an electromagnetic motor that moves a lever which is attached to a collapsible rubber cap. There is an inlet with a valve, which sucks in atmospheric air as the cap expands. On collapsing, the valve closes and the air is pushed into an intravenous (IV) line connected to the infusion bottle (see Figure 7-1). The lever vibrates at a frequency of approximately 10 oscillations per second. The rubber cap ceases to expand at this pressure level. A micropore air filter is used between the air pump and the infusion bottle so that the air pumped into the bottle is clean of particulate matter.
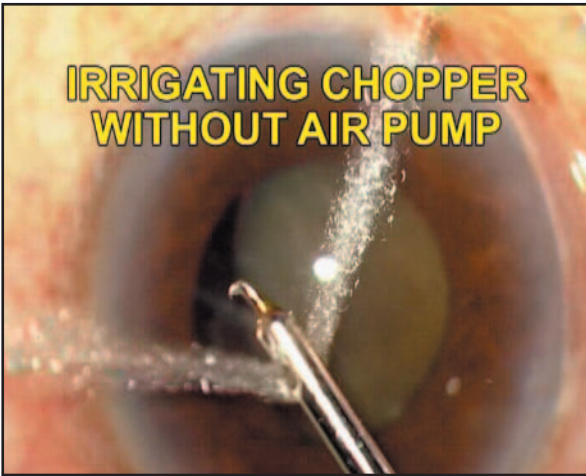
Figure 7-2. Flow of fluid through the irrigating chopper without an air pump
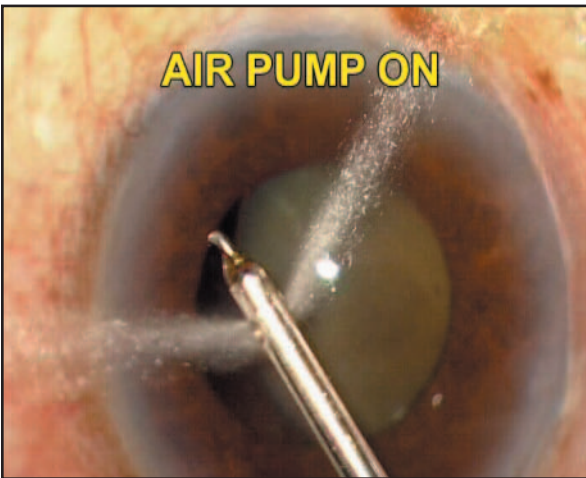
Figure 7-3. Flow of fluid through the irrigating chopper with an air pump. Note when the air pump is on the amount of fluid coming out of the irrigating chopper is much more.

Method

1. First of all, the balanced salt solution (BSS) bottle is taken and put in the IV stand.
2. Now we take an air pump. This air pump is the same as is used in fish tanks (aquariums). The air pump is plugged into the electrical connection.
3. An IV set now connects the air pump to the infusion bottle. The tubing passes from the air pump to the infusion bottle.
4. What happens now is that when the air pump is switched on, it pumps air into the infusion bottle. This air goes to the top of the bottle and because of the pressure, it pumps the fluid down with greater force. With this, the fluid now flows from the infusion bottle to reach the phaco handpiece or irrigating chopper. The amount of fluid now coming out of the handpiece is much more than what would normally come out and with more force (Figures 7-2 and 7-3).

Figure 7-4. Phakonit being per-formed in a mature brown cataract. Such difficult cases can be operated upon by phakonit because of the air pump. It deepens the chamber and prevents any surge.
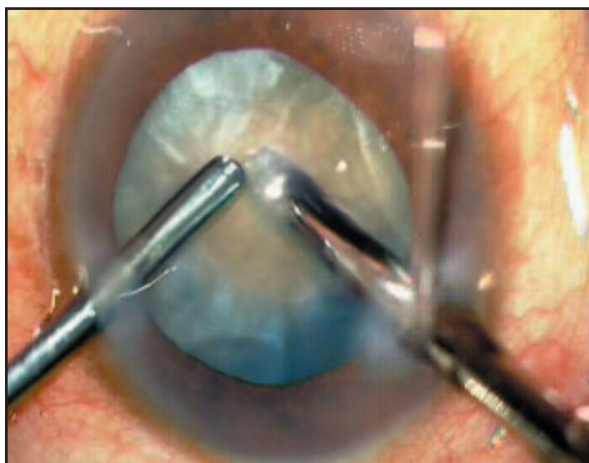
5. An air filter is connected between the air pump and the infusion bottle so that the air being pumped into the bottle is sterile.
6. This extra amount of fluid coming out compensates for the surge that would otherwise occur.

CONTINUOUS INFUSION

Before we enter the eye, the eye is filled with viscoelastic. Then once the tip of the phaco handpiece (in phaco) or irrigating chopper (in bimanual phaco) is inside the anterior chamber, we shift to continuous irrigation. This is very helpful especially for surgeons who are starting phaco or bimanual phaco. This way, the surgeon, never comes to position zero and the anterior chamber never collapses. This is an advantage for even the experienced surgeon.

ADVANTAGES

1. With the air pump, the posterior capsule is pushed back and there is a deep anterior chamber.
2. The phenomenon of surge is neutralized. This prevents unnecessary posterior capsular rupture.
3. Striate keratitis postoperatively is reduced, as there is a deep anterior chamber.
4. One can operate hard cataracts (Figure 7-4) also quite comfortably, as striate keratitis does not occur postoperatively.
5. The surgical time is shorter as one can emulsify the nuclear pieces much faster as surge does not occur.
6. One can easily operate cases with the bimanual phaco technique as quite a lot of fluid now passes into the eye. Thus, the cataract can be removed through a smaller opening.
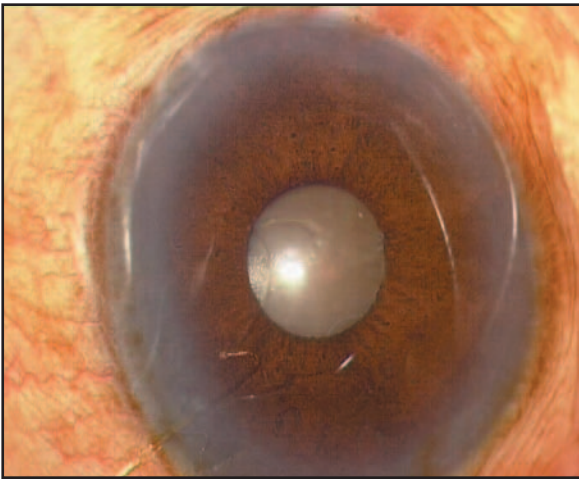7. It is quite comfortable to do cases under topical or no anesthesia.

Figure 7-5. Miotic pupil.

Topical or No Anesthesia Cataract Surgery

When one operates under topical or no anesthesia, sometimes the pressure is high, especially if the patient squeezes the eye. In such cases, the posterior capsule comes up anteriorly and one can produce a posterior capsular rupture. To solve this problem, surgeons tend to work more anteriorly, performing supracapsular phacoemulsification/bimanual phaco. The disadvantage of this is that striate keratitis tends to occur.

With the air pump, this problem does not occur. When we use the air pump, the posterior capsule is quite back, as if we are operating a patient under a block. In other words, there is a lot of space between the posterior capsule and the cornea, preventing striate keratitis and inadvertent posterior capsular rupture. If one is operating on a patient with a small pupil (Figure 7-5) and shallow anterior chamber, iris hooks (Figures 7-6 and 7-7) can be used to dilate the pupil and then perform bimanual phaco with the air pump on (Figure 7-8). This will help deepen the chamber and one can complete the case. Such cases cannot be operated comfortably without the air pump.

Discussion

Surge is defined as the volume of the fluid forced out of the eye into the aspiration line at the instant of occlusion break. When the phacoemulsification handpiece tip is occluded, flow is interrupted and vacuum builds up to its preset values. Additionally, the aspiration tubing may collapse in the presence of high vacuum levels. Emulsification of the occluding fragment clears the block and the fluid rushes into the aspiration line to neutralize the pressure difference created between the positive pressure in the anterior chamber and the negative pressure in the aspiration tubing. In addition, if the aspiration line tubing is not reinforced to prevent collapse (tubing compliance), the tubing, constricted during occlusion, then expands on occlusion break. These factors cause a rush of fluid from the anterior chamber into the phaco probe. The fluid in the anterior chamber is not replaced rapidly enough to prevent shallowing of the anterior chamber.

Figure 7-6. Iris hooks used to dilate the pupil.
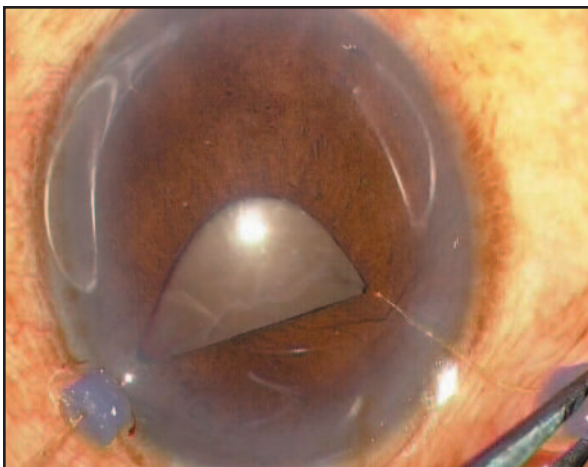
Figure 7-7. Four iris hooks are in place. This way the pupil is well dilated. It is better to do bimanual phaco than phaco in such cases as four areas have already been blocked by the iris hooks. As there is little space left, bimanual has an advantage. One should use the air pump as it makes the procedure easier.
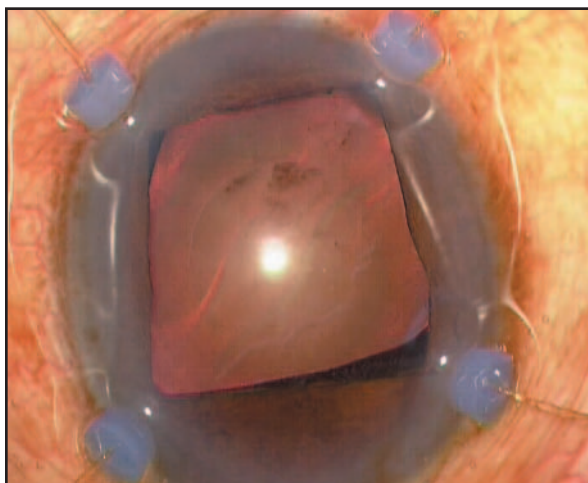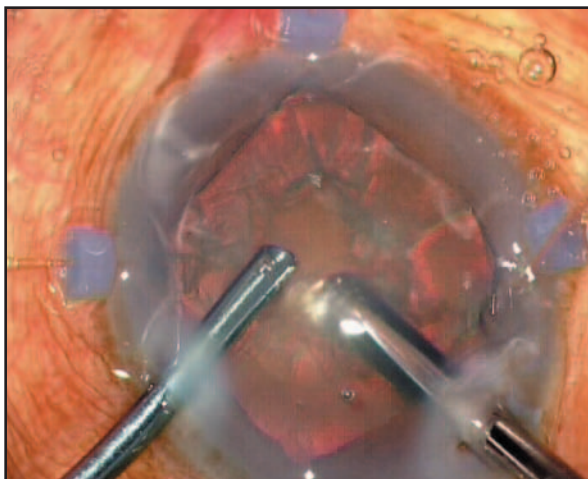

Figure 7-8. Bimanual phaco started. Note the irrigating chopper in the left hand and a sleeveless phaco needle in the right hand.

The maintenance of intraocular pressure (steady–state IOP)[2] during the entire procedure depends on the equilibrium between the fluid inflow and outflow. The steady state pressure level is the mean pressure equilibrium between inflow and outflow volumes. In most phacoemulsification machines, fluid inflow is provided by gravitational flow of the fluid from the BSS bottle through the tubing to the anterior chamber. This is determined by the bottle height relative to the patient's eye, the diameter of the tubing, and most importantly, by the outflow of fluid from the eye through the aspiration tube and leakage from the wounds.[2]

The inflow volume can be increased by either increasing the bottle height or by enlarging the diameter of the inflow tube. The IOP increases by 10.0 mmHg for every 15.0 cm increase in bottle height above the eye.[5]

High steady-state IOPs increase phaco safety by raising the mean IOP level up and away from zero (ie, by delaying surge related anterior chamber collapse).[2]

The air pump increases the amount of fluid inflow thus making the steady-state IOP high. This deepens the anterior chamber, increasing the surgical space available for maneuvering and thus prevents complications like posterior capsular tears and corneal endothelial damage. The phenomenon of surge is neutralized by rapid inflow of fluid at the time of occlusion break. The recovery to steady-state IOP is so prompt that no surge occurs and this enables the surgeon to remain in foot position 3 through the occlusion break. High vacuum phacoemulsification/bimanual phaco can be safely performed in hard brown cataracts using an air pump. Phacoemulsification or bimanual phaco under topical or no anesthesia[6,7] can be safely done neutralizing the positive vitreous pressure occurring due to squeezing of the eyelids.

SUMMARY

The air pump is a new device, which helps prevent surge. This prevents posterior capsular rupture, helps deepen the anterior chamber and makes phacoemulsification and bimanual phaco safe procedures even in hard cataracts.

KEY POINTS

✔ Using an air pump is a simple and effective method to prevent anterior chamber collapse during phacoemulsification and bimanual phaco by increasing the velocity of the fluid inflow into the anterior chamber.

✔ This is achieved by an automated air pump which pumps atmospheric air through an air filter into the infusion bottle thereby preventing surge.

✔ A micropore air filter is used between the air pump and the infusion bottle so that the air pumped into the bottle is clean of particulate matter.

✔ Surge is defined as the volume of the fluid forced out of the eye into the aspiration line at the instant of occlusion break.

✔ The air pump is a new device, which helps to prevent surge. This prevents posterior capsular rupture, helps deepen the anterior chamber and makes phacoemulsification and bimanual phaco safe procedures even in hard cataracts.

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GAS FORCED INTERNAL INFUSION FOR BIMANUAL PHACO

Arturo Pérez-Arteaga, MD

INTRODUCTION

Since the early days of bimanual phaco, one of the main problems to solve was to increase the amount of irrigation incoming into the eye. As was proposed by Amar Agarwal, simply separating the infusion from the phaco probe is not enough to perform this technique because the amount of fluid coming into the eye is less that with the sleeve in traditional phacoemulsification; so he developed the use of an external air pump (*external forced infusion* or EFI) to increase this fluid with an air pump. The first description of an air pump included two bottles connected in a "Y" intersection and a transuretral tubing instead the traditional IV set.[1] Later the air tubing was connected into the bottle through the hole provided for the routine airway. This made the system simple and more reproducible. It was at this point that the air pump of the same phaco machine was used to create this forced infusion.

GAS FORCED INFUSION

The surgical systems described here are the Anterior Vented Gas Forced Infusion tubing of the Accurus Surgical System (Alcon, Fort Worth, Tex) and the Bottle Infusion Tool of the Millennium Microsurgical System (Bausch & Lomb Surgical, San Dimas, Calif). Nevertheless, any phaco system that contains an air exit (air pump) for any purpose can be used to create the gas forced infusion.

The main advantage of this technique is that the surgeon can use the same machine with all the parameters avoiding the creation and use of an external air pump (Figure 8-1). The main disadvantage is that not all phaco machines contain an air pump.

SURGICAL CONCEPTS

The traditional bimanual phaco technique uses an irrigating chopper and a sleeveless ultrasonic tip.[2] Unfortunately, the amount of irrigation fluid that goes through the irrigating choppers is by far less than traditional phacoemulsification.[3] Dr. Sunita Agarwal has solved this problem by the use of an air pump (see Figure 8-1).[4] The pur-

Figure 8-1. Air tubing connected from the air pump of a fish tank into the drip chamber of the irrigation administration set.

pose of this pump is to push more fluid into the eye. The air is generated by a pump, and this pushes air into the bottle of intraocular solution.[5] This is EFI.

The advantages of this air pump system are:

1. It actively pushes fluid into the eye.
2. The amount of fluid can be controlled independent of the bottle height.
3. The increase of fluid prevents surge and its consequences.
4. The continuous maintenance of the anterior chamber allows the surgeon to freely manipulate the instruments and tissues inside the eye.
5. The positive pressure creates a tense zonule and so a firm capsular bag and it facilitates the chop maneuvers.
6. The endothelium is pushed forward while the posterior capsule is pushed back.
7. The continuous irrigation through the phaco tip incision cools continuously the tip and the cornea, avoiding thermal burns.[6]

When the surgeon uses the air pump contained in the same phaco machine (Figure 8-2), it is called internal forced infusion (IFI).[7,8] The advantages of IFI over EFI are:

1. The surgeon doesn't have to incorporate an external air pump into the surgical system to obtain the advantages of the forced infusion.
2. The surgeon can control all the parameters (forced infusion rate, ultrasonic power modulations, and vacuum settings) in the same panel of the surgical system he or she is using.
3. The forced infusion rate can be actively and digitally controlled during the surgery, adjusting the parameters to the conditions and/or the surgical steps of each individual case.

Figure 8-2. Forced infusion through the irrigating chopper created with the Accurus surgical system.

Surgical Technique

Mechanics of Fluidics in Bimanual Phaco

As a general principle the amount of fluid coming into the eye must be more than the fluid going out of the eye. If the surgeon follows this simple rule, surge will never occur. The amount of fluid coming into the eye is only determined by the rate at which infusion occurs. This means the cubical centimeters of water that can go by the infusion line through a specific diameter of irrigating chopper or cannula in a specific period of time (cc/minute). Unfortunately the amount of outgoing fluid is not so simple to measure, because it depends on five variables:

1. The vacuum settings in the phaco machine.
2. The diameter of the phaco tip and the aspirating cannula.
3. The desired insensible loss of fluid. This means the amount of fluid that exits the eye through the incisions during the procedure. This loss is desired because it cools the cornea and the phaco tip.
4. The undesired insensible loss of fluid. This happens when the incision size is larger than needed, so more quantities of fluid (more than desired) are lost through one or both incisions.
5. The use of some aspiration controllers like the ABS McKool system or the Cruise Control (STAAR Surgical, Monrovia, Calif).[9]

Fortunately many manufacturers of choppers and cannulae are understanding these issues and are creating specific knives for each handpiece, phaco tips, and irrigating and aspirating choppers or cannulas. They are also taking care of the internal and external diameters of their irrigating and aspirating devices. Even with these important advances, the amount of fluid that reaches the eye is a concern to the surgeon.

The passive infusion (not-forced) depends only gravity. Many variables are influencing how it works, like the material containing the solution (glass, plastic, rigid, solid), the possibility to increase the bottle level (extension in the elevation arm, height of the operating theatre roof), the capacity of the bottle, the diameter of the irrigation line and irrigation cannula, level above the sea where the surgeon is working, and the

Figure 8-3. Air filter used to prevent any infection when using the gas forced infusion. The filtered end of the air exchange line is connected to the air connector of the module.

amount of fluid remaining inside the bottle. Because of the sleeve, one can manage in traditional phacoemulsification , but in bimanual phaco, with smaller irrigation diameters and because it is an almost closed system, the principle of increasing the amount of irrigation to compensate the outgoing fluid sometimes can not be achieved only with passive infusion but it is very easy to reach with forced infusion. Amar Agarwal advocates the usage of the air pump in not only all bimanual phaco cases but also in all phaco cases.

Basic Principles to Create Internal Forced Infusion

The surgical equipments that contain an air pump are basically those with the capability to perform posterior segment surgery. The air pump is included in these systems for the fluid interchange in vitreoretinal surgery. It is used to pressurize the eye. This air pump is the main element to create IFI. The management of the air pump system is in the panel or in the digital controls of the phaco system. There, the surgeon can turn on/off the pump and increase or decrease the amount of desired air.

The elements to create IFI are as follows :

1. The air pump of the phaco system should be functional.

2. The line to connect the air pump to the drip chamber of the irrigation administration set should be present. This line is provided by each manufacturer. The end that is connected to the air pump must have an air filter (Figure 8-3) and the other end must have the adapter to the drip chamber.

3. The bottle of intraocular solution: To create always a standard positive pressure my suggestion is to use always a 500.0-cc glass bottle. The height of the bottle now is not important. Once the active column of air has reached the drip chamber, the air will go over the water inside the bottle creating the positive pressure needed within the bottle. This is the reason why a plastic bottle or a bag containing the intraocular solution are not good options; if you have a material with low compliance like glass, you can be sure to obtain the desired pressure. If you use a plastic bottle, insert the needle connected to the air pump at the top of the bottle.

4. The irrigation administration set: It will connect the pressurized bottle to the irrigating chopper or cannula, and also will keep the pressure inside, because it has to go through a roller clamp (outside or inside a cassette) that will be controlled by the footswitch. When the roller clamp is closed the pressure is kept inside but when it is opened by the foot of the surgeon the predetermined pressure is liberated and the forced infusion is obtained.

5. The control panel: It is different in each surgical system.

The AVGFI Tubing System of the Accurus Surgical System

The Anterior Vented Gas Forced Infusion (AVGFI) tubing of the Accurus Surgical System is an air pump integrated inside the machine designed by the Alcon engineers to pressurize the infusion line for posterior segment surgery. The main application has been in vitreoretinal surgery for the interchange between air and fluid and has not been used in phacoemulsification because the passive infusion has been enough to perform a traditional technique. But now in bimanual phaco, the AVGFI system has found a precise application.

This system contains all the elements described to create IFI. The control of the AVGFI system is in the digital panel and once it has been turned on the display will show 65.0 cmH$_2$O of positive pressure. Now the surgeon can increase or decrease the desired pressure. The surgeon can also preset two different values of pressure at the footswitch and reach them easily any time during the surgery by a simple movement of the foot. The display can also be in mmHg if the surgeon wants.

I have found that the adequate positive pressure for bimanual phaco goes from 80.0 to 140.0 cmH$_2$O. The variation will depend upon the kind of irrigating chopper in use, the behavior of the anterior chamber during the procedure, the aspiration rate of the phaco tip and the mentioned factors influencing the outgoing fluid. The recommendable presetting in the Accurus system are 110.0 cmH$_2$O of positive pressure, 20 to 30% of ultrasonic power, 180.0 mmHg of vacuum for MicroTip, and 120.0 mmHg for high rate tip. From this point the surgeon can move up and down depending on the individual case. For irrigation/aspiration the forced infusion remains the same and the vacuum can be at 400.0 mmHg.

The Bottle Infusion Tool of the Millennium Microsurgical System

This is an air pump integrated in the posterior segment module of the surgical system (Figure 8-4). Not all of Millennium's machines contain this module, so the surgeon must be sure it is integrated in the machine with which he or she is working.

The surgeon can get from Bausch & Lomb only the air line ready to connect. It is not preconnected like the AVGFI system. So the surgeon must obtain an independent irrigation administration set to make this system work. The line is connected to the drip chamber and the drip chamber of the irrigation administration set is connected to the bottle. This irrigation administration set must go through the roller clamp (this system uses an external clamp) and the surgeon controls the forced infusion with the footswitch. Finally, the irrigating chopper or cannula is connected to the end of the irrigation line.

The Bottle Infusion Tool control is in the panel of the Millennium system. The surgeon must press Tools and then choose "Bottle Infusion." When it is turned on, the air will start to flow through the air pump. The measure in this machine is displayed in

Figure 8-4. The bottle infusion mode appears at the bottom left corner of the panel.
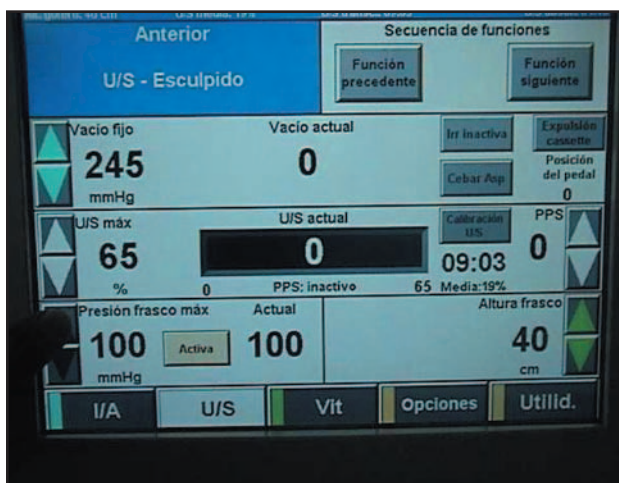
mmHg. My settings in the Millennium are 80.0 mmHg of positive pressure, 15 to 30% of phaco power, and 130.0 to 150.0 mmHg of vacuum (the phaco tip of the Millennium is 1.1 mm while the Microtip in the Accurus is 0.9 mm).[9]

During the surgery, the surgeon can increase or decrease the forced infusion according to the case and instrumentation used. In this system the surgeon cannot program different positive pressures in the footswitch like in the Accurus machine, so each change must be done in the panel. Also in this system there is no rigid line to connect the drip chamber with the bottom of the bottle, so bubbles within the solution are generated frequently. If the surgeon doesn't want bubbles, a sterile AVGFI system can be used, only the air filter must be changed because is not compatible with the Millennium´s air pump.

Internal Forced Infusion With Other Machines

All phaco machines capable of performing phacoemulsification and posterior vitrectomy can be used to develop IFI for bimanual phaco. The following steps should be done:

1. Find the air pump in the phaco system.
2. Find the tool to control the air pump (on/off and increase or decrease the fluid)
3. Connect a line with an air filter to the air pump and the other extreme to the drip chamber and to the irrigation administration set.
4. Connect the irrigation administration set to the 500.0 cc glass bottle and pass the line through the internal or external clamp of the phaco machine managed with the footswitch.
5. Start with a positive pressure between 70.0 to 90.0 mmHg or 100.0 to 120.0 cmH$_2$O and increase or decrease according to the case and the parameters of the phaco machine in use.
6. If the surgeon doesn't want to have bubbles in the bottle an AVGFI system can be used. Just look for a compatible air filter and switch it if needed.

The air coming inside the bottle will actively push the fluid into the eye at the desired pressure. As the irrigation fluid is consumed, the air column inside the bottle

is increased and the compliance inside the system is also increased. So one recommendation for the surgeon is to remember to change the bottle when approximately 150 cc of solution are remaining inside it. This precaution has two reasons:

1. As the air column grows the capacity of response of the system becomes slow.

2. It avoids creating forced infusion of "air" inside the eye when the bottle gets empty.

Internal Forced Infusion in Vitreous Loss

The management of posterior capsule rupture with or without vitreous loss is another important advantage of the use of a bimanual technique. The variations in the forced infusion when it occurs are as follows:

1. If the hyaloid face remains intact and there is no vitreous loss, do not change the parameters of forced infusion. The force of water will push away the entire vitreous body and vitrectomy will not be needed. If the surgeon has no forced infusion, surge can occur and damage the hyaloid face.

2. If the surgeon is quite sure that vitreous loss is present then the forced infusion must be reduced at the control panel. I recommend 60.0 to 80.0 cm of water. This is because of two reasons:

   • First, excessive force of fluid will push the vitreous body away from the vitreous cavity.

   • Second, the aspiration rate during a vitrectomy is by far less than during phacoemulsification and irrigation/aspiration, because of the small diameter of the vitrectomy hand piece.

Never forget to change the position of the irrigating cannula to a horizontal direction to avoid pushing more vitreous into the anterior chamber. Also never think of performing anterior vitrectomy with a coaxial vitrectomy set (irrigation and aspiration in the same hand). Always use a bimanual vitrectomy set and separate the infusion from the cutter.

SUMMARY

We have learned from the posterior vitrectomy system that it is a closed one, with irrigation and aspiration and with small incisions. The retinal surgeons are able to pressurize the eye in order to avoid bleeding, attach the retina and even produce intentional ischemia. We have learned from the posterior vitrectomy surgeon to irrigate with one hand and aspirate with the other hand. This is much better for control than to get both functions in one instrument managed with the same hand.

In traditional phacoemulsification, the size of the wound and the use of one hand for both functions (irrigation and aspiration) decrease the effect of the water loss through the incision. It is not a totally enclosed environment, and so passive infusion is enough.

In bimanual phaco the environment is much more closed and the maneuvers are performed with both hands. These two factors make this surgery to appear more like a posterior vitrectomy surgery. This is why the fluidics in bimanual phaco are far more demanding than in traditional phaco, and this is why a positive pressure is effective. Furthermore, the decreased amount of irrigation fluid in bimanual phaco in comparison to a traditional sleeve phacoemulsification and the behavior of the corneal tissue (where the incisions are placed) increases the need of positive pressure.

The advantage to having both hands in use and the irrigation and aspiration in separate lines increases the importance of forced infusion. The force of the water becomes a "third hand" for the surgeon inside the eye. This water force can drive the tissues where the surgeon wants. The posterior capsule moves far away from the phaco tip, the endothelial cells move far from the instruments and the nuclear pieces move to the phaco tip. A complete luxation of the nucleus to the iris plane can be done with the force of the water. Of course with forced infusion the spaces (anterior and posterior chambers and capsular bag) increase in amplitude and this is another advantage of bimanual surgery.

Perhaps many surgeons around the world are performing bimanual phaco without forced infusion, but I think for all these reasons the safety margin is by far less.

As the reader can see, it is very easy to create forced infusion and it is not a real increase in the cost of surgery. It is a measure of safety for the surgeon and for the patients. It does not cause damage to the endothelial cells, posterior capsule or the zonnules if the surgeon remains at the recommended values. Each phaco machine has its own measure of positive pressure. Just remember 100.0 cc of water is equivalent to 76.0 mmHg, and the initial settings will be safe. Only do not forget to decrease this positive pressure when vitreous loss occurs.

In some cases, the surgeon can work with the phaco machine that they really want, but it is not always so, although many surgeons are working only with the machine they currently have. It is not true that there is a specific machine to perform bimanual phaco (as has been demonstrated by Amar Agarwal). Any machine can be used to perform this technique. There is also no special machine to create IFI for bimanual phaco and any machine with an air pump can be used. So I strongly believe that if your phaco machine has no air pump, then you can create one by using the fish tank air pump as in external forced infusion; if you have a machine that has an air pump, then you should use it.

KEY POINTS

✔ The main advantage of the gas forced internal infusion is that the surgeon can use the same machine and avoid the use of an external air pump. The main disadvantage is that not all phaco machines contain an air pump.

✔ The purpose of the air pump is to push more fluid into the eye. The air is generated by a pump, and this pushes air into the bottle of intraocular solution. This is called, external forced infusion (EFI).

✔ When the surgeon uses the air pump contained in the same phaco machine, it is called internal forced infusion (IFI).

✔ As a general principle, the amount of fluid coming into the eye must be greater than the fluid going out of the eye. If the surgeon follows this simple rule, surge will never occur.

✔ Amar Agarwal advocates the usage of the air pump in not only all bimanual phaco cases, but also in all phaco cases.

✔ In bimanual phaco, the environment is much more closed and the maneuvers are performed with both hands. These two factors make this surgery to appear more like a posterior vitrectomy surgery.

✔ The decreased amount of irrigation fluid in bimanual phaco in comparison to a traditional sleeve phacoemulsification and the behavior of the corneal tissue (where the incisions are placed) increases the need of positive pressure.

✔ It is not true that there is a specific machine to perform bimanual phaco (as has been demonstrated by Amar Agarwal). Any machine can be used to perform this technique.

✔ There is no special machine to create IFI for bimanual phaco, as any machine with an air pump can be used. If your phaco machine does not have an air pump, then you can create one by using a fish tank air pump, as in EFI.

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CRUISE CONTROL
FOR BIMANUAL PHACO

David F. Chang, MD

INTRODUCTION

The introduction of new "cold" phaco modalities such as WhiteStar technology (Advanced Medical Optics [AMO], Santa Ana, Calif) has sparked renewed interest in microincisional bimanual phaco.[1,2] The parallel development of smaller incision IOL designs is also underway.[3,4] Cadaver and clinical temperature studies have confirmed that the strategy of micro-pulsing bursts of phaco reduces heat generation to a clinically safe level that avoids tissue burns.[5-8]

These innovative power modulations have essentially solved the problem of incisional burn from a sleeveless phaco needle. However, the early clinical experience with bimanual microincisional phaco demonstrated that improving fluidic balance and chamber stability would be another significant challenge. Eliminating the coaxial infusion sleeve reduces irrigation inflow enough to cause postocclusion surge at the higher vacuum levels typically used for coaxial phaco. Because of problematic chamber stability with typical 20-gauge instrumentation, several different strategies have been adopted.

FLUIDICS

Methods to increase irrigation flow include bottle height extenders, the addition of a separate self-retaining chamber maintainer, and the use of forced infusion pumps. Examples of the latter would be Amar Agarwal's modified air pump and the pressurized infusion provided by combination anterior-posterior segment machines, such as the Accurus (Alcon, Fort Worth, Tex), and the Millennium (Bausch & Lomb Surgical, San Dimas, Calif).[9,10] In addition, the incisions must be tight enough to avoid leakage around the instrument shafts, and yet not so tight that movement of the instruments is restricted. Metal and diamond mini-keratomes to create reproducibly precise incisions of 1.2 mm have been designed.

There are many irrigating chopper instruments currently available on the market. Microsurgical Technologies (MST, Redmond, Wash) provides a paired system of irriga-

Figure 9-1. Schematic diagram of Cruise Control device. The mesh filter traps the nuclear particles, allowing only fluid to pass through the 0.3-mm diameter restrictive lumen. The bottom photo shows the device attached to the aspiration port of the phaco handpiece. The aspiration tubing would be attached to the other end. (courtesy of STAAR Surgical).
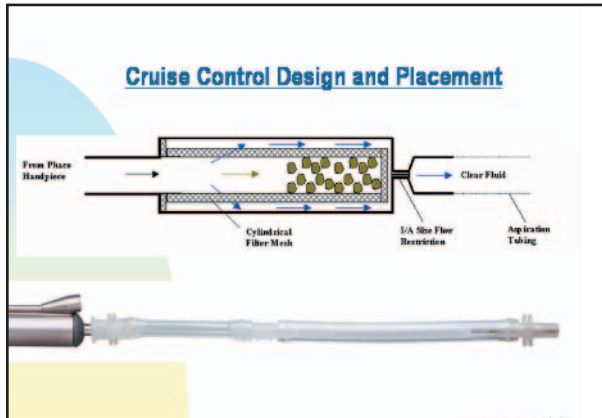
tion and aspirating handles to which interchangeable tips can be attached. Called the Duet system, their 20-gauge irrigating choppers were among the first front-irrigating choppers to be introduced. With a larger lumen thanks to narrower shaft walls, the Duet design gives an impressive inflow rate of 40.0 cc/min at 30.0 inches of bottle height and is available with an assortment of interchangeable chopper tips. Katena (Denville, NJ) has also introduced a series of front-irrigating "hydrochoppers" that provide a comparably high inflow rate.

CRUISE CONTROL

In May 2003, STAAR Surgical (Monrovia, Calif) introduced its Cruise Control device, which can be used with any manufacturer's phaco machine.[11] The Cruise Control is a disposable flow-restrictor (0.3-mm internal diameter) that is placed in between the phaco handpiece and the aspiration tubing (Figure 9-1). Regardless of whether coaxial or bimanual phaco is being performed, the objective is to prevent surge upon occlusion breaks at higher vacuum levels.

If one considers the entire aspiration pathway extending from the phaco tip to the machine pump, the narrowest part of system—typically the shaft of the phaco needle—determines the maximum resistance to outflow. Within the Cruise Control device, a 2.0-cm long flow restrictor is positioned behind a mesh filter that traps all of the nuclear emulsate (Figure 9-2). This prevents the narrow 0.3-mm lumen from becoming clogged with lens material like the bottleneck within a flare tip (Figure 9-3). However, like a flare tip design, this flow restrictor significantly reduces surge without reducing the diameter of the phaco tip opening (thus maintaining the same holding power). In fact, the Cruise Control shaft is much narrower than a flared phaco tip shaft (of approximately 0.7 mm internal diameter) and provides far greater surge suppression.

With any flow-restricting device, one does not want to slow down the normal aspiration flow rate that attracts pieces to the tip, improves followability, and creates a rapid vacuum rise time. The Cruise Control device is specifically engineered to create a non-linear restriction of outflow. This means that it has virtually no effect on regular aspiration outflow rates below 50.0 cc/min, but limits the unwanted flow surges above 60.0 cc/min (Figure 9-4). Indeed, surge can momentarily reach 200.0 to 300.0 cc/min when occlusion breaks from a 400.0-mmHg vacuum level.

Figure 9-2. Photo of mesh filter before (A) and after (B) use. The yellow nuclear material is visibly trapped in the filter.
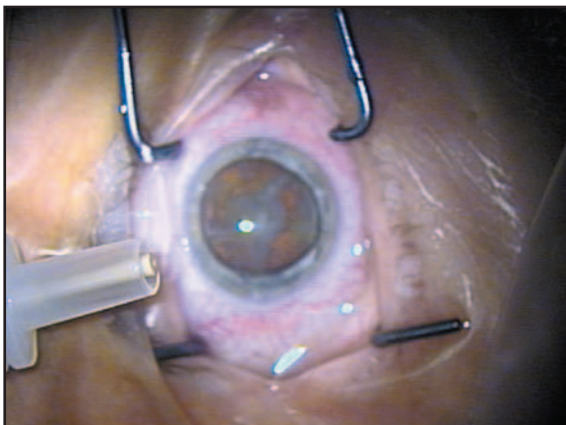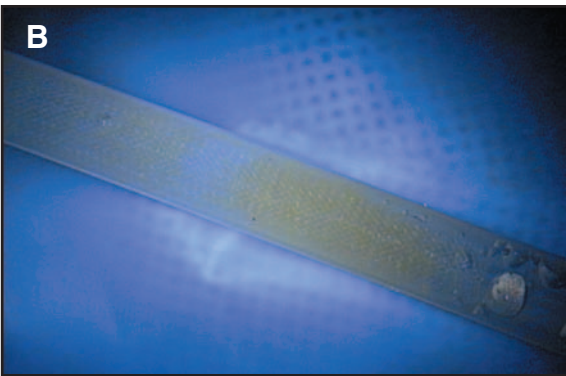

Figure 9-3. Photo of 0.3 mm lumen of the flow restrictor.

Surge Suppression for Bimanual Phaco

Although Cruise Control was conceived as a surge-limiting device for conventional phaco, chamber instability with bimanual phaco prompted me to evaluate the device for this application beginning in June 2003. As reported at the 2004 ASCRS meeting, I performed bimanual microincisional phaco chop using Cruise Control in a consecutive series of 50 nuclei ranging in density from grade 2 to 3+.[12] The AMO Sovereign

Figure 9-4. (A) Nonlinear flow restriction does not impede flow rates below 40 to 50 cc/min. Higher outflow rates (ie, surge flow) are restricted. (B) Diagrammatic representation of vacuum surge (top image) that is effectively prevented by use of the Cruise Control device (courtesy of STAAR Surgical).
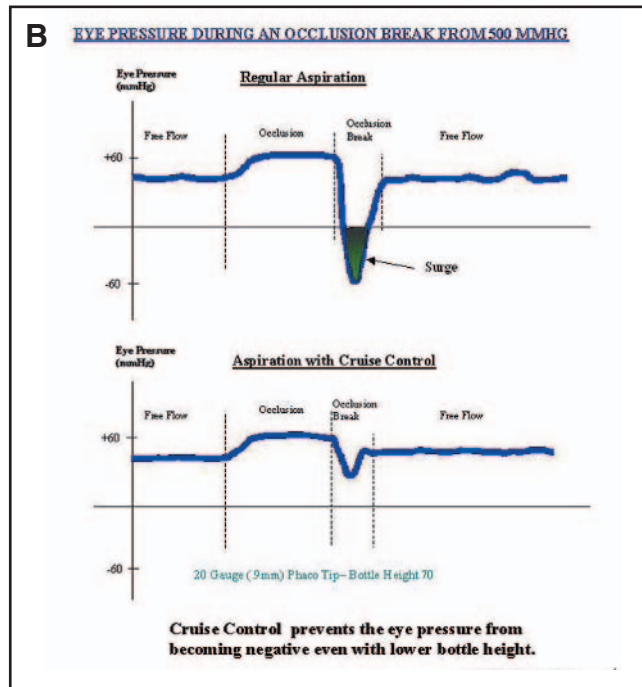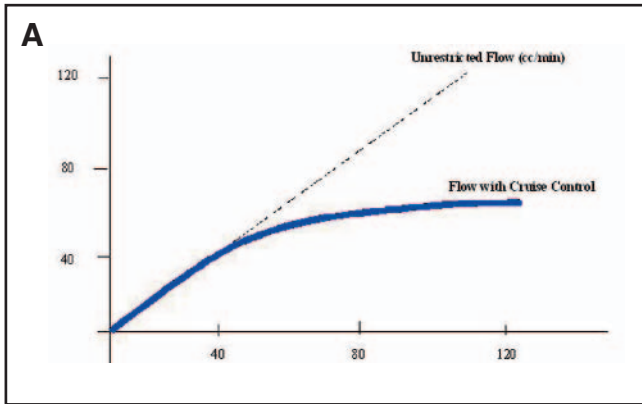
with WhiteStar system was used with a 20-gauge beveled phaco tip, and the MST 20-gauge Chang irrigating chopper. With a bottle height of 30.0 inches and an aspiration flow rate of 26.0 cc/min, the vacuum was set at 400.0 mmHg during nuclear emulsification, and lowered to 200.0 mmHg for the epinucleus (Figure 9-5). Chamber stability was excellent and there were no instances of capsular rupture. Using identical instrumentation without Cruise Control, vacuum levels of 300.0 mmHg or greater resulted in unacceptable postocclusion surge.

By allowing surgeons to use their usual high vacuum coaxial settings, the Cruise Control device is an important innovation for the aspiration side of the bimanual fluidic equation. Because of chamber instability, many surgeons reduce their vacuum limit settings to the 100.0- to 200.0-mmHg range for bimanual phaco. The inability to
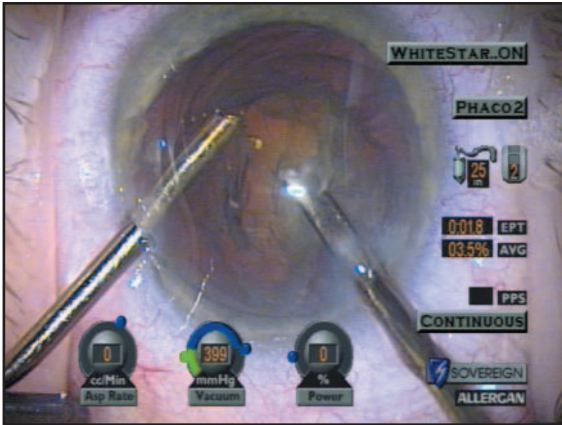
Figure 9-5. Video overlay demonstrating use of high vacuum (400.0 mmHg) setting with bimanual phaco with the Cruise Control device.

use higher vacuum is a significant disadvantage. Because of the larger handle and shaft, the tight incision, and the tethering effect of the irrigation tubing, the irrigating chopper is much more difficult to manipulate than a standard nonirrigating chopper. Thus, the high vacuum-aided ability to carry pieces into the center of the chamber with the phaco tip is necessary to reduce the maneuvers required of the chopper.

Summary

The added chamber stability and safety afforded by STAAR's Cruise Control represents an important advance for the field of bimanual microincisional phaco. This disposable device is both simple and inexpensive to use. Because it can be attached to the handpiece of any phaco machine, it is particularly ideal for surgeons experimenting with or transitioning to bimanual phaco. Most importantly, it allows the bimanual microincisional surgeon to utilize high vacuum techniques without the need for other compensatory strategies such as a chamber maintainer or forced infusion pump. Thanks to higher flow, front-irrigating choppers on the infusion side, and the Cruise Control flow restrictor on the aspiration side, the gap in fluidic performance between bimanual and coaxial phaco has been virtually eliminated.

<div style="border:1px solid">

KEY POINTS

- ✔ The Cruise Control is a disposable flow-restrictor (0.3-mm internal diameter) that is placed in between the phaco handpiece and the aspiration tubing.
- ✔ Regardless of whether coaxial or bimanual phaco is being performed, the objective is to prevent surge upon occlusion breaks at higher vacuum levels.
- ✔ Within the Cruise Control device, a 2.0-cm long flow restrictor is positioned behind a mesh filter that traps all of the nuclear emulsate. This prevents the narrow 0.3-mm lumen from becoming clogged with lens material like the bottleneck within a flare tip.
- ✔ Like a flare tip design, this flow restrictor significantly reduces surge without reducing the diameter of the phaco tip opening (thus maintaining the same holding power). In fact, the Cruise Control shaft is much narrower than a flared phaco tip shaft (of approximately 0.7 mm internal diameter) and provides far greater surge suppression.
- ✔ By allowing surgeons to use their usual high vacuum coaxial settings, the Cruise Control device is an important innovation for the aspiration side of the bimanual fluidic equation.

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Dr. Chang has no financial interest in any instrument mentioned in this chapter.

Machines and Modalities for Bimanual Phaco

*I. Howard Fine, MD; Mark Packer, MD;
and Richard S. Hoffman, MD*

Introduction

New technology brings challenges and opportunities to the anterior segment surgeon. The drive towards less traumatic surgery and more rapid visual rehabilitation after cataract surgery has spawned various modalities for reducing incision size and decreasing energy utilization.

Although ultrasonic phacoemulsification allows for relatively safe removal of cataractous lenses through astigmatically neutral small incisions, current technology still has its drawbacks. In ultrasonic phacoemulsification, piezoelectric crystals convert electrical energy into mechanical energy, which emulsifies the lens material by means of tip vibration. Ultrasonic tips create both heat and cavitational energy. A conventional phaco tip moves at ultrasonic frequencies of between 25 KHz and 62 KHz. The amount of heat generated is directly proportional to the operating frequency. In addition, cavitational effects from the high frequency ultrasonic waves generate even more heat.

Because of the liberation of heat, phacoemulsification needles have required an irrigation sleeve for cooling. This irrigation sleeve carries heat away from the tip and necessitates an incision size larger than the tip alone would require. Nevertheless, standard ultrasonic phacoemulsification with an irrigation sleeve still carries with it the potential for thermal injury to the cornea in case of diminished flow. Flow and aspiration problems may be caused by compression of the irrigation sleeve at the incision site, kinking of the sleeve during manipulation of the handpiece, tip clogging by nuclear or viscoelastic material, and inadequate flow rate or vacuum settings.[1] Heating of the tip can create corneal incision burns.[2] When incisional burns develop in clear corneal incisions, there may be a loss of self-sealability, corneal edema, and severe induced astigmatism.[3]

Cavitational energy results from pressure waves emanating from the tip in all directions. Although increased cavitational energy can allow for phacoemulsification of dense nuclei, it can also damage the corneal endothelium and produce irreversible corneal edema in compromised corneas with pre-existing endothelial dystrophies.

Reduction in average phaco power and effective phaco time has been correlated with improved patient outcomes after cataract surgery.[4] Low power phaco technology will have an important advantage in minimizing intraoperative damage to ocular structures and maximizing the level and rapidity of the visual rehabilitation of the patient.

The last decade has given rise to some of the most profound advances in both phacoemulsification technique and technology. Techniques for cataract removal have moved from those that use mainly ultrasound energy to emulsify nuclear material for aspiration to those that utilize greater levels of vacuum and small quantities of energy for lens disassembly and removal. Advances in phacoemulsification technology and fluidics have allowed for this ongoing change in technique by allowing for greater amounts of vacuum to be safely utilized, while power modulations that have allowed for more efficient utilization of ultrasound energy with greater safety for the delicate intraocular environment.[5]

Elimination of the frictional heat produced during ultrasound phacoemulsification and reduction of the power required for cataract extraction represent important steps towards the goal of atraumatic surgery. The sonic phacoemulsification system (STAAR Wave, STAAR Surgical, Monrovia, Calif) demonstrates another new approach to elimination of heat and the danger of thermal injury to the cornea. Modification of ultrasound energy through refinement of power modulation offers yet another route leading to elimination of heat and reduction of incision size (WhiteStar, Advanced Medical Optics, Santa Ana, Calif). The introduction of innovative oscillatory tip motion in coordination with power modulation permits further reduction of average phaco power and effective phaco time (NeoSonix, Alcon, Fort Worth, Tex). Other new modalities under investigation, which promise low-energy, nonthermal cataract extraction, include vortex phacoemulsification (Avantix, Bausch & Lomb, Rochester, NY) and Aqualase (Alcon, Fort Worth, Tex), a fluid-based cataract extraction system.

Sonic Phacoemulsification

Sonic technology offers an innovative means of removing cataractous material without the generation of heat or cavitational energy by means of sonic rather than ultrasonic technology. Its operating frequency is in the sonic rather than the ultrasonic range, between 40 Hz and 400 Hz. In contrast to ultrasonic tip motion, the sonic tip moves back and forth without changing its dimensional length. The temperature of the tip of an ultrasonic handpiece can exceed 500°C, while the tip of the Wave handpiece in sonic mode barely generates any frictional heat. In addition, the Sonic tip does not generate cavitational effects and thus fragmentation, rather than emulsification or vaporization, material takes place.

The same handpiece and tip can be utilized for both Sonic and Ultrasonic modes. The surgeon can alternate between the two modes using a toggle switch on the foot pedal when more or less energy is required. The modes can also be used simultaneously with varying percentages of both sonic and ultrasonic energy. We have found that we can use our same chopping cataract extraction technique in sonic mode as we utilized in ultrasonic mode with no discernable difference in efficiency.

The STAAR Wave also allows improved stability of the anterior chamber with coiled SuperVac tubing, which increases vacuum capability to up to 650.0 mmHg (Figure 10-1). The key to chamber maintenance is a positive fluid balance between infusion flow and aspiration flow. When occlusion is broken, vacuum previously built in the aspiration line generates a high aspiration flow that can be higher than the infusion flow. This

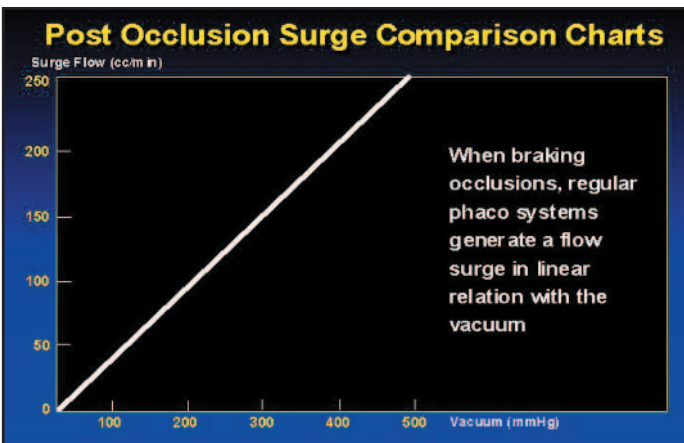**Figure 10-1.** Coiled SuperVac tubing.

Figure 10-2. Postocclusion surge comparison chart in a normal phaco machine

results in anterior chamber instability. The coiled SuperVac tubing limits surge flow resulting from occlusion breakage in a dynamic way. The continuous change in direction of flow through the coiled tubing increases resistance through the tubing at high flow rates such as upon clearance of occlusion of the tip (Figures 10-2 and 10-3). This effect only takes place at high flow rates (greater than 50.0 cc/min). The fluid resistance of the SuperVac tubing increases as a function of flow and unoccluded flow is not restricted (personal communication, Alex Urich, STAAR Surgical).[6]

The STAAR Wave combines important innovations in phacoemulsification technology, which satisfy the demands of non-thermal, low power cataract extraction.

NeoSonix Phacoemulsification

NeoSonix technology represents a hybrid modality involving low frequency oscillatory movement that may be used alone or in combination with standard high frequency ultrasonic phacoemulsification (Figure 10-4). Softer grades of nuclear sclerosis may be completely addressed with the low frequency modality, while denser grades will likely require the addition of ultrasound.

In the NeoSonix mode, the phaco tip has a variable rotational oscillation up to two degrees at 120 Hz. As with sonic phacoemulsification, this lower frequency does not produce significant thermal energy and so minimizes the risk of thermal injury.

Figure 10-3. Postocclusion surge comparison chart with a coiled SuperVac tubing.
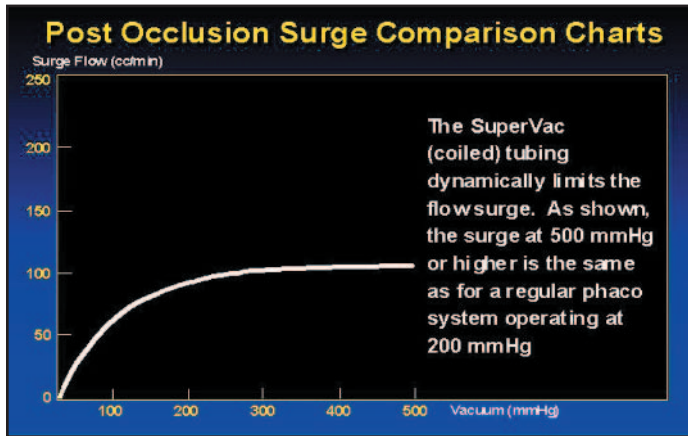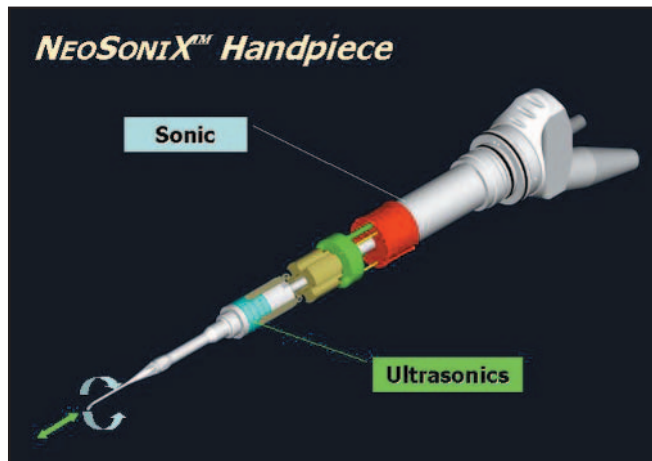

Figure 10-4. Neosonix handpiece.

The Legacy may be programmed to initiate NeoSonix at any desired level of ultrasound energy. Thus, the surgeon may utilize the low frequency mode to burrow into the nucleus for stabilization prior to chopping by setting the lower limit of NeoSonix to 0% phaco power. This approach works best with a straight tip, which acts like an apple corer to impale the nucleus. Alternatively, NeoSonix may be initiated as an adjunct to ultrasound at the 10 or 20% power level.

We have found NeoSonix most efficacious at 50% amplitude with a horizontal chopping technique in the AdvanTec burst mode at 50% power, 45.0 mL/min linear flow and 450.0 mmHg vacuum. A 0.9 mm microflare straight ABS tip rapidly impales and holds nuclear material for chopping. During evacuation of nuclear segments the material flows easily into the tip, with very little tendency for chatter and scatter of nuclear fragments. With refinement of our parameters, we have found a 57% reduction in average phaco power, and an 87% reduction in effective phaco time, compared with the data we previously published with the Legacy system.[7]

NeoSonix has permitted further reduction in the application of ultrasonic energy to the eye when used in conjunction with ultrasound, and allowed nonthermal cataract extraction when used alone. It represents an important new modality in phacoemulsification technology.

WHITESTAR TECHNOLOGY

WhiteStar (AMO) represents a new power modulation within ultrasonic phacoemulsification that virtually eliminates the production of thermal energy. Analogous to the ultrapulse mode familiar to users of carbon dioxide lasers, WhiteStar extrapolates pulse mode phacoemulsification to its logical limit. As the duration of the energy pulse is reduced, it eventually becomes less than the thermal relaxation time of ocular tissue. Thus, it is theoretically impossible to produce a corneal wound burn.

WhiteStar technology sets the stage for bimanual cataract extraction with the Sovereign phacoemulsification machine. The absence of thermal energy obviates the need for an irrigation sleeve on the phaco tip, thus permitting reduction of incision size and allowing irrigation through a second instrument, such as an irrigating chopper, placed through the side-port. With an incision size for cataract extraction less than 1 mm, the challenge becomes production of intraocular lenses capable of insertion through such microphaco incisions.

Olson[8] and Packard[9] have reported exciting results using a 21-gauge irrigating chopper and a 21-gauge bare phaco needle with the bimanual technique. Olson's study of cadaver eyes has demonstrated that thermal injury does not occur even in the absence of aspiration with 100% power for 3 minutes. Packard reported an absence of wound burns with excellent surgical ease and efficiency via sub-2.0 mm incisions.

The WhiteStar technology demonstrates important advantages in improved safety and efficiency of cataract extraction, whether used in standard fashion or with the microphaco technique.

AVANTIX

Vortex phacoemulsification involves placement of a tiny rotary impeller inside the capsular bag through a 1.0-mm capsulorrhexis. The impeller rotates at 60 kHz and causes expansion of the capsular bag with rotation of the nuclear complex, thus allowing extraction of the cataract from a nearly intact lens capsule. Expansion of the capsular bag minimizes risk of capsular rupture.

The tiny circular capsulorrhexis is constructed with a round diathermy instrument, thus reducing the technical demands of achieving such a surgical feat. The irrigation/aspiration tube containing the rotary impeller is placed over the capsulorrhexis while hydrodissection is performed with gentle irrigation. The tube is then inserted into the capsular bag through the 1.0-mm capsulorrhexis prior to initiation of rotation, thus completely isolating the anterior chamber from the activity of cataract extraction. Nuclear material is effectively removed from the capsular bag with vortex action, after which cortex is actually stripped away and extracted.

The advantages of leaving nearly the entire capsular bag in situ following cataract extraction will not be realized until an injectable artificial crystalline lens becomes available and the problem of capsular opacification is eliminated. Okahiro Nishi and others are currently investigating these devices, and may soon have a prototype available.[10]

AQUALASE

Research at Alcon has led to the development of a fluid-based cataract extraction system. Another non-thermal modality, Aqualase employs pulses of balanced salt solu-

tion at 50 to 100 Hz to dissolve the cataract. This modality may potentially demonstrate advantages in terms of safety and prevention of secondary posterior capsular opacification. Still early in its development, Aqualase represents an innovative and potentially advantageous modality for cataract extraction.

CONCLUSION

Since the time of Charles Kelman's inspiration in the dentist's chair (while having his teeth ultrasonically cleaned), incremental advances in phacoemulsification technology have produced ever-increasing benefits for patients with cataracts. The modern procedure simply was not possible even a few years ago, and until recently, prolonged hospital stays were common after cataract surgery.

The competitive business environment and the wellspring of human ingenuity continue to demonstrate synergistic activity in the improvement of surgical technique and technology. Future advances in cataract surgery will continue to benefit our patients as we develop newer phacoemulsification technology.

KEY POINTS

✔ In ultrasonic phacoemulsification piezoelectric crystals convert electrical energy into mechanical energy, which emulsifies the lens material by means of tip vibration. Ultrasonic tips create both heat and cavitational energy.

✔ A conventional phaco tip moves at ultrasonic frequencies of between 25 KHz and 62 KHz. The amount of heat generated is directly proportional to the operating frequency. In addition, cavitational effects from the high frequency ultrasonic waves generate even more heat.

✔ Low power phaco technology has an important advantage in minimizing intraoperative damage to ocular structures and maximizing the level and rapidity of visual rehabilitation of the patient.

✔ The sonic phacoemulsification system (STAAR Wave) demonstrates a new approach to elimination of heat and the danger of thermal injury to the cornea.

✔ Modification of ultrasound energy through refinement of power modulation offers yet another route leading to elimination of heat and reduction of incision size (WhiteStar).

✔ The introduction of innovative oscillatory tip motion in coordination with power modulation permits further reduction of average phaco power and effective phaco time (NeoSonix).

✔ Other new modalities under investigation, which promise low-energy, nonthermal cataract extraction, include vortex phacoemulsification (Avantix) and Aqualase, a fluid-based cataract extraction system.

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WHITESTAR "COLD PHACO" TECHNOLOGY

David F. Chang, MD

INTRODUCTION

WhiteStar technology for the Advanced Medical Optics (AMO, Santa Ana, Calif) Sovereign phaco system debuted at the 2001 ASCRS meeting. This is a revolutionary new power modulation, in which a digitally driven phaco handpiece can be programmed to deliver energy in a surprisingly precise fashion. Most importantly, WhiteStar is still ultrasound technology, which is deployed with the same standard handpiece and phaco needle as with conventional phaco. Similar technology has been incorporated into the Alcon Infiniti (Fort Worth, Tex) system as well.

WhiteStar technology changes the way ultrasound energy is delivered in two important ways. First, the duration of each phaco pulse can be shortened to as little as 6 msec. This allows surgeons to vary and increase the pulse rate to frequencies as high as 50 to 100 pulses per second (pps) (Figure 11-1). Second, the technology allows one to change the phaco *duty cycle* by prolonging and varying the amount of time that ultrasound is cycled off. The practical significance of these innovations is best understood by comparing continuous and pulse mode phaco.

CONVENTIONAL POWER MODULATIONS

With first generation phaco machines, ultrasound could only be delivered in continuous mode and at a 100% phaco power level. The advent of linear foot pedal control of power was a significant advance. As the surgeon gradually depresses the foot pedal in position three, the axial stroke length of the vibrating needle increases until the maximal programmed power setting has been reached. If the surgeon presets the maximum phaco power at 60%, the needle never vibrates at more than 60% of its maximum stroke length. Nevertheless, with continuous mode, ultrasound is always "ON" in foot pedal position 3.

In pulse mode phaco, ultrasound is delivered for a brief period (ON time) followed by a rest period where it is automatically shut off (OFF time). The ON and OFF periods are of equal duration. With a setting of 4 pps, each ON pulse is 125 msec long.

Figure 11-1. Schematic diagram showing frequent brief 6 msec pulses (red) with prolonged rest periods, compared with continuous mode ultrasound delivery (blue) (courtesy of Advanced Medical Optics).
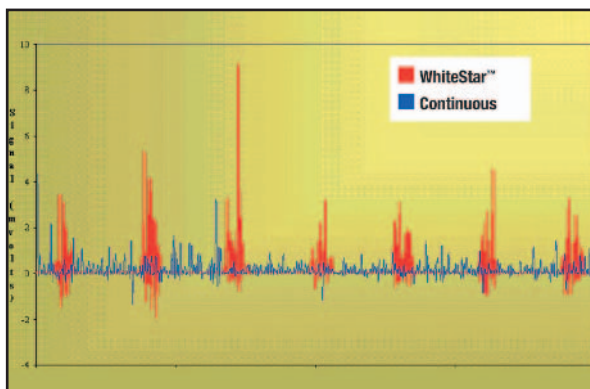
Each cycle of an ON pulse followed by an OFF rest period is 250 msec long. In pulse mode one can change the frequency of pulses, and shortening the duration of each ON pulse results in more pps. As an example, decreasing the ON time to 62.5 msec produces a rate of 8 pps.

The *duty cycle* refers to the percentage of time that ultrasound is ON while in foot pedal position three. It is equal to ON time divided by (ON + OFF time). Therefore, in continuous mode, the duty cycle is 100% because the phaco power is always ON. In conventional pulse mode, the duty cycle is always 50%.

Pulse mode provides several important advantages over continuous mode. First, the total amount of energy output in pedal position 3 is cut in half. Second, the interspersed OFF rest periods reduce the mechanical repelling force of the axially vibrating phaco needle. Clinically, this is seen as a reduction in chatter of nuclear fragments at the phaco tip. This jiggling or momentary bouncing of pieces off of the vibrating tip indicates that the tip repelling force is momentarily exceeding the attracting force of fluidic suction. Since increasing phaco power means increasing the axial stroke length of the vibrating tip, excessive power levels will also exacerbate chatter.

How Does WhiteStar Work?

By virtue of its ability to further shorten the pulse duration and to precisely vary the duty cycle, WhiteStar represents the next major innovation in power modulation. Being able to shorten the ON pulse to 6 msec permits a higher rate of 80 pps with a 50% duty cycle. In addition, WhiteStar allows us to vary the duty cycle by lengthening or shortening the rest periods. For example, following a 6-msec phaco pulse with a 12-msec rest period creates a 33% duty cycle and 55 pps. A 24-msec rest period would create a 20% duty cycle and 33 pps. A 3-msec rest period creates a 66% duty cycle and over 100 pps.

This combination of features provides three distinct clinical benefits. First, using a lower duty cycle further reduces the amount of ultrasound energy delivered. This, in combination with interrupting ultrasound delivery more frequently, significantly decreases heat buildup from the vibrating phaco needle. Finally, both factors substantially reduce the tip repelling forces. This noticeably enhances nuclear followability and reduces turbulence of particles at the tip.
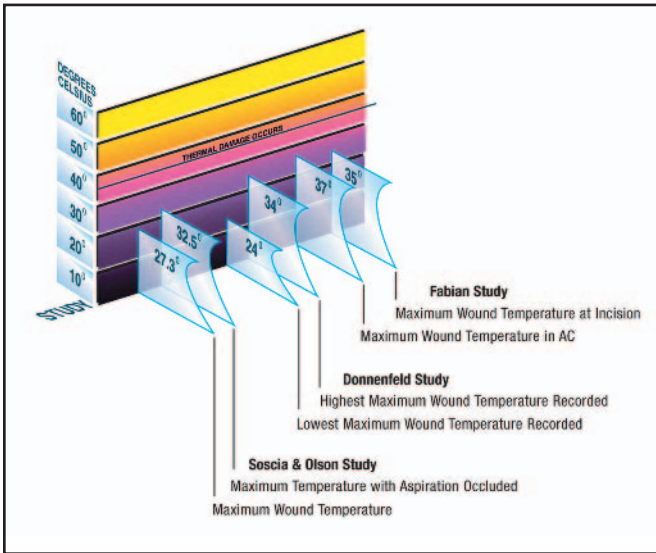
Figure 11-2. Composite representation of temperature studies of WhiteStar technology (courtesy of Advanced Medical Optics).

In 2001, in one of the first articles on WhiteStar, I coined the term "hyperpulse" to help doctors conceptualize the clinical benefits of using WhiteStar.[1] If one understands the advantages of pulse mode over continuous mode, hyperpulse implies a many-fold amplification of these benefits as a result of a lower duty cycle and more frequent interruption of phaco energy. Let's analyze each of these three major benefits to WhiteStar hyperpulse technology in greater detail.

REDUCTION IN PHACO ENERGY

By enabling us to use a lower duty cycle, WhiteStar can dramatically lessen phaco time. Recording and assessing the *effective phaco time* (EPT) can readily quantify this reduction. The EPT is a composite value that factors both the ON/OFF time and the percentage of phaco power used, and converts this to an equivalent amount of time hypothetically spent in continuous mode at 100% phaco power.

Unfortunately, various manufacturers measure and define stroke length in different ways. Lacking a standard methodology, it is not possible to meaningfully compare EPTs between different manufacturer's machines. However, EPTs can provide valuable comparisons within the same phaco system, such as the varying energy requirements for different nuclear grades. One can also compare EPTs for different techniques, such as divide and conquer and chopping. Finally, using the same technique and machine for the same grade of nucleus, one can assess the energy reduction from using different power modulations such as pulse or WhiteStar hyperpulse modes.

REDUCTION IN THERMAL HEAT

Cadaver studies conducted by Dr. Olson and Dr. Donnenfeld have confirmed a dramatic reduction in thermal heat compared to conventional non-WhiteStar ultrasound[2-4] (Figure 11-2). In their studies, it was virtually impossible to create an incisional burn. This confers an enormous advantage in terms of decreasing the risk of wound burn or thermal injury to the cornea. This is especially important when one is removing brunescent cataracts via a clear corneal incision.

Figure 11-3A through C. Bimanual horizontal phaco chop (AMO Sovereign with WhiteStar and MST Chang horizontal irrigating chopper)
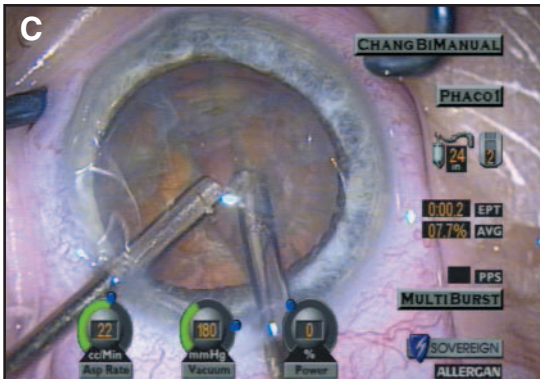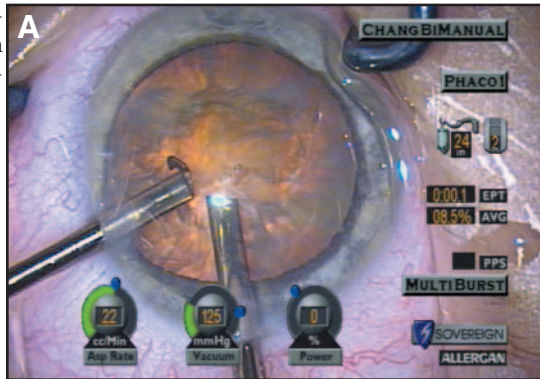
This characteristic of WhiteStar has rekindled much interest in performing bimanual microincisional phaco with a sleeveless phaco needle (Figure 11-3). In standard non-WhiteStar phaco, the hot phaco tip is cooled by the surrounding irrigation inflow, along with fluid escaping through an incision that is slightly, and intentionally, oversized. Although a misnomer in the strict sense, the term "cold phaco" conveys the concept of lens removal technology that does not pose a danger of wound burn. This provides an important measure of safety, and creates the potential to downsize the phaco incision by detaching the infusion sleeve.

Over the years, there have been numerous and extensive efforts to find a superior alternative to ultrasound. Other "cold phaco" technologies have included laser phaco (Erbium or Nd:YAG laser source), STAAR Surgical's (Monrovia, Calif) sonics which uses a much lower frequency of tip vibration, and Alcon's Aqualase (Fort Worth, Tex), which uses fluid jets instead of ultrasound. Like WhiteStar, each of these technologies will prevent wound burns and, by obviating the need for a cooling fluid leak, the incisions can be made tighter. In addition, these technologies are all adaptable to bimanual microincisional surgery in that they do not require a coaxial infusion source.

The critical difference, however, is that these other technologies all achieve their "cold" status by eliminating ultrasound as the source of energy. As a result, these other cold technologies are effective for soft nuclei, but become less efficient and less effective with increasing nuclear density. While proponents will point out that denser nuclei can be removed with these modalities, the procedure becomes so slow and inefficient that any advantages over standard ultrasound are greatly overshadowed. Finally, none of these competing technologies is effective or appropriate for brunescent nuclei.

Given the prior experience with laser phaco and sonics, a crucial question when WhiteStar was launched was whether it would be effective for dense lenses. In fact, it turns out that WhiteStar is actually superior to conventional phaco for brunescent nuclei. At the 2002 ASCRS meeting, I reported on 30 consecutive 4+ brunescent nuclei removed with WhiteStar.[5] Using vertical phaco chop with no sculpting, the range in EPT was 6 to 30 seconds, with an average EPT of 9.1 seconds. Clearly, what differentiates WhiteStar from the other "cold" modalities is that this technology is still capable of delivering full ultrasound power. Instead of using a different energy source, it is the alternative delivery modulation that limits heat production. As a result, surgeons can still access maximal phaco power and tip stroke length for brunescent material, while minimizing heat and energy delivery at the same time.

Mark Shafer, PhD, an engineer specializing in ultrasound systems, has provided an explanation for this win-win solution. According to Dr. Shafer, there are two types of acoustic cavitational energy involved in phacoemulsification—transient and stable.[6] Transient cavitation creates a momentary water jet that breaks up the nuclear tissue. This is immediately followed by a longer period of stable cavitation, which causes vibration of cavitational bubbles without energy release. This can therefore be considered wasted energy, compared to the transient cavitation that is effective at cutting the nucleus. By interspersing microbursts of ultrasound energy delivery with microrest periods, WhiteStar generates transient cavitation with each microburst, and limits stable cavitation by immediately cycling the phaco tip off. By selectively maximizing the effective transient cavitational energy, and minimizing the ineffective stable cavitational energy, WhiteStar is able to optimize cutting performance, while at the same time reducing overall heat and energy output.

REDUCTION IN PARTICLE CHATTER AND TURBULENCE

The third major advantage of WhiteStar is its ability to facilitate followability of mobile lens fragments. This refers to the degree to which particles stay on the phaco tip as ultrasound is delivered, instead of momentarily deflecting away. As mentioned earlier, this jiggling and bouncing of pieces is called chatter, and indicates momentary periods where the repelling force of the axially vibrating phaco tip exceeds the aspirating force of the pump.

Figure 11-4. Improved fragment followability using AMO Sovereign with WhiteStar mode in a 4+ brunescent nucleus.
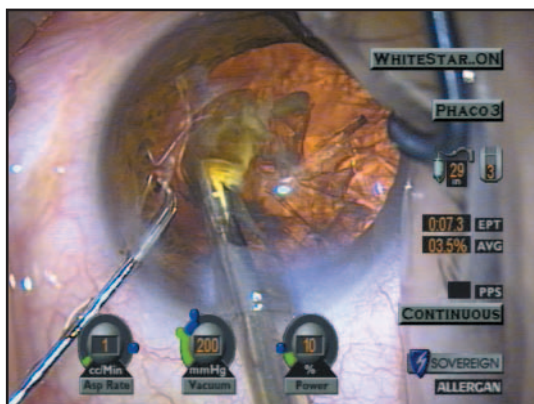
Chatter is less of a problem with soft nuclei because the "gummy" material readily molds into the mouth of the tip and the vacuum takes hold. However, with brunescent cataracts, the rigid fragment contours do not easily conform to the mouth of the phaco tip, rendering vacuum less effective. When you combine the fact that these nuclei require higher power settings and longer tip stroke lengths, the result is chatter and a greater tendency for particles to bounce away.

The frequent interspersed rest periods characteristic of hyperpulse dramatically reduce this repelling force and better enable the aspirating forces to hold pieces at the tip. The technical term for these repelling cavitational forces is acoustic streaming, and this contributes to fluid and particle turbulence that can be injurious to the endothelium.

Chatter also increases if the size of a dense nuclear fragment is much larger than the size of the phaco tip opening. Chopping a large fragment into smaller pieces is therefore one way to reduce chatter. However, using micro phaco tips, whose smaller diameter openings impede this molding process, exacerbates chatter. The need for 20-gauge phaco tips is another important reason why WhiteStar is particularly suitable for bimanual phaco.

Benefits for Brunescent Nuclei

In assessing the value of any new lens removal technology, the most important test is the brunescent nucleus. These cases take the longest time to phaco, and they challenge us with an increased risk of wound burn, posterior capsule rupture, and endothelial cell loss. While we don't routinely do endothelial cell counts, the postoperative day one corneal clarity gives us immediate feedback about how traumatic our procedure was to the endothelium. While the corneas are generally clear following phaco of soft to medium density nuclei, we are certainly accustomed to seeing more edema in eyes with brunescent cataracts. Endothelial cell count studies have confirmed greater cell loss following surgery in these eyes.[7]

In my personal experience with WhiteStar, postoperative day 1 corneal edema is significantly less in this subgroup of brunescent cataracts.[5,6] While decreased energy delivery may play a role, I believe that the most important factor is the reduced particle turbulence at the tip (Figure 11-4). The brunescent lens tends to have the largest
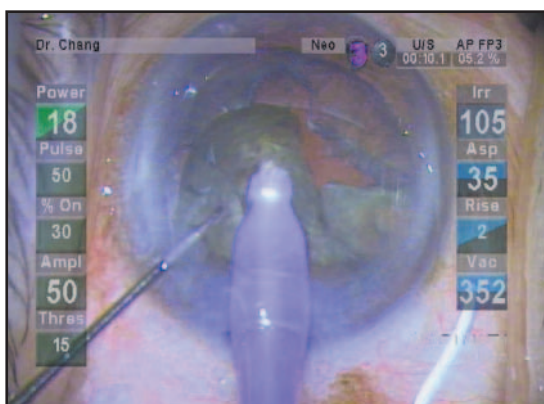
Figure 11-5. Alcon Infiniti hyperpulse mode with overlay showing 50 pps and 30% duty cycle.

nuclear mass, and normally requires the longest phaco time and highest phaco power levels to remove. As stated earlier, the larger size and rigid contours of the fragments, and the longer tip stroke lengths combine to produce much greater amounts of particle chatter and turbulence. This undoubtedly increases endothelial cell loss, and explains why the improved nuclear followability seen with WhiteStar would be particularly beneficial for corneal safety with dense cataracts.

Although WhiteStar technology can be used with any phaco technique, it compliments phaco chop particularly well. This is because during phaco chop, the majority of ultrasound is used for removing chopped fragments, and enhanced tissue followability facilitates this step. By eliminating sculpting, chopping also further reduces overall use of ultrasound.[8,9] The ability to chop dense nuclei into multiple small fragments, as opposed to dividing/cracking them into four large quadrants, also helps to reduce particle turbulence and chatter. Finally, chopping is the phaco technique that seems most suitable for bimanual microincisional phaco.[10]

ALCON INFINITI SYSTEM

In 2003, Alcon introduced the Infiniti phaco system. The Infiniti also offers the option of hyperpulse with the ability to vary both duty cycle and pps (Figure 11-5). The shortest duration pulse available is 5 msec. The duty cycle can be altered in 5% increments and the pulse rate can be set as high as 100 pps (5 msec pulse/50% DC). Both cadaver heat studies and clinical experience have shown that this delivers the same benefits as WhiteStar technology (Figure 11-6).[10]

SUMMARY

WhiteStar hyperpulse technology represents a quantum leap in phaco efficiency and safety. It eliminates the risk of wound burn without requiring an alternative energy source. Of all of the so-called "cold" phaco technologies, it is the only one that can efficiently handle the entire spectrum of nuclear density. Finally, it is truly superior to standard ultrasound for brunescent cataracts. By limiting particle turbulence and overall phaco energy delivery, it reduces the greater endothelial trauma associated with phacoemulsification of these lenses. That WhiteStar is able to do so with a standard phaco handpiece and without any alteration of surgical technique is even more satisfying.

Figure 11-6. Bimanual horizontal phaco chop (Alcon Infiniti with hyperpulse, and Katena's [Denville, NJ] Chang horizontal irrigating hydrochopper).
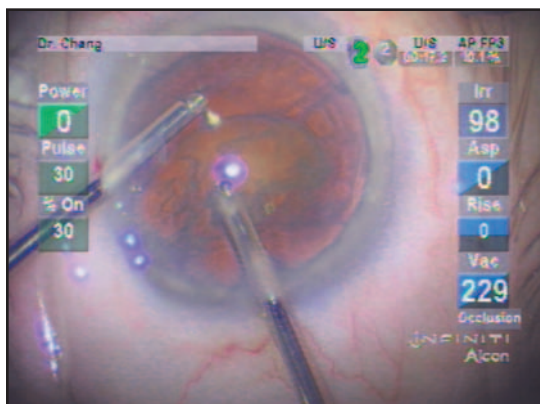

KEY POINTS

✔ The WhiteStar is a revolutionary new power modulation, in which a digitally driven phaco handpiece can be programmed to deliver energy in a surprisingly precise fashion.

✔ WhiteStar technology changes the way ultrasound energy is delivered in two important ways. First, the duration of each phaco pulse can be shortened to as little as 6 msec. This allows surgeons to vary and increase the pulse rate to frequencies as high as 50 to 100 pps. Second, the technology allows one to change the phaco duty cycle by prolonging and varying the amount of time that ultrasound is cycled off.

✔ By virtue of its ability to further shorten the pulse duration and to precisely vary the duty cycle, WhiteStar represents the next major innovation in power modulation. Being able to shorten the ON pulse to 6 msec permits a higher rate of 80 pps with a 50% duty cycle.

✔ By enabling us to use a lower duty cycle, WhiteStar can dramatically lessen phaco time.

✔ The WhiteStar has an ability to facilitate followability of mobile lens fragments. This refers to the degree to which particles stay on the phaco tip as ultrasound is delivered, instead of momentarily deflecting away.

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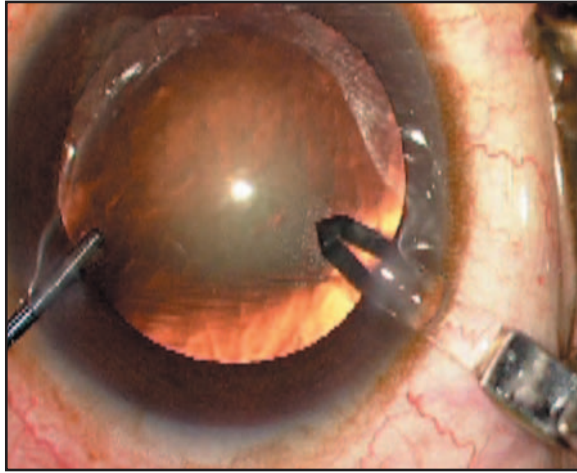
SURGICAL TECHNIQUES
AND COMPLICATIONS

BIMANUAL PHACO: SURGICAL TECHNIQUE

Amar Agarwal, MS, FRCS, FRCOphth

TECHNIQUE OF BIMANUAL PHACO FOR CATARACTS

Anesthesia

The technique of bimanual phaco (ie, Phakonit, MICS, microphaco, or sleeveless phaco) can be done under any type of anesthesia. In the cases done by the author, no anesthetic drops are instilled in the eye, nor is any intracameral anesthetic injected inside the eye. This is known as *no anesthesia cataract surgery*. The author has analyzed that there is no difference between topical anesthesia cataract surgery and no anesthesia cataract surgery. If there is a difficult case, the author uses a peribulbar block.

Incision

In the first step, a needle with viscoelastic is taken and pierced in the eye in the area where the side-port has to be made (Figure 12-1). The viscoelastic is then injected inside the eye. This will distend the eye so that the clear corneal incision can be made. Now a temporal clear corneal incision is made. A special knife can be used for this purpose. (Figure 12-2). This keratome and other instruments for bimanual phaco are made by Huco (Switzerland), Gueder (Heidelburg, Germany), and Microsurgical Technologies (MST, Redmond, Wash).

Rhexis

The rhexis of about 5.0 to 6.0 mm is then performed. This is done with a needle (Figure 12-3). In the left hand, a straight rod is held to stabilize the eye; this is the globe stabilization rod. The advantage of this is that the movements of the eye can be controlled as one is working without any anesthesia.

Hydrodissection

Hydrodissection is performed and the fluid wave passing under the nucleus is checked. (Check for rotation of the nucleus.)

Figure 12-1. A 26-gauge needle with viscoelastic making an entry in the area where the side-port is. This is for entry of the irrigating chopper.

Figure 12-2. Clear corneal incision made with the keratome. Note the left hand has a straight rod to stabilize the eye as the case is done without any anesthesia. These instruments are made by Katena (Denville, NJ).
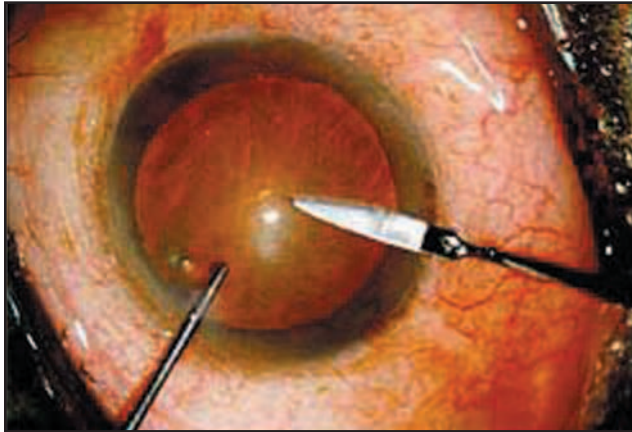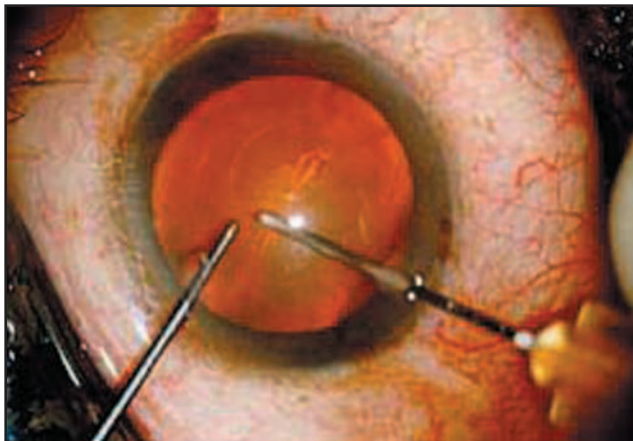
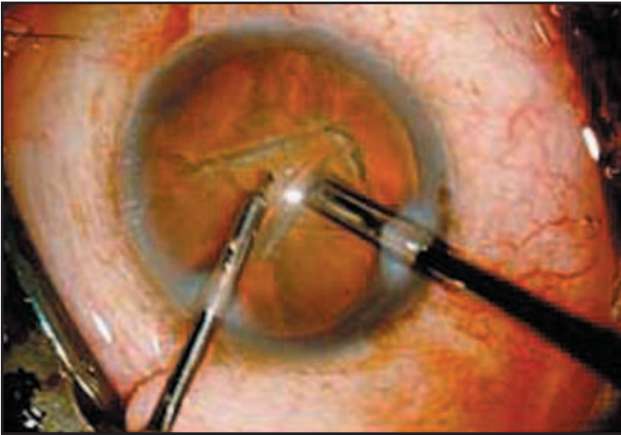**Figure 12-3.** Rhexis started with a needle.

Figure 12-4. Bimanual phaco irrigating chopper and phaco probe without the sleeve inside the eye.

Bimanual Phaco

After enlarging the side-port a 20- or 21-gauge irrigating chopper connected to the infusion line of the phaco machine is introduced with foot pedal on position 1. The Agarwal irrigating chopper, specially designed by Larry Laks from United States, has been made by MST and incorporated into the Duet system. Other excellent irrigating choppers by the same company include the ones designed by David Chang, Randall Olson, Robert Osher, I. Howard Fine, and Hiroshi Tseunoka. Other Agarwal irrigating choppers are available with Geuder, Huco, and Katena. The phaco probe is connected to the aspiration line, and the phaco tip without an infusion sleeve is introduced through the clear corneal incision (Figure 12-4). Using the phaco tip with moderate ultrasound power, the center of the nucleus is directly embedded starting from the superior edge of rhexis with the phaco probe directed obliquely downward towards the vitreous. The settings at this stage is 50% phaco power, flow rate 24.0 mL/min, and 110.0 mmHg vacuum (Alcon Univ II phaco machine). When nearly half of the center of nucleus is embedded, the foot pedal is moved to position 2, helping to hold the nucleus due to vacuum rise. To avoid undue pressure on the posterior capsule, the nucleus is lifted a bit and with the irrigating chopper in the left hand the nucleus chopped. This is done with a straight downward motion from the inner edge of the rhexis to the center of the nucleus and then to the left in the form of a laterally reversed L shape (Figure 12-5). Once the crack is created, the nucleus is split to the center. The nucleus is then rotated 180 degrees and cracked again so that the nucleus is completely split into two halves.

The nucleus is then rotated 90 degrees and embedding is done in one half of the nucleus with the probe directed horizontally (Figure 12-6). With the previously described technique, three pie-shaped quadrants are created in one half of the nucleus. Similarly, three pie-shaped fragments are created in the other half of the nucleus. With a short burst of energy at pulse mode, each pie-shaped fragment is lifted and brought at the level of iris where it is further emulsified and aspirated sequentially in pulse mode. Thus the whole nucleus is removed (Figure 12-7). Note in Figure 12-7, no corneal burns are present. Cortical wash-up is the done with the bimanual irrigation aspiration technique (Figures 12-8 and 12-9).

Figure 12-5. Bimanual phaco started. Note the phaco needle in the right hand and an irrigating chopper in the left hand. Bimanual phaco being performed. Not the crack created by "karate" chopping. The assistant continually irrigates the phaco probe area from outside to prevent corneal burns.
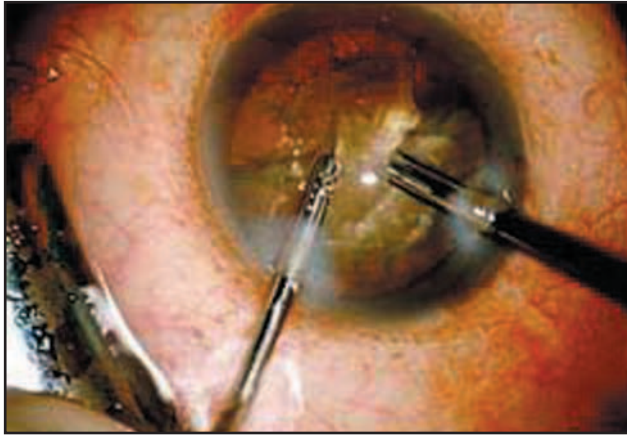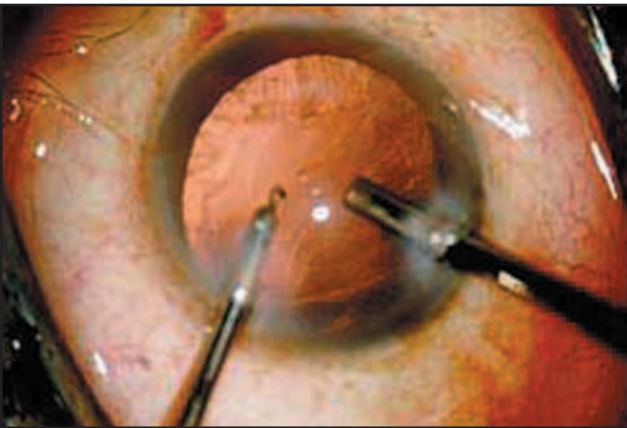
Figure 12-6. Bimanual phaco continued. The nuclear pieces are chopped into smaller pie-shaped fragments.

Figure 12-7. Bimanual phaco completed. Note the nucleus has been removed and there are no corneal burns.
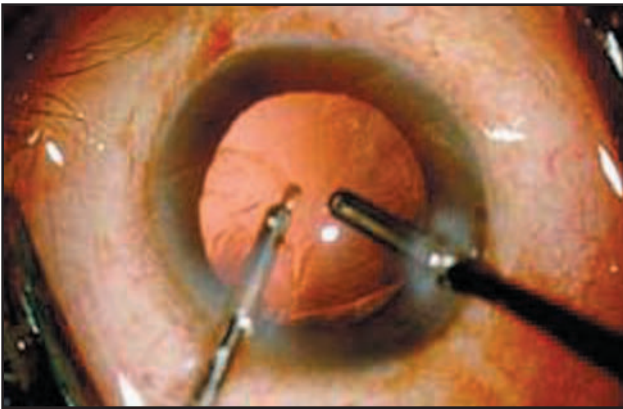
Figure 12-8. Bimanual irrigation aspiration started.
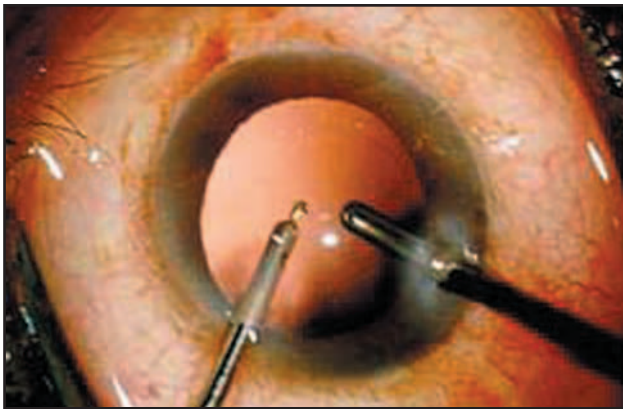
Figure 12-9. Bimanual irrigation aspiration completed.

BIMANUAL PHACO WITH CUT SLEEVE

Another unique problem faced during bimanual phaco was that of fluid splashing from the base of the phaco needle outside the incision during emulsification. This splashing is due to the fact that the fluid in contact with the base of the vibrating phaco needle during emulsification was churned, thus releasing droplets of fluid. These fluid droplets could hamper the surgeon's view directly or by getting deposited on the microscope objective.

To eliminate wound burns, we should have some way of cooling the corneal wound of entry. This is usually remedies by the fluid that leaks out of the eye from the main wound, since the naked phaco needle without the sleeve does not provide a water tight wound. To provide irrigation into the anterior chamber, we use the irrigating chopper through the side-port connected to the irrigating bottle along with an air pump specially devised for this purpose. To prevent the splashing of fluid from the base of the needle during emulsification, we use the cut sleeve around the base of the phaco needle. We cut the sleeve in such a manner that it covers only the base of the phaco needle and does not enter the eye. Thus, we are able to prevent the splashing of fluid during emulsification.

During bimanual phaco surgery, fluid is constantly leaking out of the eye from the main wound of entry, as the incision around the phaco needle without the sleeve is not watertight. This fluid is coming from the irrigating chopper connected to the air injector. If we connect another fluid irrigating line the phaco needle with cut sleeve, fluid travels from the base of the phaco needle towards the wound of entry from outside. This stream of fluid meets the stream coming from inside eye at the corneal entry wound causing turbulence and fluid collection in the operating field. This reduces visibility during surgery. Moreover, since the wound is cooled internally by the fluid leaking from the eye outward, there is no need for this second irrigation line. More importantly, when we connect the second irrigation line to the phaco hand piece with the cut sleeve, the irrigation is always on but we need it only during emulsification. Hence, it is better to use an assistant who could drop cooled BSS at the external wound only during emulsification. We advocate bimanual phaco with a cut sleeve without irrigation to eliminate water splashing during bimanual phaco to improve visibility during the surgery.

AIR PUMP

One of the real concerns when we started bimanual phaco was the problem of destabilization of the anterior chamber during surgery. This was solved to a certain extent by using an 18-gauge irrigating chopper. A development made by Sunita Agarwal was to use an anti-chamber collapser[4,5] which injects air into the infusion bottle (see Chapter 7). This is an air pump. This pushes in more fluid into the eye through the irrigating chopper and also prevents surge. Thus we were not only able to use a 20-gauge irrigating chopper but also solve the problem of destabilization of the anterior chamber during surgery. This increases the steady-state pressure of the eye making the anterior chamber deep and well maintained during the entire procedure. It even makes phacoemulsification a relatively safe procedure by reducing surge even at high vacuum levels. Thus, this can be used not only in bimanual phaco but also in phacoemulsification.

BIMANUAL PHACO CAN BE DONE WITH ANY PHACO MACHINE

A top-end phaco machine is not required to perform bimanual phaco. The key is to use any machine already present and start bimanual phaco. The parameters for an Alcon (Fort Worth, Tex) or AMO machine are:

- Power: 50% phaco power for a moderate cataract. The power can be increased to 70% for hard cataracts. Start in the continuous mode and once chopping has been done then shift to the pulse mode.
- Suction: 100.0 mmHg. One has to use the air pump or anti chamber collapser so that no surge occurs. In other words some sort of forced gas infusion has to be used. One can do without it but the problem will come in difficult cases and one has to go slower.
- Flow rate: 20.0 to 24.0 mL/min.
- Phaco needle: if one uses a 0.8-mm phaco needle with a 21-gauge irrigating chopper then one can do a sub-1.0-mm cataract surgery.
- Irrigation over corneal incision. It is better than not applying it. You can feel very safe with it as it negates the possibility of a corneal burn.

THINOPTX ROLLABLE IOL

ThinOptX (Abingdon, Va), the company that manufactures these lenses, has patented technology that allows the manufacture of lenses with plus or minus 30 diopters (D) of correction on the thickness of 100 μm. The ThinOptX technology developed by Wayne Callahan, Scott Callahan, and Joe Callahan is not limited to material choice, but is achieved instead of an evolutionary optic and unprecedented nano-scale manufacturing process. The lens is made from off-the-shelf hydrophilic material, which is similar to several IOL materials already on the market. The key to the ThinOptX lens is the optic design and nano-precision manufacturing. The basic advantage of this lens is that they are ultrathin lenses. I modified this lens to make a special 5.0-mm optic rollable IOL.

ThinLens Optics

The front surface of the ThinOptX IOL is a curve that approximates a radius. The back curve is a series of steps with concentric rings. The back surface can be concave, convex, or plano. The combination of steps with the front radius corrects for spherical aberrations. The convex and plano back designs can be used for positive power lenses. The concave or meniscus back surface is used for negative powered lenses.

Glare

In the late-1970s, lens companies made a lens with an optic that was 5.0 by 6.0 mm. The edge for a 20.0-D lens with a 0.25-mm haptic was 0.50 mm. The edge was twice as thick as a standard 6.0-mm lens. Reports began of patients getting glare and halos in low light conditions. It is doubtful the pupil was opening to something greater than 5.0-mm. For light to strike the edge of the lens with the lens in the posterior chamber, it seems the pupil would have to be greater than 5.0 mm.

In other laboratory work, extreme edge glare was encountered when a light source was placed near a thick flat piece of plastic. The large edges were covered and never exposed to direct light rays. An extremely small angle of incidence was created. The absorbed light hit the large edge and was reflected back across the sheet of plastic to the opposite edge. The light in the lens gave the appearance of a laser generation tube. When the light source was removed the glare faded away.

A conclusion was reached that much of the light hitting the plastic with small angles of incidence was being absorbed. When the light rays reached the edge, the rays were reflected back across the plastic sheet. The light rays then struck the opposite edge of the plastic sheet and bounced back across the sheet. The same principle seems logical in a lens with a thick edge. This would explain why patients with a high negative lens get glare in bright sunlight.

With the ThinLens technology, each ring has an exposed edge of 50.0 μm or less. On average, there are three rings per lens plus the outer edge of the lens. The cumulative ring edges are 200.0 μm. This is much less area than a standard or meniscus lens. This helps patients not complaining of glare or halos, even under low light conditions.

Spherical Aberration

Spherical aberrations arise from the fact that lens are most often designed as a portion of a sphere. For a theoretically perfect lens, the radius of the lens surface should increase as the distance from the central axis increases. The lens should be aspheric.

A sphere is not a perfect lens model. The error can be as much as 1.5 D when measured 2.0 mm from the central optic. The majority of cataract lenses are manufactured with spherical aberrations. The standard aperture on a lens bench is approximately 3.0 mm. Many lens manufacturers will not have acceptable optics if the apertures were opened to 4.0 mm.

The ThinOptX lens is manufactured to eliminate most of the spherical aberrations. Each curve on the back has a slightly different radius. The slight change in curvature on each back surface will assure one focal point.

Other Aberrations

Thickness causes a form of aberration due to light rays traveling longer in the thicker portion of the lens. The error is additive to spherical aberrations, but is small if the lens manufacturer controls the thickness of the lens or compensates for the differences in thickness when measuring the lens. The error is not as much from the thickness as the fact that most lens benches are calibrated using the back focal length of the lens. A correction factor for thickness is added to determine the lens power. The process can be very accurate if the differences in thickness of the lens are not significant or the lens bench is calibrated between each lens power. The bench should be calibrated even with the same lens power if the lens thickness changes significantly.

The ThinLens is so thin that the error is negated. With a central axis thickness of 50 µm for a meniscus lens and 300 µm for a biconvex or plano optic, there is little error in measuring the lens due to thickness. In fact with the ThinLens one can measure lens designed to the same power without adjusting the lens bench. The thinness is one of the reasons the ThinLens can be manufactured in increments of one-eighth of a diopter.

Fresnel Lens

By definition, the ThinOptX lens is not a Fresnel lens. The normal lines on the back surface of the Fresnel lens do not originate from the same point; therefore, the back surface of the lens functions as a series of prisms. By selecting the angle the incoming light rays make with the normal line of each prism, one can choose the focal pattern of the resulting light. One such application is the headlamps of an automobile. The second surface of the ThinLens is designed to assist the front surface in focusing the light at a single point, which by definition is a REFRACTIVE lens.

Lens Insertion Technique

The lens is taken out from the bottle and held with a forceps (Figure 12-10). Then the lens is placed in a bowl of balanced salt solution (BSS) solution that is approximately body temperature. This makes the lens pliable. Once the lens is pliable, it is taken with the gloved hand holding it between the index finger and the thumb. The lens is then rolled in a rubbing motion. It is preferable to do this in the bowl of BSS so that the lens remains rolled well.

The lens is then inserted through the sub-1.4-mm incision carefully (Figure 12-11). One can then move the lens into the capsular bag (Figure 12-12). The natural warmth of the eye causes the lens to open gradually. Viscoelastic is then removed with the Bimanual irrigation aspiration probes (Figure 12-13). The tips of the footplates are extremely thin, which allows the lens to be positioned with the footplates rolled to fit the eye.

Figure 12-10. The bimanual phaco ThinOptX rollable IOL when removed from the bottle.
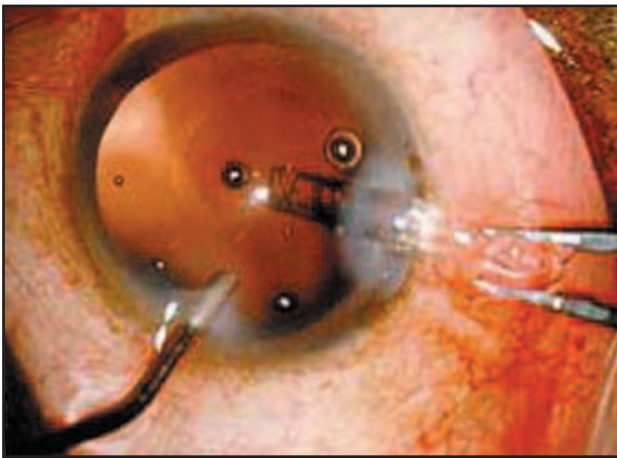

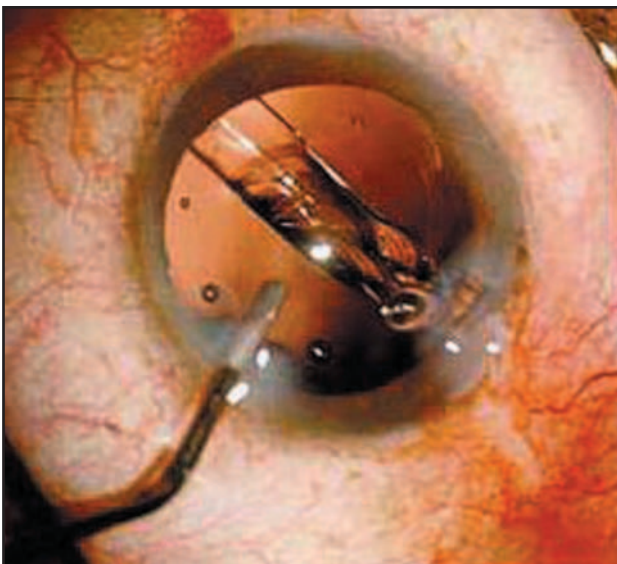**Figure 12-11.** The rollable IOL inserted through the incision.

Figure 12-12. The rollable IOL in the capsular bag.

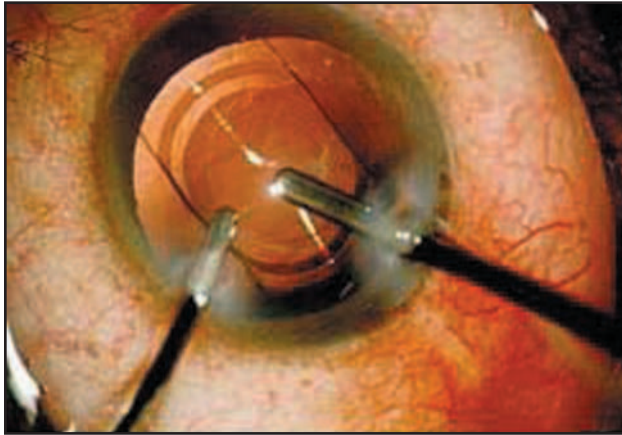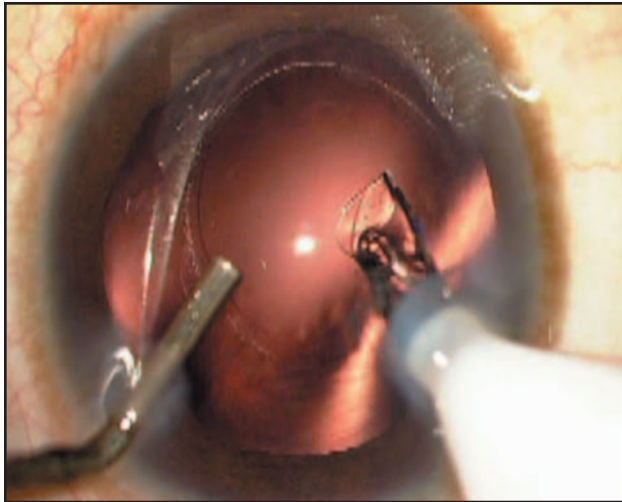**Figure 12-13.** Viscoelastic removed using bimanual irrigation aspiration probes.

Figure 12-14. ThinOptX roller cum injector. Note the IOL being injected in the capsular bag.

ThinOptX has now made a special injector that not only rolls the lens but also inserts the lens. This way we do not need to use our fingers for rolling the lens. In Figure 12-14, you will notice this special injector injecting the IOL in the capsular bag. The tip of the nozzle is kept at the edge of the incision.

TOPOGRAPHY

We also performed topography with the orbscan to compare cases of bimanual phaco and phaco and we found that the astigmatism in bimanual phaco cases is much less compared to phaco (Figure 12-15). Stabilization of refraction is also faster with Bimanual phaco compared to phaco surgery. Table 12-1 compares the differences between phaco and bimanual phaco.
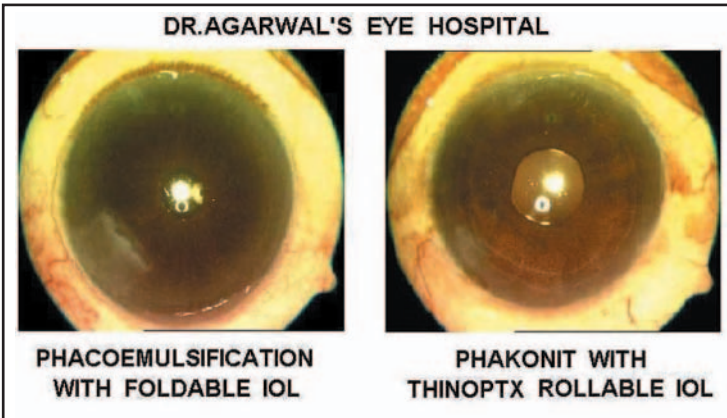
Figure 12-15. Comparison between phaco foldable and bimanual phaco ThinOptX IOL.

TABLE 12-1		
PHACO VS BIMANUAL PHACO		
Feature	*Phaco*	*Bimanual Phaco*
• Incision size	3.0 mm	Sub-1.4 mm
• Air pump	Not mandatory	Mandatory
• Hand usage	Single-handed phaco possible	Two hands (bimanual)
• Nondominant hand entry and exit	Last to enter and first to exit	First to enter and last to exit
• Capsulorrhexis	Needle or forceps	Better with needle
• IOL	Foldable IOL	Rollable IOL
• Astigmatism	Two unequal incisions create astigmatism	Two equal ultrasmall incisions negate the induced astigmatism
• Stability of refraction	Later than bimanual phaco	Earlier than phaco
• Iris prolapse-intra-operative	More chances	Fewer chances due to smaller incision

ACRI.TEC GMBH IOL

The Acri.Lyc IOL is manufactured by the Acri.Tec GmbH company in Berlin, Germany. This lens is a sterile foldable IOL made of hydrophobic acrylate. The IOLs consists of highly purified biocompatible hydrophobic acrylate with chemically bonded UV-absorber. It is a single piece foldable IOL like a plate-haptic IOL. The lens is sterilized by autoclaving. The lens comes in a sterile vial, filled with water, and wrapped in a sterile pouch.

THREE-PORT BIMANUAL PHACO

Another technique by which one can perform bimanual phaco is to use an anterior chamber maintainer. I started this technique[1], and called it *three-port bimanual phacoectomy* or *three-port Phakonit* (see Chapter 17). Just as a three-port vitrectomy, here also we have three ports, hence the name.

There are pros and cons in every technique. The problem in three port phacoectomy is that it is too cumbersome. Surgeons prefer to have two ports only. Some surgeons prefer three ports as an anterior chamber maintainer is present in the eye and thus the anterior chamber is always formed. At present, it is easier to perform bimanual phaco using a 20-gauge irrigating chopper with the air pump.

AC STABILITY IN BIMANUAL PHACO

An issue in bimanual phaco when we started it was about the problem of destabilization of the anterior chamber during surgery.[1-5] This was solved to a certain extent by using an 18-gauge irrigating chopper. Another solution would be to raise the bottle to the roof which is not very practical. The main problem in bimanual phaco was that the amount of fluid entering the eye through the irrigating chopper was not equal to the amount of fluid exiting the eye through the sleeveless phaco needle.

Solution

Different surgeons have tried different methods to solve this problem of anterior chamber stability. The various methods are:
- Air pump or antichamber collapser
- Anterior vented gas forced infusion system (VGFI) of the Accurus surgical system (Alcon)
- STAAR Surgical's (Monrovia, Calif) disposable Cruise Control device
- Well-designed irrigating choppers

The Anterior Vented Gas Forced Infusion System of the Accurus Surgical System in the Performance of Bimanual Phaco

This method was started by Arturo Pérez-Arteaga from Mexico. The AVGFI is a system incorporated in the Accurus machine that creates a positive infusion pressure inside the eye; it was designed by the Alcon engineers to control the intraocular pressure (IOP) during the anterior and posterior segment surgery. It consist of an air pump and a regulator who are inside the machine; then the air is pushed inside the bottle of intraocular solution, and so the fluid is actively pushed inside the eye without raising or lowering the bottle. The control of the air pump is digitally integrated in the Accurus panel; it also can be controlled via the remote. Also the footswitch can be preset with the minimal and maximum of desired fluid inside the eye and go directly to this value with the simple touch of the footswitch. Arturo Pérez-Arteaga recommends to preset the infusion pump at 100.0 to 110.0 cmH$_2$O; it is enough strong irrigation force to perform a microincision phaco (see Chapter 8). This parameter is preset in the panel and also as the minimal irrigation force in the footswitch; then he recommends to preset the maximum irrigation force at 130.0 to 140.0 cmH$_2$O in the foot pedal, so if a surge occurs during the procedure the surgeon can increase the irrigation force by the simple touch of the footswitch to the right. With the AVGFI, the surgeon has the capability to increase these values even more.

Cruise Control

The Cruise Control (STAAR Surgical, Monrovia, Calif) is a disposable, flow-restricting (0.3-mm internal diameter) device that is placed in between the phaco handpiece and the aspiration tubing of any phaco machine. The goal is very similar to that of the flare tip (Alcon)—combining a standard phaco tip opening with a narrower shaft to provide more grip with less surge. This has been popularized by David Chang and I. Howard Fine for bimanual phaco surgery. STAAR Surgical introduced this disposable Cruise Control device, which can be used with any phaco machine.

Well-Designed Irrigating Choppers

Well-designed irrigating choppers which have better flow of fluid inside the eye also help to prevent any collapse of the anterior chamber.

INTRAOPERATIVE PROTOCOL FOR VANCOMYCIN PROPHYLAXIS

One can inject vancomycin inside the eye at the end of the surgery to prevent endophthalmitis from occurring. For this the intraoperative protocol is:

1. 250.0 mg vial of vancomycin is taken to be dissolved in 25 mL of Ringer's lactate (Abbott Laboratories, Abbott Park, Ill) (RL) or BSS.

2. This will give a concentration of 1.0 mg in 0.1 mL.

3. At the end of the surgery, insert 0.1 ml of vancomycin containing 1.0 mg into the capsular bag behind the IOL. If needed, additional BSS/RL can be injected into the eye to make the eye firm.

CONVERSION TO PHACO OR ECCE

While performing bimanual phaco, if the surgeon experiences difficulties like corneal edema on table or continuous destabilization of the anterior chamber, one should convert to phaco or extracapsular cataract extraction (ECCE). One should not be egoistical about this as the patient's vision is of utmost importance.

There will be slight difficulty in doing phaco as the side-port incision is 1.0 mm and there will be fluid leakage. In such a case, one can suture the side-port incision to make things easy. The normal chopper will be able to pass through a sutured side-port and there will not be a leakage. While converting to ECCE, suturing of the clear corneal incisions should be done. The ECCE should then be performed as usual from the superior end through a scleral incision after cutting the conjunctiva.

If bimanual phaco is continued with destabilization of the anterior chamber, there can be permanent endothelial damage. Therefore, it is more prudent to convert in such cases.

SUMMARY

There are various problems encountered in any new technique, and bimanual phaco is no different. With time, these will have to be solved. The important point is that today we have broken the 1.0-mm barrier for cataract removals. This can be done easily by separating the phaco needle from the infusion sleeve. As the saying goes— "We have miles to go before we can sleep."

KEY POINTS

✔ The technique of bimanual phaco can be done under any type of anesthesia. Dr. Agarwal prefers the no anesthesia cataract surgery technique. In this, no anesthetic drops are instilled in the eye nor any intracameral anesthetic injected inside the eye. If there is a difficult case, they use a peribulbar block.

✔ The rhexis is preferably performed with a needle. In the left hand, a straight rod is held to stabilize the eye; this is the globe stabilization rod. The advantage of this is that the movements of the eye can get controlled as one is working without any anesthesia.

✔ Using the phaco tip with moderate ultrasound power, the center of the nucleus is directly embedded starting from the superior edge of rhexis with the phaco probe directed obliquely downward towards the vitreous. The settings at this stage is 50% phaco power, flow rate 24.0 mL/min, and 110.0 mmHg vacuum.

✔ When nearly half of the center of nucleus is embedded, the foot pedal is moved to position 2 as it helps to hold the nucleus due to vacuum rise.

✔ To avoid undue pressure on the posterior capsule, the nucleus is lifted a bit and with the irrigating chopper in the left hand the nucleus chopped. This is done with a straight downward motion from the inner edge of the rhexis to the center of the nucleus and then to the left in the form of an inverted "L" shape.

✔ The air pump increases the steady-state pressure of the eye making the anterior chamber deep and well maintained during the entire procedure. It even makes phacoemulsification a relatively safe procedure by reducing surge even at high vacuum levels.

✔ The air pump should be used not only in bimanual phaco, but also in phacoemulsification.

✔ Bimanual phaco with a cut sleeve is used to eliminate water splashing during surgery and thus improve visibility.

✔ A top end phaco machine is not required. If one has the money, they can buy a top end machine, otherwise the key is to use the machine already present and start bimanual phaco.

✔ The parameters in bimanual phaco with an Alcon or AMO machine are:
  • Power: 50% phaco power. Start in the continuous mode and once chopping has been done then shift to the pulse mode.
  • Suction: 100.0 mmHg. One has to use the air pump or anti chamber collapser so that no surge occurs. One can do without it but the problem will come in difficult cases and one has to go slower.
  • Flow rate: 20.0 to 24.0 mL/min.

✔ One can inject vancomycin inside the eye at the end of the surgery to prevent endophthalmitis from occurring.

✔ If one is performing bimanual phaco and cannot complete the case as one is just starting bimanual phaco and is in the learning curve, one can either convert to phaco or to extracapsular cataract extraction (ECCE).

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MICS: Microincision Cataract Surgery

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Introduction

Microincision cataract surgery (MICS) is bimanual phaco surgery performed through incisions of 1.5 mm or less. Understanding this global concept implies that it is not only about achieving a smaller incision size but about making a global transformation of the surgical procedure towards minimal aggressiveness.

MICS is a Must Today

The incision size has been an important issue of investigation for many years and there have been progressive steps forward, starting from reducing the size from 10.0 mm in the intracapsular era to 7.0 mm in extracapsular cases and finally from 3.4 mm to 2.8 mm, which was the minimum incision performed before the recent era of MICS. The need to reduce the incision size was mainly for the purpose of reducing the induced astigmatism developing after the surgery which affected the refractive results of the procedure. Cataract surgery nowadays, in addition to being considered a therapeutic procedure to cure cataracts, is also considered a refractive surgery. Surgeons are now trying to deal with the issue of postoperative use of glasses for distant and near vision. Hence the need to reduce the incision to the minimum possible to reduce the induced astigmatism that may reach up to 3.0 diopters (D) of astigmatism with conventional techniques.

The other essential factor in the development of a new technique was to reduce the amount of energy being liberated inside the eye when using ultrasound emulsification. Until now the amount of energy being liberated or the power used to operate a cataract inside the eye has not yet been determined. As it is a source of mechanical, waveshock, constitutional, and thermal damage, this energy or power delivered inside the eye has an effect on the ocular structures. The intraocular structures, endothelial cells, corneal stroma, and incisions are all affected by the liberated thermal effects of this energy. A modern cataract surgery is not only aiming to remove the cataract but also to protect the intraocular structures and to ensure a safe surgery with no compli-

cations. Lowering the energy levels as achieved in MICS surgery is considered an important step in this technique. Lower energy levels cause no burns at the incision sites in addition to the other biophysical effects with reduced loss of endothelial cells and less intraocular tissue trauma.

TRANSITION

The main issues and steps involved the transition from phaco to MICS could be summarized as follows:

1. *Fluidics optimization*: MICS surgery should be performed in a closed environment. Due to the fact that the incision is just the size to fit the probe the fluid outflow through the incision is minimal or absent. It is impossible to have a system with no outflow, but basically with MICS we have a much greater possibility of working in a closed environment in comparison to the routine cataract surgery where the closed chamber concept is not available. Taking this into account, we need to optimize the probe function and diameter that allow the balance between the outflow and inflow which is taking place every second in this new environment.[1]

2. *Bimanuality and separation of functions*: This is of great importance especially when we use high vacuum levels as in MICS. The use of both hands simultaneously is another factor which added to the success of MICS surgery. The surgeon should be aware that working with two hands means working with irrigation and aspiration separately. In this way, irrigation and aspiration not only become part of the procedure but also become instruments in the hands of the surgeon. Bimanuality will need appropriate training to work with irrigation/aspiration separately, taking into account that the incorporation of new instruments to these probes will require further training for correct coordination of fluidics, handling maneuvers of the nucleus and other instruments inside the eye.[1]

3. *New microinstruments*: New microinstruments have already been designed to be incorporated in the probes. They do not necessarily need to be similar to the ones that we use today like the choppers or hooks that have mostly been manufactured or created in the extracapsular era. These new specifically designed instruments coordinated with the fluidics and combined with the new maneuvers shall improve efficiency over normal phacoemulsification as it has been performed until now through "small" incisions. The new MICS instruments may have common names but definitely have a different function and a smaller size.[1]

4. *Lasers*: Lasers have become a technological possibility in performing cataract surgery. It is true that their capability of handling very hard nuclei is subject to debate. However, the elegance of laser, the very low levels of energy developed inside the eye, and the possibilities of improving the efficiency of this technology in the future make them attractive for the MICS surgeon. MICS now has and will have in the future, an important role in laser cataract surgery especially with the development of new instrumentation and the new parameters of the laser machines.

5. *Ultrasonic probes*: Ultrasonic probes have to be modified in order to be used without sleeve. Taking off the sleeve is not the only way to use the probes in performing microsurgery.[2,3] These probes should be designed to be used more effi-

ciently, manipulating through micro-incisions without creating any tension in the elasticity of the corneal tissue. Furthermore, the friction created between the probe and the corneal tissue should be avoided with the special protection and smoothness of the external profile of the probe. In addition to the newly developing materials, we can say that ultrasonic MICS probes will have an important future development in the coming years.

6. *New intraocular lens (IOL) technology*: The technological development that enables operation of cataracts through 1.5 mm should be adequately balanced with the development of IOL technologies capable of performing this surgery with IOL implantation though this microincision. At present, different IOLs of new designs, new biomaterials, and new technologies are capable and available for implantation through microincisions.

INDICATIONS AND PATIENT SELECTION

The application of MICS in cataract surgery is unlimited with regards to cataract density or hardness as this technique is able to treat all grades of cataract density according to the nuclear density scale. The authors have found that an optimal elective indication nowadays of MICS is "lens refractive surgery." Considering the delicate working technique, MICS can also be indicated for subluxated cataractous lenses and post traumatic cataracts of grade I or II, zonular laxity, and finally congenital cataracts.[4]

ANESTHESIA

Generally MICS can be done using topical anesthesia 0.75% Bupivacaine plus 2% Lidocaine by instillation of 2 drops every 5 minutes before surgery, with supplemental intra-cameral preservative-free 1% Lidocaine diluted 1:1 in balanced salt solution (BSS). Additionally, sedation with 1.0 mg of Dormicum and 0.5 mg of Limifen might be used when needed.

MICS SURGICAL INSTRUMENTS

Based on the new assumption that the modern cataract surgeon is a bimanual surgeon with equal efficiency in both hands in addition to the new concept of separation of functions and using the irrigation as an instrument in the surgery, the new MICS instruments were developed (Katena, Denville, NJ).

MICS Micro Blade

To create a trapezoidal incision from 1.2- to 1.4-mm a microblade (Figure 13-1) is available made of diamond or stainless steel. The anterior tapering tip is 1.2 mm and the base is 1.4 mm. This design is essential to perform incisions with an internal diameter smaller than the external diameter. This incision design enables the surgeon to move his instruments freely inside the anterior chamber without performing any stress on the incision lips thus avoiding tissue distortion and induced astigmatism.[1]

MICS Capsulorrhexis Forceps

No more worries about how you are going to perform your rhexis, because through the smallest incision the delicate body of this instrument (Figure 13-2) can pass—even

Figure 13-1. MICS blades.

Figure 13-2. MICS rhexis forceps.

Figure 13-3. MICS hydrodissector or irrigating-fingernail.

through a paracentesis incision. This extremely delicate forceps, was designed to function efficiently through a side-port incision enabling the surgeon to have precise control of the capsulorrhexis maneuver. It has micro triangular tips that can be used to puncture and grasp the capsule to perform the capsulorrhexis with a single instrument. Besides that, you can use it for other intraocular maneuvers such as grasping the iris to perform small iridotomies or to cut pre-existing synechia in the anterior or posterior chambers.[1]

Alió MICS Prechoppers

These two twin instruments are an essential step of the procedure. They have been designed with the idea of cutting the cataract with counter chopping technique without the induction of zonular stress. They are to be used bimanually and, as opposed to the single handed prechopping technique, can be used in all types of cataracts regardless of the hardness. The tip has a blunt square hook that should be introduced gently underneath the anterior capsular rim, one instrument opposite the other. The two advancing sides of the instruments have a cutting edge so the instrument sharply cuts the cataract as it progresses from the periphery towards the center. When the instruments reach the center of the nucleus both sides pass the deep central most posterior part of the nucleus to divide it into two hemispherical parts. One of the choppers should be kept in position to protect one hemisphere from moving forward and then the second chopper is taken to the periphery again underneath the anterior capsular rim, 90 degrees apart from the created groove, thus making the dissection of one of the parts and then the same maneuver is performed again with the other. Another alternative is to rotate the two hemispherical fragments and to repeat the initial maneuver 90 degrees apart from the initial one. In both cases, four quadrants are created. This allows for a sharp decrease in the use of the ultrasonic energy and makes the whole procedure faster. Ultrasound (or laser) energy is no longer necessary to cut a cataract but to emulsify cataract fragments instead.[1]

MICS Hydrodissector or Irrigating-Fingernail

It makes manipulation of the nucleus fragments easy as well functioning as an irrigating instrument (Figure 13-3). This can also be useful to further divide the nuclear fragments. With soft to medium density cataracts there are no problems at all but you should use it with care for further segment dissection as cataract density increases. The forward directed pointing tip is a fingernail-like, hence its name. It has a highly blunt

point-like end. The irrigating fluid exits through a large port (1.0 mm) directed under the tip. This feature helps push away the posterior capsule to obtain stable fluidic control in the anterior chamber when combined with phaco or the MICS aspirating tip. The flow rate or the free irrigation flow of this instrument is 72.0 cc/min, which is considered the highest flow compared to other instruments performing the same function in the market. This generates anterior chamber stability regardless of the high vacuum in MICS.[1] Another point is the rate of endothelial cell loss associated with conventional phacoemulsification which is related to the fluidics. The problem is that the side-ports are situated on the lateral sides of the phaco tip and are small in diameter giving exit to the fluids under high pressure. Bearing in mind the position of the phaco tip inside the anterior chamber during the process, we will notice that if the side-ports are horizontally oriented and at a higher level than the iris plane, the irrigating fluids directly reduce endothelial cell number, in addition to severe turbulence in the anterior chamber with direct effect on the endothelial cells. This never happens in our MICS hydrodissector as the irrigating port is deep inside the posterior chamber and facing the posterior capsule, stabilizing the anterior chamber, cleaning the posterior capsule of the cortical cells and protecting the endothelium. Irrigating instruments in MICS are designed to work in nonleaking incisions to guarantee anterior chamber stability.[1]

MICS Irrigating Chopper

This instrument was designed to chop medium to hard cataracts if pre-chopping has not been performed. It has a sharp pointed triangular shaped tip which is angled downward to "chop" off segments of the nucleus. The irrigating fluid exits through a large port (1.0 mm) directed under the tip of the instrument. This feature helps to push away the posterior capsule to obtain stable fluidic control in the anterior chamber when combined with phaco or MICS aspirating tip.[1]

MICS Aspiration Handpiece

The bullet shaped tip is designed for easy entry through a paracentesis incision and has a 0.3-mm diameter aspirating port close to the tip in the interior part of the curvature. This design works to maintain the fluid balance in the anterior chamber when used with the MICS irrigating-fingernail and MICS chopper, and while aspirating the residual cortex. It is to be used in combination with other irrigating instruments to keep an adequate balance of the fluidics in MICS.[1]

Intraocular Manipulator

The manipulator is multifunctional. It provides efficient help in iridolenticular synechia dissection, IOL manipulation, and other intraocular maneuvers such as vitreous knuckles or stabilization of the IOL. It moves safely and effectively with a very delicate blunt tip of its conical shaped design. The base is wide enough to seal the incision, maintaining the stability of the anterior chamber, preventing as much trauma as possible to the intraocular structures. The conical base is the same diameter as the internal MICS incision in order to keep the anterior chamber stability, thus preventing outflow of the viscoelastic.[1]

MICS Scissors

The handling of any membranes (even delicate ones), such as synechia or fibrosed capsules, is made easy by using these unique scissors (Figure 13-4). The design has a 23-gauge (0.6 mm) shaft, making it fit exactly through a very small paracentesis. It has

Figure 13-4. MICS scissors.

extremely delicate blunt tipped blades, which are ideal for cutting synechia and capsular fibrosis and membranes as well as for performing small iridotomies.[1]

Low Ultrasound-MICS

Mackool Tips

Mackool tips contain a thin polymer tubing loosely attached to the tip and this special polymer is characterized by having a very low friction coefficient. The purpose of the tubing in MICS is to isolate the vibrating needle from the incision. The tubing is stationary but is always in contact and rubbing the tip. This system liberates much less heat as compared to the tip rubbing against the infusion as occurs in conventional phaco systems. In general, Mackool tips generate less heat at the incision compared to the non-Mackool tips. The thickness of the polymer is only 50 to 75 μm—much less

Tips	Internal Diameter	External Diameter	Easy to Occlude	Thermal Protection	Vacuum
TABLE 13-1 MACKOOL TIPS					
MicroTip Mackool	0.66	0.88	++++	++	++
MicroTip Flared Mackool	0.57/0.8	0.79/1.0	++	++++	++++
Standard Flared Mackool	0.57/1.1	0.79/1.3	+	+++++	++++

than the thickness of the infusion sleeve and its thermal conductivity is also much less than that of the conventional infusion sleeve material. This tubing system also prevents the spraying effect caused by the solution coming out of the irrigating tip occurring when power settings higher than 30% are used for MICS.

Most of the tips are approximately three-quarters of an inch long and have a 45-degree angulation. There are different Mackool tips and their different characteristics are shown in Table 13-1.

What is the Grade of Cataract You Can Operate With MICS

Soft and moderately hard nuclei up to +2 hardness can be easily emulsified by using low ultrasound MICS (Lus-MICS). Prechopping will shorten the time of surgery and the energy delivered inside the eye. Hard nuclei of grade 3 or over are more amenable to Lus-MICS which is capable of emulsifying hard nuclei of any density.

Incisions

After the surgical field is isolated and an adjustable eye speculum (Duckworth & Kent, England) is inserted, the positive corneal meridian is marked and two trapezoidal incisions of 1.2 mm internally and 1.4 mm externally are performed using the Alió corneal keratome (Katena, Denville, NJ) (Figure 13-5). With this, an external incision of 1.4 mm will be adequate for better instrument manipulation. The two incisions are performed in clear cornea 90 degrees apart at 10 and 2 o'clock followed by the injection of 1% Lidocaine preservative free diluted 1:1 in BSS.

Prechopping (Counter Chopping Technique)

After performing the capsulorrhexis using Alió's capsulorrhexis forceps prechopping is performed. This is a bimanual technique requiring the use of both hands with the same efficiency. This technique allows manual cutting of the nucleus, without creating any grooves prior to the MICS procedure. In order to protect the endothelium and to perform an adequate counter chopping technique, more dispersive or cohesive viscoelastic material is injected. The technique of counter prechopping could be applied
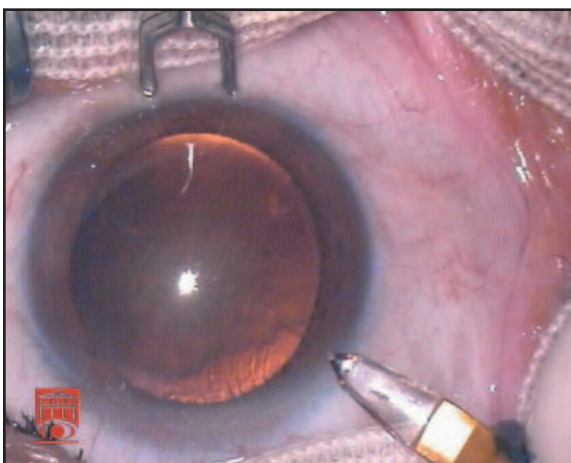
Figure 13-5. Incisions made in MICS.

to all surgical grades of cataract density (up to grade +5). A chopper is introduced through one of the two incisions depending on the surgeon's preference. Through the other incision a nuclear manipulator is introduced to decrease the stress on the capsule and zonules being inserted beneath the anterior capsulorrhexis edge and the rounded microball tip of the nuclear manipulator will protect the posterior capsule during the prechopping procedure. The tips of the nuclear manipulator and the chopper should be aligned on the same axis together with the hardest point of the nucleus along the direction of the lens fibers then appropriate force is applied between the two instruments. After cracking the nucleus into fragments, the nucleus is rotated and the maneuver is repeated on the other axis to crack the nucleus into four quadrants. Once the fragments have been obtained, the MICS Mackool tip and Alió hydromanipulator fingernail are introduced to manipulate and emulsify the fragments.[1]

Low Ultrasound (LUS)-MICS Surgical Steps

The MICS technique could be performed using phacoemulsification which is termed low ultrasound MICS (LUS-MICS) or by using laser which is termed laser-MICS. After termination of pre-chopping the Accurus machine is adjusted. MICS Mackool tip and Alió's hydromanipulator fingernail are introduced through the two incisions and an inferior segment is mobilized and brought in contact with the MICS tip assisted with Alió's hydromanipulator in order to be emulsified. After the elimination of the first heminucleus, the second prechopped heminucleus is rotated to the distal portion of the bag and Alió's hydromanipulator is used to mobilize the segments making them easy to be emulsified. Using this technique reduces the tendency for the nuclear material to come up into the anterior chamber during the procedure maintaining its position within the epinuclear cover. Following the emulsification of all the nuclear segments, the epinuclear rim is trimmed in the different quadrants in such way to remove all the cortical material remaining in the capsular bag. An adequate OVD is injected deep in the capsular bag to reform the bag and prepare it for IOL implantation and helps to force the Viscoat anteriorly facilitating its removal to prevent postoperative rise of IOP.[1]

TIPS AND PEARLS IN LUS-MICS SURGERY

Left-Handed Surgeons

The need for bimanuality in cataract surgery is a very important issue since 15% or more of surgeons are left handed. Developing the concept of bimanuality helps us to perform cataract surgery with two equal incisions whatever the dominant hand is as the instruments needed for MICS surgery can be used with equal efficiency with right or left hands. With MICS instruments, the surgeon is now capable of performing more complicated simultaneous functions that would need more than one step and more time in conventional surgery. Bear in mind that you are using instruments that can aspirate and irrigate at the same time, requiring good coordination between both hands and instruments to perform the surgery. High vacuum assisted by adequate irrigation creates the ideal fluidics solution for MICS in a closed anterior chamber. Fluctuations in the anterior chamber at this moment are either caused by inadequately leaky incisions or due to the use of inadequate instruments that create a fluidic imbalance.

Pain

Working in a pressurized chamber might lead to some degree of pain through stimulating the iris and ciliary body receptors. The most frequent feeling referred by patients is a feeling of pressure as moderate pain associated to the high anterior chamber pressure. Intraoperative pain sensation is eliminated by decreasing to 80.0 or 70.0 mmHg the anterior chamber pressure or mild enlargement of the incision to create a minimal amount of leakage.

Induction of Astigmatism

The clinical results concerning the possibility of inducing astigmatism developed with MICS microincisions due to tissue distortion is under intense investigation. MICS incisions should be placed 90 degrees apart to neutralize the vectorial components they may induce. Remember, one of the main issues involved in MICS is to perform surgery in a closed anterior chamber.

Corneal Burn

Small incisions carry the risk of corneal burns when using MICS-US probe as the flow of fluid might be obstructed and this leads to loss of the cooling effect around the probe causing corneal burns and induced astigmatism. Before starting the emulsification, be sure to aspirate an adequate amount of OVD to avoid total occlusion of the tip in the absence of irrigation with the initial use of the phacoemulsification probe. Remember that irrigation is essential for the cooling of the phaco tip even when using small amounts of energy like in MICS.

IOL Implantation—Enlarging the Leading Incision

IOL implantation in MICS surgery can be done with or without viscoelastics. By maintaining the irrigation flow through the second incision a conventional IOL can be implanted with a 2.0-mm injector through the adequately enlarged incision. An MICS IOL fits well through a 1.5-mm incision. Micromanipulation using the Alió's MICS intraocular manipulator to help implanting the IOL helps in these maneuvers. The pressure of the irrigating fluid over the IOL has another advantage as it compresses the

retrolental space facilitating the exit of the viscoelastics out of the capsular bag and preventing postoperative elevation of the IOP and formation of retrolental space. For easy and complete aspiration of the viscoelastics following IOL implantation, the irrigation flow should be maintained through the second incision while aspirating from the other incision using the aspiration probe or the phaco probe and at the same time exerting little pressure on the inferior lip of the incision to facilitate the exit of viscoelastic.

LASER-MICS SURGERY— DODICK PHOTOLYSIS: ND:YAG MICS

Dodick Photolysis,[5-8] indirect Nd:YAG laser (ARC Laser, Salt Lake City, Utah) is the only US Food and Drug Administration (FDA)-approved method of laser cataract extraction. This technology is currently capable of removing cataracts through incisions of approximately 1.0 mm in size.

Principle

In 1990, Dodick studied the use of the Q-switched pulsed 1064 nm Nd:YAG laser for a single-stage photolysis of cataractous lenses. The Dodick Photolysis system operates by directing laser energy towards a titanium plate in the tip of the laser probe. The effect of the laser energy striking the plate is the creation of a plasma wave, which lyses the cataract. As the shock wave proceeded towards the mouth of the aspiration port, only the attenuated shock waves radiated from the probe. Using high-speed photography methods, they were successfully able to continue to modify the configuration of the target to maximize shock waves within the probe while minimizing their propagation outside the tip.

The amount of energy produced by this method is much smaller than the energy reportedly produced by conventional phacoemulsification, and this eliminates the risk of corneal burns, a rare but serious complication of conventional phacoemulsification techniques. The laser probe produces no significant heat and thus requires no irrigation-cooling sleeve, unlike phacoemulsification, which generates heat by the transformation of electrical energy into mechanical energy with the subsequent generation of emulsifying shock waves.[5] This allows the laser cataract extraction wound size to be reduced, as the irrigation flow can be separated from the laser/aspiration handpiece.

Dodick Photolysis System

The Dodick Photolysis system is a Venturi-pump system that generates aspiration with a range of 0 to 650.0 mmHg. The linear infusion system ranges from 0 to 200.0 mmHg. The laser output can be used with a pulse rate of 1 to 20 Hz, with an output of 8 or 10 mJ per pulse. The laser/aspiration probes are lightweight and completely disposable and the quartz-clad fiber and titanium target are relatively inexpensive to produce. The probes in current use have an external diameter of 1.2 mm and an internal diameter of 0.75 mm, and smaller probe designs (0.9 mm external diameter) are currently being investigated. The photolysis unit comes with a Venturi phacoemulsification unit that uses 2.75 mm phacoemulsification needles and either one-piece or bimanual irrigation/aspiration handpieces for cortical removal. It also contains a superior high-speed vitrectomy unit that can be used as a one-piece or split vitrector.

Surgical Steps

The surgical procedure is performed though two 1.4-mm incisions, one for the irrigation/infusion cannula and the other for the combination laser/aspiration probe.

Laser emulsification of the nucleus is done by placing the aspiration/laser handpiece on the surface of the lens and pulses the laser until the central core of the nucleus is eliminated. Throughout the procedure, the infusion cannula remains in the eye to maintain the anterior chamber. The remaining cortex then can be removed using the same handpieces for automated irrigation and aspiration. This technique is most suitable for lenses of 1 to 2+ density. Another technique is by using "prechopping" of nuclei prior to their removal. This can be accomplished using two Dodick-Kamen choppers, which are placed equatorially after hydrodissection of the lens, to hemisect the nucleus and, then, to bisect the heminuclei. After this is accomplished, the lens is then photolysed and aspirated using the two handpieces. This is very effective for nuclei up to 3+ in density.

The Wehner technique, pioneered by Dr. Wolfram Wehner, relies upon the use of a Wehner spoon for irrigation. The Wehner spoon has a sharp and pointed tip, which serves as a chopper during photolysis. In this technique, a large capsulorrhexis is used to facilitate the lifting of the cataract *in toto* out of the capsular bag. After the nucleus is lifted using the aspiration handpiece, the Wehner irrigating spoon is placed beneath the nucleus, and the two handpieces are brought together to "back-crack" the nucleus. The heminuclei are further emulsified using both photolysis and chopping techniques with this unique chopper. This technique is effective for cataracts up to 3+ in density. Alternate irrigating choppers are currently in development. Raut has reversed the irrigation and aspiration on the handpieces. Thus, one handpiece delivers a combination of laser energy and irrigation and the other handpiece delivers aspiration. The laser handpiece is used to "shatter" the nucleus, and the aspiration handpiece removes the residual pieces. This technique is reportedly effective in nuclei up to 5+ in density.

Aqualase in MICS Surgery

Using a water-jet (Aqualase) machine in MICS in place of laser energy is a new alternative in MICS surgery. The pulsed fluid passes through a tip that is lighter and smaller than the current ultrasound tips. If compared to ultrasound, there is no heat production and consequently no thermal damage. It seems that the water flow does not damage the posterior capsule. Preliminary results show that the removal of the cortex is also improved and is more complete compared to the situation with ultrasound.

Summary

Technological developments in cataract surgery are progressing towards the use of microincisions of 1.5 mm or less for cataract removal. However, the full benefit of microincisional surgery cannot been realized without the development of IOLs that can be inserted through a microincision. The parallel development of instruments and low energy providing systems is making MICS surgery a more practical procedure that could be performed in every clinic.

KEY POINTS

✔ Microincisional cataract surgery (MICS) is surgery performed through incisions of 1.5 mm or less.

✔ Modern cataract surgery is not only aiming to remove the cataract but also to protect the intraocular structures and to ensure a safe surgery with no complications. Lowering the energy levels as achieved in MICS surgery is considered an important step in this technique. Lower energy levels cause no burns at the incision sites in addition to the other biophysical effects with reduced loss of endothelial cells and less intraocular tissue trauma.

✔ MICS incisions should be placed 90 degrees apart to neutralize the vectorial components they may induce.

✔ In MICS, we have a much greater possibility of working in a closed environment in comparison to the routine cataract surgery where the closed chamber concept is not available.

✔ The prechopping technique allows manual cutting of the nucleus, without creating any grooves prior to the MICS procedure.

✔ Small incisions carry the risk of corneal burns when using MICS-US probe as the flow of fluid might be obstructed and this leads to loss of the cooling effect around the probe causing corneal burns and induced astigmatism.

✔ IOL implantation in MICS surgery can be done with or without viscoelastics. By maintaining the irrigation flow through the second incision a conventional IOL can be implanted.

✔ The amount of energy produced by laser photolysis in MICS is much smaller than the energy reportedly produced by conventional phacoemulsification, and this eliminates the risk of corneal burns, a rare but serious complication of conventional phacoemulsification techniques.

✔ Using a water-jet (Aqualase) machine in MICS in place of laser energy is a new alternative in MICS surgery. The pulsed fluid passes through a tip that is lighter and smaller than the current ultrasound tips.

✔ Mackool tips contain a thin polymer tubing loosely attached to the tip and this special polymer is characterized by having a very low friction coefficient. The purpose of the tubing in MICS is to isolate the vibrating needle from the incision. The tubing is stationary but is always in contact and rubbing the tip. This system liberates much less heat as compared to the tip rubbing against the infusion as occurs in conventional phaco systems.

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Safe Chopping in Bimanual Phaco

L. Felipe Vejarano, MD and Alberto Vejarano, MD

History of Bimanual Phaco

Phacoemulsification has progressively become the standard method for cataract surgery around the world, because it offers less astigmatism induction, more rapid astigmatism stabilization, less postoperative inflammation, and less possibility of postoperative complications than extracapsular cataract extraction.[1-7] Developments in surgical techniques and instruments have made phacoemulsification more safe and effective, even in advanced cataracts. Lately, a crucial breakthrough in phacoemulsification has been to perform the surgery through a microincision (1.0 to 1.5 mm), yielding the further advantages of such a small wound. Independently, Agarwal in India and Tsuneoka in Japan began that technique in 1998 and 1999, respectively.[8,9] Agarwal coined the term *phakonit*, which stands for phacoemulsification (phaco) performed with a needle opening (N) via an ultrasmall incision (I) with the sleeveless ultrasound tip (T).[10] Internationally, the procedure is known as bimanual phaco.

Around the world, several other surgeons have reported that it is currently possible to perform safe phacoemulsification through microincisions. Alió reported his microincision cataract surgery (MICS) technique in 2001[11] and Centurion also published his preliminary results.[12]

Phaco Chop

Although some have performed cracking techniques through microincision, we believe that mastering phaco chop technique is a prerequisite to perform bimanual phaco, and we think that phaco chop is not a technique for beginners. Compared to divide-and-conquer, phaco chop is more difficult to learn because the most difficult maneuvers are performed with the nondominant hand. This is one of the reasons why the learning curve may be longer than what people anticipate. We think that due to the higher possibility of intraoperative complications, the inexperienced cataract surgeon should start phacoemulsification with divide and conquer, through a standard size incision, in order to develop a feeling for the consistency of the nucleus, and then

go to chopping techniques. One of the possible complications of phaco chop using the Nagahara´s horizontal technique, secondary to mistakenly placing the chopper anterior to the anterior capsule, is the rupture of the edge of the continuous curvilinear capsulorrhexis (CCC) that may lead ultimately to a tear of the posterior capsule. Another issue is that while horizontally chopping the nucleus, the phaco tip may become dislodged and some of the nucleus material emulsified, creating a crater, and making more difficult the new purchase of the nuclear substance. This situation is more probable in beginners, since they are more prone to use lower vacuum, which determines holding power, and to place the tip so that the occlusion is not complete. One of us, L. Felipe Vejarano, based on his large experience in phaco chop, designed a variation of the horizontal chopping technique, the "Vejarano's Safe Chop," in order to avoid the mentioned risks and difficulties. That technique initially was thought for performing surgery in brunescent cataracts, but subsequently it was found to be very useful in almost every case of phaco chop, and very suitable for microincision phaco too.

SURGICAL TECHNIQUE

Preoperatively, the pupil is dilated with tropicamide 1% (Mydriacyl, Alcon, Fort Worth, Tex) and phenylephrine 10% (Fenilefrina, Oftalmoquímica, Bogotá, Colombia). Peribulbar anesthesia of lidocaine 2% (Roxicaina, Ropsohn Therapeutics Ltda, Bogotá, Colombia) and bupivacaine 0.5% (Bupirop, Ropsohn Therapeutics Ltda, Bogotá, Colombia), or topical tetracaine 0.5% (Tetcaine Ocusoft, Richmond, Tex) is administered according to the surgeon's selection. Povidone-iodine 5% (OQSeptic â, Oftalmoquímica, Bogotá, Colombia) is instilled into the conjunctival cul-de-sac, and washed out 3 to 5 minutes later. A 1.0-mm side-port incision is made using a Lancet Side Port Diamond Knife (Accutome, Malvern, Pa) and 0.3 mL intracameral lidocaine 2% (Roxicaina, Ropsohn Therapeutics, Bogotá, Colombia) administered, in cases of topical anesthesia; Hydroxypropylmethylcellulose 2% (Metilcelulosa, Oftalmo-química, Bogotá, Colombia) in 75% of the cases and DUOVISC (Alcon, Fort Worth, Tex) in the 25% remaining cases, using Arshinoff´s Soft Shell technique,[14] are injected through the side port incision. The main incision, 1.5 mm in length, is made using a Natural Clear Cornea Vejarano's Microincision Diamond Knife (Accutome, Malvern, Pa). The size of the incisions is confirmed using the Osher incision caliper, for internal measurement of the incision (Katena, Denville, NJ). A 5.5- to 6.0-mm continuous curvilinear capsulorrhexis (CCC) is created using 23g microincision capsulorrhexis forceps from Accutome (Malvern, Pa). Hydrodissection is performed using the Gimbel or Chang cannulae, previously depressing lightly the posterior lip of the incision, to let out a small amount of viscoelastic go from the anterior chamber, thus avoiding a sudden rise in the intraocular pressure during hydrodissection. Hydrodelineation, may be performed optionally, according to the surgeon's personal preferences.

VEJARANO´S SAFE CHOP

This chopping technique is very safe and user friendly, and is very suitable for microincision phacoemulsification. The Vejarano's Irrigating Chopper (Accutome, Malvern, Pa), designed by L. Felipe Vejarano introduced through the side port, in order to maintain adequate space in the anterior chamber. The features of this chopper are shown in Figure 14-1. It has an outer diameter of 0.9 mm (approximately 20-gauge) that fits rather tightly in the 1.0 mm side port incision. We have found it to be very use-

Figure 14-1. Vejarano's irrigating chopper. It is 0.9 mm in diameter, and has two irrigation holes close to the tip.

ful, and with a high safety profile. For all the cases, the Vejarano's Safe Chop technique was performed using a Storz Premiere unit (Bausch & Lomb Surgical, San Dimas, Calif).

A sleeveless MicroFlow (Bausch & Lomb, Reference DP8230) 1.07 mm outer diameter and 0.5 mm inner diameter needle (approximately 19-gauge), 30-degree tip, is introduced into the anterior chamber through the main incision, which is 1.5 mm in length. In the last 82 cases, a cut sleeve was used over the phaco needle, according with the description by Prakash, and we found that it is useful to diminish the amount of fluid splashed from the phaco needle during the application of ultrasound energy.[15] Like Prakash, we do not use any additional external fluid to cool the wound (D.P. Prakash, personal communication). After aspirating the anterior cortex and epinucleus, the phaco tip, bevel up, is placed in the proximal portion of the nucleus, and pulse ultrasound energy is applied, so that it penetrates deep in the nuclear core. High vacuum (160.0 mm which is the maximum level of the Premiere machine), and pulsed phaco (8 pps), linear ultrasound energy (set from 30 and to no more than 50%, according to the hardness of the nucleus) are used. When the tip is buried into the nucleus, the foot pedal is switched to position 2. In this moment the irrigating chopper is lightly rotated horizontally, so that the longest length of the tip is not presented toward the space between the CCC edge and the lens material (space that in brunescent cataracts is very small, even absent). The chopper is slid beneath the anterior capsule, opposite the side-port; this maneuver is much easier to perform than trying to slide it under the anterior capsule in front of the phaco tip. (Figure 14-2). It is very important to look through the microscope, at the tip of the chopper while the second hand is performing these maneuvers, in order to maintain a perfect control. Afterward, when reaching the equator of the nucleus, the chopper is rotated vertically and moved inside the bag, to the position in front of the phaco tip, and the chopping maneuvers take place. In hard cataracts, we hold the nucleus between the two instruments for a moment, and apply a small amount of additional pulsed ultrasound energy, so that the S-tip penetrates deeper into the nuclear material (Figure 14-3). This allows us to gain improved control of the whole nucleus during the chopping process, since it doesn't become

Figure 14-2. The irrigating chopper is inserted beneath the edge of the capsulorrhexis, opposite the side-port incision.

L. Felipe Vejarano, M.D.
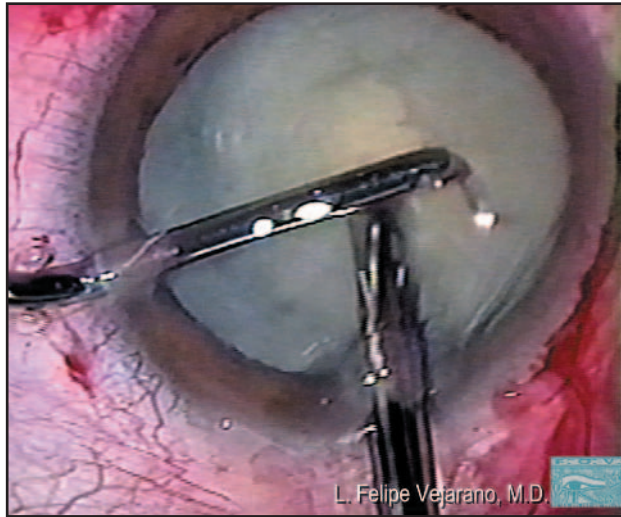
Figure 14-3. The irrigating chopper is moved inside the capsular bag, along the lens equator, and placed in front of the phaco tip. At that moment additional pulsed ultrasound is applied, so that the tip buries deeper into the nucleus, before the chopping is started.

L. Felipe Vejarano, M.D.
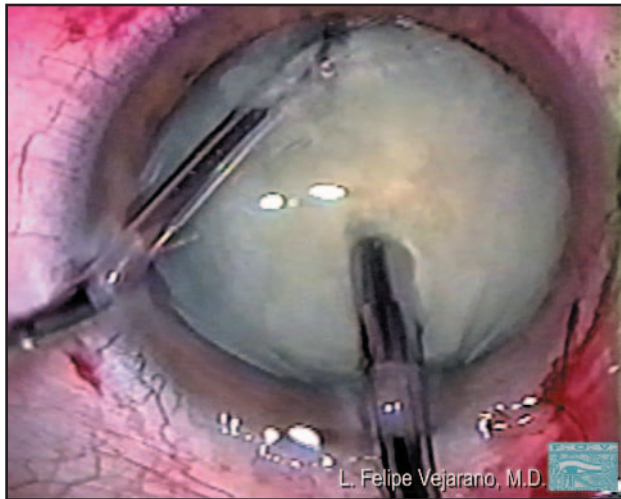
easily dislodged, as long as the high vacuum and the deep position of the tip maintain a tight occlusion seal around the tip. One very important advantage of this technique is that with this very good purchase of the nucleus, especially in hard cataracts, the chopping process is more effective, and let us to separate the leather like very hard posterior layers of those cataracts, that often present a challenge to the surgeon.

After dividing the nucleus in halves, we rotate it 45 degrees to get the first piece of the heminucleus. The clue to avoid damaging the CCC while chopping the nuclear fragments, is to insert the irrigation chopper vertically and always along the fracture lines of the nucleus, where there is more room for the chopper, and move it to reach its chopping position only when it is already at the lens equator, in this way making this step completely safe (Figures 14-4 and 14-5). The subsequent fragments are managed in the same way. When reaching the nucleus equator, in not too hard cataracts,
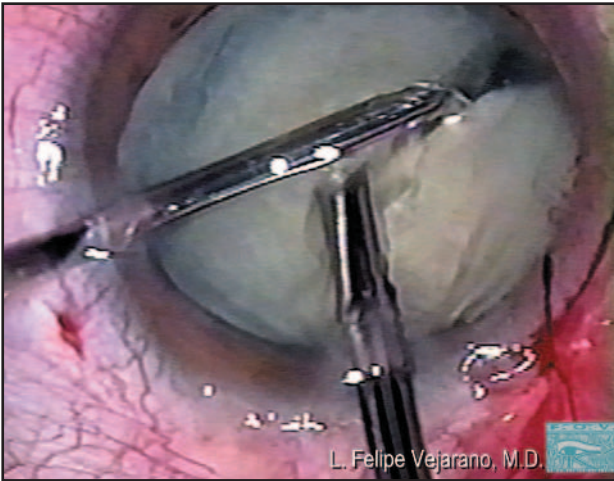
Figure 14-4. After dividing the nucleus in halves, it is rotated and the irrigating chopper is inserted into the capsular bag, along the fracture line, up to the equator.
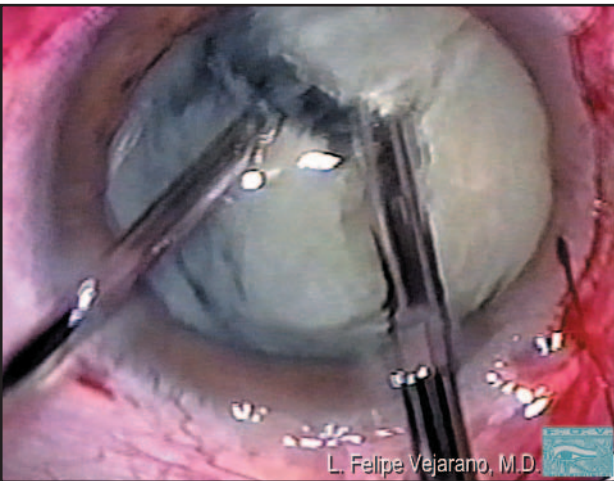
Figure 14-5. The second fracture is performed, and the nuclear fragment is brought to the center in order to be emulsified.

it is usually evident that the chopper performs a separation of the epinucleus. This is not a problem at all, and is actually convenient, since we are interested in chopping the nucleus, not the epinucleus. When several nuclear fragments have been emulsified, the amount of remaining nuclear material is less, therefore there is more room in the center and so it is not usually necessary to go beneath the anterior CCC in order to chop the remaining nucleus. The epinucleus is aspirated using a flip technique, and protecting the posterior capsule with the irrigating chopper, which is very friendly with the posterior capsule, since its tip has an olive to avoid damaging tissues.

Bimanual irrigation/aspiration of cortical remnants using bimanual handpieces (Gusor Ltd, Bogotá, Colombia) is done and if necessary, posterior capsule polishing also done.

Transition to Bimanual Phaco

The surgeon beginning bimanual phaco will find new challenges:
- The possibility of corneal burn.
- The different way to move the instruments inside the eye through such small incisions.
- The stability of the anterior chamber throughout the procedure (fluidics).

The doubt of a possible thermal burn, due to the use of a sleeveless phaco tip was dispelled by the initial works of Agarwal and Tsuneoka. Tsuneoka showed experimentally in a porcine eye that using a sleeveless ultrasound tip, the temperature of the cornea at the incision elevated only 8.4°C, without developing thermal burns.[9] Agarwal reported 305 eyes that underwent the technique successfully. In his cases he used a chopping technique, and had the assistant continuously pour cooled balanced salt solution (BSS) over the phaco needle. Not one case of thermal wound occurred.[16] Tsuneoka and coauthors[17] reported 637 cases that underwent cataract surgery through a 1.4-mm incision or smaller, using a chopping technique, without a case of thermal burn. This does not mean that the risk of corneal burn does not exist. I think that the relation between the size of the incision and the outer diameter of the phaco needle is critical to avoid this potential damage: a too tightly inserted phaco needle, could cause, at least theoretically, a significant rise in temperature, due to the close contact with the tissue and the lack of the cooling effect of an outgoing fluid. It is necessary that a small amount of fluid goes out around the phaco tip. With this condition we think, like Prakash, that it is not necessary to use any additional external irrigation in the wound (D.P. Prakash, personal communication). The level of ultrasound is directly related with the possibility of corneal wound, and from our experience we think that a critical issue is the phaco tip itself, and its relation to the incision. We use the MicroFlow, which is designed with cooling grooves that efficiently mitigate against temperature increases. With the Storz Premiere unit, the maximum power of ultrasound for bimanual phaco that we use is 50%. We have not had even one case of thermal burn. There are other technologies like sonic energy (Sonic Wave, STAAR, Monrovia, Calif), or AMO's Sovereign WhiteStar system (Santa Ana, Calif) that address the issue of corneal burn modulating the kind or delivery of energy. They could be a good option, that may let the surgeon use a higher level of energy.

Moreover new designs of phaco tips may be more efficient, and thus the ultrasound energy necessary will be less. We have experience using the Gravlee Safety Bevel Phaco Tip, designed by Joseph F. Gravlee, Jr. (Mastel, Rapid City, SD). It has a rounded external edge, and sharp inner edge, in contrast with all the other phacoemulsification tips, and it would be a feature that would make this tip safer (less possibility of damaging the capsule or the iris) and more effective (the sharp internal edge will cut the material during the emulsification process more efficiently). In the clinical setting it seems to work really well.

Secondly, since the instruments move so tightly through the microincisions any lateral movement of the instrument tends to move the entire eye and distorts the cornea. It is necessary to learn how to move the instruments in order to minimize this. It is similar to moving an oar through an oarlock, and any movement should be done aligned with the axis of the incision (to and fro). If a lateral movement is necessary, the instruments must rotate using the incision like a fulcrum.

CONCLUSION

Bimanual phaco through 1.5 mm is a safe and effective procedure, using Vejarano's Safe Chop technique. The availability of the ultrasmall incision IOLs lets us take advantage of these microincisions.

KEY POINTS

✔ Vejarano's irrigating chopper is used with a Microflow sleeveless phaco needle to perform safe chopping in bimanual phaco.

✔ The phaco tip, bevel up, is placed in the proximal portion of the nucleus, and pulse ultrasound energy is applied with high vacuum and pulsed phaco.

✔ The irrigating chopper is lightly rotated horizontally and slid beneath the anterior capsule, and the chopping maneuver done.

✔ A technique to avoid damaging the CCC while chopping the nuclear fragments is to insert the irrigation chopper vertically and always along the fracture lines of the nucleus, where there is more room for the chopper.

✔ The MicroFlow is designed with cooling grooves that efficiently mitigate against increase in temperature.

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NIC Bimanual Phaco

Arturo Pérez-Arteaga, MD

Bimanual phaco (or Phakonit, MICS, microphaco, etc) is a cataract surgical technique growing faster worldwide because of its advantages. In the traditional description the technique uses a sleeveless phaco tip in one hand and an irrigating chopper in the other hand. Because the sharp side of the irrigating chopper can produce damage to the intraocular tissues, specially the posterior capsule, many attempts have been made to avoid it, like some prechopper techniques. We are describing here a surgical technique to avoid the use of the irrigating chopper during the entire surgery without pre-chop maneuvers. The main advantages of this technique are: avoiding posterior capsule damage with the chopper, complications of prechop maneuvers, constant maintenance of anterior chamber during the entire procedure and to keep all the benefits of microincision surgery. This technique is called *NIC Bimanual phaco* or no irrigating chopper bimanual phaco.

INTRODUCTION

With the increasingly widespread implementation of ultrasmall incision cataract surgery new developments in instrumentation, fluidics management, and techniques are becoming familiar to the anterior segment surgeons.[1] A traditional bimanual phaco technique uses two instruments in each hand: one sleeveless phaco tip and an irrigating chopper.[2] The purposes of this irrigating chopper are: 1) to maintain of the anterior chamber because the irrigating fluid reaches the anterior chamber through it, and 2) to perform the mechanical fragmentation of the nucleus in order to phacoemulsify. Many variations of this technique have been described, but the theoretical principles are the same.[3]

Some surgeons are afraid of the damage that the sharp side of the irrigating chopper can cause to the posterior capsule during chop maneuvers or once the nucleus has been removed. Because of this, many variations to the traditional bimanual phaco technique have been described:[4]

- To change the irrigating chopper to an irrigating cannula after the chop maneuvers have been completed.
- To hide the sharp side of the irrigating chopper in the anterior chamber when the chop maneuvers are not needed.
- To use only an irrigating cannula and avoid the use of the irrigating chopper in particular in soft nucleus (like in refractive lensectomy cases).
- To perform prechop techniques.

Unfortunately all these technique variations have some disadvantages. To switch the irrigating chopper to a cannula can lead to a collapse of the anterior chamber during the maneuver. With consequent eye movement, keeping the irrigating chopper inside the eye in an apparently safe place can damage other intraocular structures. With the use of only an irrigating cannula, the chop maneuvers are not easy, and to perform prechop techniques one can damage the capsular bag if not properly done.[5] Also, some manufacturers are developing some irrigating choppers that can be converted to an irrigating cannula during surgery, hiding or folding the sharp side of the chopper by a mechanical system, to avoid the damage it can cause.[6]

Here we are describing a NIC bimanual phaco. This:

- Avoids the damage that the irrigating chopper can produce inside the eye because it is not used.
- Does not need prechop maneuvers.
- Uses the irrigating cannula as a phacofragmentation device.
- Permits the irrigating cannula from being changed any time during the phacoemulsification and the irrigation/aspiration steps, so there is no collapse of the anterior chamber at any time during the surgery.[7]

Surgical Technique: Theoretical Principle

The main principle of all choppers is to "cut the nucleus." The first chop maneuver to divide the nucleus into two pieces is a real cut (especially in karate chop and anterior vertical chop). The rest of the dividing maneuvers are a mechanical fragmentation between the chopper and the phaco tip, and no more cuts are performed. So, if one can do a mechanical fragmentation after the first divide, maneuvering a sharp instrument inside the eye can be avoided. Then only safe mechanical fragmentation maneuvers between a strong irrigating cannula and the phaco tip, with the help of high vacuum, can divide the nucleus into multiple pieces.

Following this principle, there is no need to insert a sharp or cutting instrument inside the eye, and so there is a decreased risk of damage to intraocular structures, because only a blunt instrument will be used to irrigate and divide.

Presettings

With refinement of bimanual phaco techniques the surgeons are understanding new concepts in fluidics management. *The NIC bimanual phaco technique uses forced infusion, high vacuum levels, and low ultrasonic power.*

Forced Infusion

I recommend 110.0 to 140.0 cmH$_2$O of positive (active) infusion. Maybe infusion performed only under gravity basis (passive infusion) can be enough to create a wide

anterior and posterior chambers (it will depend on the irrigating chopper/cannula the surgeon is using), but it is not enough to create a real force inside the eye like active infusion. This force of the fluid works like a "third hand" of the surgeon, pushing the nuclear pieces where required, facilitating the mechanical nuclear fragmentation maneuvers needed to perform this technique. This active force increases the advantages of separating the irrigation from the aspiration in comparison to traditional phacoemulsification techniques. Forced infusion can be achieved with an external air pump (independent of the phaco machine) or with the air pump integrated in some phaco machines, like the Accurus (Alcon, Fort Worth, Tex), Millennium (Bausch & Lomb Surgical, San Dimas, Calif), or others capable also to perform posterior segment surgery.

Vacuum Levels

NIC bimanual phaco uses a variation of the high vacuum chop technique. High vacuum levels are needed in order to move the nucleus only with vacuum forces so that mechanical fragmentation can be done. I recommend 170.0 to 200.0 mmHg of vacuum. If forced infusion is working fine, high vacuum levels are safe and no collapse of the anterior chamber will occur. Other devices, like Cruise Control (STAAR Surgical, Monrovia, Calif) can be used to increase the safety of high vacuum if the surgeon wants, but it is not mandatory.

Ultrasonic Power

I recommend 15 to 30% of phaco power. Low ultrasonic power is needed because the mechanical maneuvers are the main tools to produce phacofragmentation. After the nucleus has been multifragmented, pulse or burst mode can be used (keeping the power low) to emulsify. Currently these techniques are mechanical fragmentation and phacoaspiration assisted with low ultrasound.

INSTRUMENTATION

Irrigating Cannula

The key in NIC bimanual phaco is to avoid the use of the irrigating chopper. Instead of the chopper, the irrigation and the mechanical breaking of the nucleus are performed only with the irrigating cannula. There are many types of irrigating cannulas since the very first description of a bimanual irrigation/aspiration technique by J.I. Barraquer. As the irrigating cannula is not only doing the function of irrigation but is also the tool to perform mechanical fragmentation of the nucleus, it has to have some special features. They are:

- High rate of irrigation.
- Two side-ports, rather than one main central port, to improve the fluidics inside the anterior chamber and to avoid pushing the nuclear fragments away.
- Smooth distal end to avoid damage to tissues, in particular the posterior capsule.
- Strong enough material of fabrication (like titanium) to have the capacity to apply the force to fracture the nucleus.
- Easy to handle.

At this time, I find the Duet irrigating cannula developed by Microsurgical Technology (Redmond, Wash) as the one to have all these particular features.

Phacoemulsification Tip

The tip will be useful to not only perform phacoemulsification and aspiration, but also to hold the nucleus at high vacuum levels and to be the force against the irrigating cannula to cause the mechanical disruption of the nucleus. Tips like the MicroTip MicroFlow of the Millennium or the Mackool 0.9 MicroTip of the Accurus, Legacy, and Infiniti machines (Alcon) are very nice tools to perform these three functions.

SURGICAL PROCEDURE

There are two different techniques to perform NIC bimanual phaco. The first is as a chop technique and it uses a large capsulorrhexis and high vacuum. The second is a divide and conquer technique, which uses a small capsulorrhexis and not very high vacuum levels.

Inverse Chop Technique

This technique divides the nucleus with the fragmentation forces between the irrigating cannula and the phaco tip, with the help of high vacuum levels and outside the capsular bag (at the iris plane). The main advantages are that the capsular bag and the zonnules are free of pushing and pulling forces, the use of very low ultrasonic power and the speed at which the surgery is performed. The main disadvantage is the large capsulorrhexis and its consequences over equatorial cell migration.

The steps of inverse chop NIC bimanual phaco technique are:

1. Large capsulorrhexis (6.0 to 6.5 mm) to facilitate the luxation of nucleus (like a supracapsular technique) outside the capsular bag.

2. Very strong hydrodissection and hydrodelamination, until a free rotation of the nucleus inside the bag or a spontaneous "hydroexpulsion" is obtained.

3. Low power of linear phaco is applied, just to penetrate the center of the nucleus until the core is reached in a single movement, to avoid make a groove. Once the phaco tip is inside the nucleus, the footswitch returns to position two, to keep just the vacuum, so the nucleus can be manipulated with the movement of the handpiece. The surgeon must be sure that this has been properly done (Figure 15-1).

4. The nucleus is "taken out" of the capsular bag in a single pull movement with vacuum. Once the nucleus has reached the iris plane, the irrigating cannula is located behind it with a small rotational movement, so one side port will face the posterior capsule and the other the posterior surface of the nucleus. The forced infusion will not only form the chamber but it will also push away these two structures making this, a safe technique (Figure 15-2).

5. The nucleus is fragmented in two pieces with the two instruments (the phaco tip in the front and the irrigating cannula behind) with the help of the vacuum holding the nucleus. This is done in a single movement of a chop maneuver, but from the back to the front of the nucleus. With this fracture "from behind," the surgeon can be sure that all the nuclear fibers have been cut without a sharp instrument inside the eye. If some fibers remain, the maneuver can be repeated many times, always holding the nucleus with vacuum (Figure 15-3).

Figure 15-1. Embed the nucleus with the phaco needle. Note the left hand has an irrigating cannula and not an irrigating chopper.

Figure 15-2. Pull the nucleus out of the bag using the vacuum and tilt the nucleus. Note the irrigating cannula is now under the nucleus to help crack it.
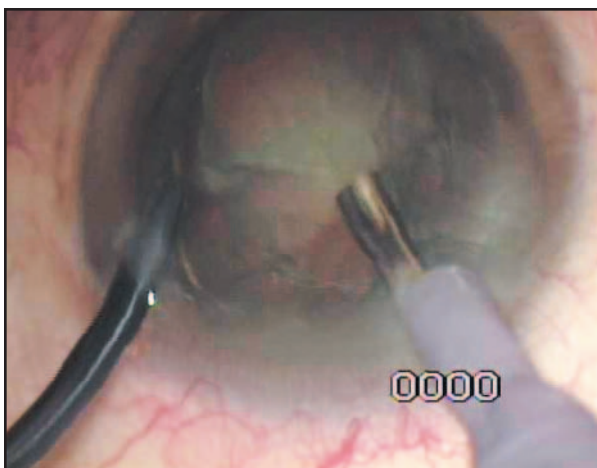
Figure 15-3. Nucleus cracking done between the phaco needle and the irrigating cannula.

Figure 15-4. Emulsification of the nuclear pieces.

Figure 15-5. Bimanual irrigation/ aspiration.
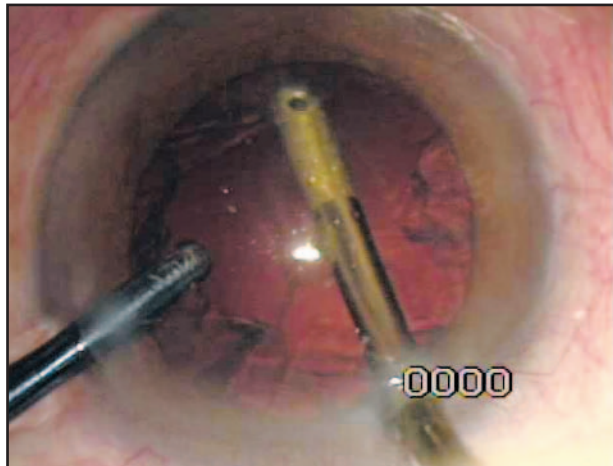
6. The rest of the surgery is to just rotate, hold, and cut the nucleus in multiple pieces using the same maneuver (Figure 15-4).

7. The irrigating cannula remains inside the eye with irrigation active during the epinuclear aspiration and cortical aspiration. There is no need to take out the irrigating cannula during the entire procedure (Figure 15-5).

Divide and Conquer Technique

This technique divides the nucleus after a groove has been made, applying the forces with the phaco tip and the irrigating cannula in a cross, horizontal movement. It does not need high vacuum levels, because the maneuver is inside the capsular bag. It also doesn´t need a large capsulorrhexis because it doesn´t need to luxate the entire nucleus, so the advantages of a small capsulorrhexis are present. This technique uses more ultrasonic time and power. It can be useful for "divide and conquer" surgeons and also for small pupil cases. The steps are:

1. A 5.0-to 5.5-mm capsulorrhexis is performed, followed by a generous hydrodissection and hydrodelamination until a free nucleus can be rotated inside the capsular bag.

2. A deep groove is performed in the center of the nucleus with low linear ultrasound and low vacuum.

3. A divide technique is performed pushing both halves of the nucleus in a cross, horizontal movement, using the phaco tip and the irrigating cannula with the footswitch in position 1. The forced infusion contributes to obtain a "nice division."

4. Once two pieces are obtained the surgeon has two options:

   a. To rotate the nucleus and follow a traditional divide and conquer technique with low vacuum, and then phacoemulsify each quadrant.

   b. To increase the vacuum levels and pull one half of the nucleus outside the capsular bag, continuing the surgery with high vacuum fragmentation. In this technique also, the surgeon keeps the irrigating cannula with the forced infusion active, inside the eye, during the entire procedure, and so never has a shallow anterior chamber.

DISCUSSION

The original description of bimanual phaco was made using an irrigating chopper. The idea was to irrigate through the side-port, because in the other hand the phaco tip was sleeveless. The idea to use a chopper at the irrigating side was because of the popularity of the chop maneuvers and the need to decrease the phaco time inside the eye. Many models of irrigating choppers have been described depending upon the rate of irrigation and the kind of chop the surgeons prefer. The main disadvantage of the choppers are the sharp sides that can produce damage. New models of blunt irrigating choppers are now in the market, with the precaution to avoid the sharp cutting edge of the irrigating choppers. These choppers do not cut the nucleus; they produce fragmentation because a combination of forces between the chopper and the phaco tip with the help of vacuum. These choppers can also remain safe inside the eye for the irrigation/aspiration step. Some of the new models help to polish the posterior capsule also.

The principle of mechanical fragmentation of the nucleus instead of cutting it, and the principle of keeping the same irrigating instrument during the entire procedure, were the basis to develop this NIC technique. This technique uses only a irrigating cannula and not a chopper. The benefits to do an entire bimanual phaco procedure using only the irrigating cannula and avoiding the irrigating chopper are multiple.

1. There is no danger to damage the intraocular structures, in particular the posterior capsule, with a sharp instrument.

2. No "cutting" maneuvers are done inside the eye.

3. There is no need to "hide" the chopper.

4. The fragmentation maneuvers are made with a blunt instrument; and the forced infusion and the high vacuum are elements that help this instrument do its job.

5. There is no need to switch the irrigating chopper to the irrigating cannula during the surgery, so the anterior and posterior chambers are deep during the entire procedure. This avoids stress to the incision and prevents anterior chamber collapse, vitreous tamponade, and choroidal effusions.

6. In almost all cases the maneuvers are outside the capsular bag and far away from the posterior capsule. Because of the forced infusion, the maneuvers are far away from the cornea too.

7. The surgery is faster, and also very easy for the assistant.

Recently we have done some modification to this technique that can increase the safety of the procedure: we are doing the main incision at 180° from the second incision, instead the traditional 90° separation between both.

This disposition was described many years ago by Dr. J.I. Barraquer to perform bimanual irrigation-aspiration of soft cataracts and cortical material; in this way, the phaco tip is just front the irrigating cannula. This particular placement increases the safety of hydrodynamic forces inside the eye to the endothelial cells, this forces help the nuclear pieces to move to and trough the phaco tip, the mechanical forces between both instruments make easier to perform high or low vacuum phacofracture and finally both instruments are easy to handle.

It is a combination of concepts of bimanual surgery by Dr. Barraquer and Phakonit by Dr. Agarwal."

KEY POINTS

✔ NIC bimanual phaco is a surgical technique devised to avoid the use of the irrigating chopper during the entire surgery without prechop maneuvers.

✔ Surgeons are afraid of the damage that the sharp side of the irrigating chopper can cause to the posterior capsule during chop maneuvers or once the nucleus has been removed.

✔ The NIC bimanual phaco technique uses forced infusion, high vacuum levels, and low ultrasonic power.

✔ The key in NIC bimanual phaco is to avoid the use of the irrigating chopper. Instead of it, the irrigation and the mechanical breaking of the nucleus are performed only with the irrigating cannula.

✔ There are two different techniques to perform NIC bimanual phaco. The first is as a chop technique, and it uses a large capsulorrhexis and high vacuum. The second is a divide and conquer technique, and it uses a small capsulorrhexis and not very high vacuum levels.

✔ The principle of mechanical fragmentation of the nucleus instead of cutting it and the principle of keeping the same irrigating instrument during the entire procedure, are the basis of this NIC technique.

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Bimanual Microincision Refractive Lens Exchange

Richard S. Hoffman, MD; I. Howard Fine, MD;
and Mark Packer, MD

Introduction

Advances in small incision surgery have enabled cataract surgery to evolve from a procedure concerned primarily with the safe removal of the cataractous lens to a procedure refined to yield the best possible postoperative refractive result. As the outcomes of cataract surgery have improved, the use of lens surgery as a refractive modality in patients without cataracts has increased in popularity.

The removal of the crystalline lens and replacement with a pseudophakic lens for the purposes of reducing or eliminating refractive errors has been labeled with many titles. These titles include clear lensectomy,[1,2] clear lens phacoemulsification,[3] clear lens replacement, clear lens extraction,[4-12] clear lens exchange, presbyopic lens exchange, and refractive lens exchange. Since these procedures may be performed in older patients with significant nuclear sclerosis but normal spectacle corrected visual acuity, the term "clear lens" may not be appropriate to describe many older individuals undergoing lens exchange surgery. Similarly, a "clear lens exchange" in a young highly hyperopic patient may be performed for refractive purposes but not necessarily to address pre-existing presbyopia and thus "presbyopic lens exchange" would not be an appropriate term for this group of patients. The term refractive lens exchange (RLE) appears to best describe the technique of removing the crystalline lens and replacing it with a pseudophakic lens in any aged patient for the purpose of reducing or eliminating refractive errors and/or addressing presbyopia.

Refractive Lens Exchange vs Corneal Refractive Surgery

Removal of the crystalline lens for refractive purposes offers many advantages over corneal refractive surgery. Patients with high degrees of myopia, hyperopia, and astigmatism are poor candidates for excimer laser surgery. In addition, presbyopia can only be addressed currently with monovision or reading glasses. RLE with multifocal or accommodating intraocular lenses (IOLs) in combination with corneal astigmatic pro-

cedures could theoretically address all refractive errors including presbyopia while simultaneously eliminating the need for cataract surgery in the future.

Current attempts to enhance refractive results and improve functional vision with customized corneal ablations using the excimer laser expose another advantage of RLE. The overall spherical aberration of the human eye tends to increase with advancing age.[13-16] This is not the result of significant changes in corneal spherical aberration but rather increasing lenticular spherical aberration.[17-19] This implies that attempts to enhance visual function by addressing higher order optical aberrations with corneal refractive surgery will be sabotaged at a later date by lenticular changes. Addressing both lower order and higher order aberrations with lenticular surgery would theoretically create a more stable ideal optical system that could not be altered by lenticular changes since the crystalline lens would be removed and exchanged with a stable pseudophakic lens.

BIMANUAL MICROINCISION PHACOEMULSIFICATION

RLE with bimanual microincision lens extraction offers a potentially safer and more controlled method of crystalline lens removal than standard coaxial phacoemulsification. Bimanual microincision phacoemulsification entails the removal of the crystalline lens through two 1.2 mm incisions. Infusion is provided through a separate irrigating handpiece and phacoemulsification and aspiration are performed through a sleeveless phacoemulsification needle.

The notion of removing the crystalline lens through two microincisions is not a new concept and has been attempted with varying degrees of success and failure since the 1970s.[20-24] With the development of new phacoemulsification technology and power modulations,[25] we are now able to emulsify and fragment lens material without the generation of significant thermal energy. Thus removal of the cooling irrigation sleeve and separation of infusion and emulsification/aspiration through two separate incisions is now a viable alternative to traditional coaxial phacoemulsification. Machines such as the AMO WhiteStar (Santa Ana, Calif), STAAR Sonic Wave (Monrovia, Calif), Alcon NeoSoniX and Infiniti (Fort Worth, Tex), Bausch & Lomb Millennium with burst mode (San Dimas, Calif), and Dodick Nd:YAG Laser Photolysis system (ARC Laser, Salt Lake City, Utah) offer the potential of relatively "cold" lens removal capabilities and the capacity for bimanual lens surgery.[26-30]

Advantages

While it is true that coaxial phaco is an excellent procedure with low amounts of induced astigmatism,[31] bimanual phaco offers the potential for truly astigmatic neutral incisions. In addition, these microincisions should behave like a paracentesis incision with less likelihood for leakage and theoretically, a lower incidence of endophthalmitis.

The major advantage we have seen from bimanual microincisions has been an improvement in control of most of the steps involved in endocapsular surgery. Since viscoelastics do not leave the eye easily through these small incisions, the anterior chamber is more stable during capsulorrhexis construction and there is much less likelihood for an errant rhexis to develop. Hydrodelineation and hydrodissection can be performed more efficiently by virtue of a higher level of pressure building in the anterior chamber prior to eventual prolapse of viscoelastic through the microincisions.
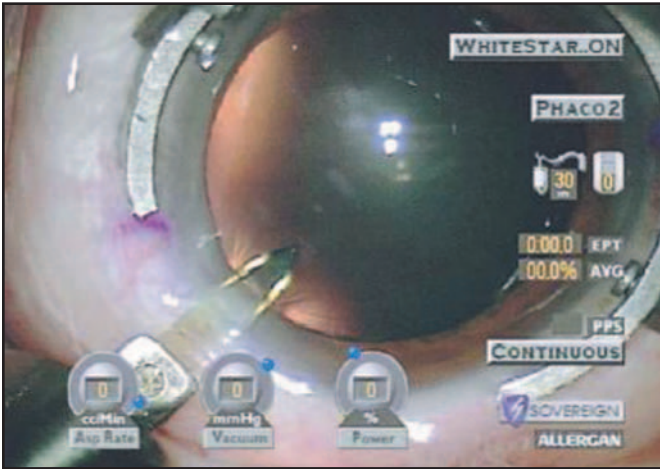
Figure 16-1. A left-handed, 1.2-mm clear corneal microincision placed 45 degrees from the temporal limbus utilizing a Mastel Paratrap diamond knife.

In addition, separation of irrigation from aspiration allows for improved followability by avoiding competing currents at the tip of the phaco needle. In some instances, the irrigation flow from the second handpiece can be used as an adjunctive surgical device—flushing nuclear pieces from the angle or loosening epinuclear or cortical material from the capsular bag. In the same respect, it is important to avoid directing the fluid flow from the second irrigating handpiece at the tip of the phaco needle since this will dislodge nuclear fragments from the tip and actually worsen the followability.

Perhaps the greatest advantage of the bimanual technique lies in its ability to remove subincisional cortex without difficulty. By switching infusion and aspiration handpieces between the two microincisions, 360 degrees of the capsular fornices are easily reached and cortical clean-up can be performed quickly and safely.

BIMANUAL REFRACTIVE LENS EXCHANGE TECHNIQUE

With advances in multifocal, accommodative, and microincision lens technology, RLE should become a more popular procedure in the future. The independent advantages of bimanual microincision phacoemulsification make it a procedure of choice for RLE. Our current technique for RLE utilizing bimanual microincision phacoemulsification is simple and straightforward.

The procedure is performed under topical anesthesia after appropriate informed consent, preoperative measurements for IOL determination, and preoperative dilation and antibiotics. A Mastel Paratrap diamond keratome (Mastel Precision, Rapid City, SD) is utilized to create two 1.2-mm clear corneal incisions 30 to 45 degrees from the temporal limbus (60 to 90 degrees from each other) (Figure 16-1). Half of a cc of non-preserved lidocaine 1% is instilled into the anterior chamber followed by complete expansion of the anterior chamber with Viscoat (Alcon, Fort Worth, Tex). A capsulorrhexis forceps, specially designed to fit and function through a 1.0-mm incision is then inserted through the right-handed incision and used to begin and complete a 5.0- to 6.0-mm rhexis (Figure 16-2).

Cortical cleaving hydrodissection[32] with decompression is then performed in two separate distal quadrants followed by a third round of hydrodissection to prolapse the entire lens or at least one-half of the lens out of the capsular bag. The microincision

Figure 16-2. Capsulorrhexis formation utilizing a ASICO microincision capsulorrhexis forceps.

Figure 16-3. The soft lens is carouselled in the iris plane and consumed utilizing high vacuum levels. Forward movement of the lens is prevented with the irrigating handpiece.

irrigating handpiece is placed in the left-hand incision and the sleeveless phaco needle is inserted through the right-hand incision. Lens extraction is then performed in most cases without phaco power, utilizing high levels of vacuum while carouselling the relatively soft lens in the plane of the iris until it is consumed (Figure 16-3). Small amounts of ultrasound energy can be utilized when needed. Care should be taken to avoid directing the infusion flow towards the phaco needle tip so as to prevent dislodging nuclear material from the tip. While maintaining infusion with the irrigating handpiece, the phaco needle is removed and the aspiration handpiece is inserted to remove residual cortex and polish the posterior capsule. If subincisional cortex is difficult to extract, the irrigation/aspiration (I/A) handpieces can be alternated between the two incisions in order to gain easier access to the subincisional capsular fornix (Figure 16-4).

Once all cortex has been removed, the aspiration handpiece is removed and viscoelastic is injected into the capsular bag and anterior chamber while withdrawing the irrigating handpiece. Following this, the viscoelastic cannula is removed from the eye and a new 2.5-mm clear corneal incision is placed between the two microincisions for
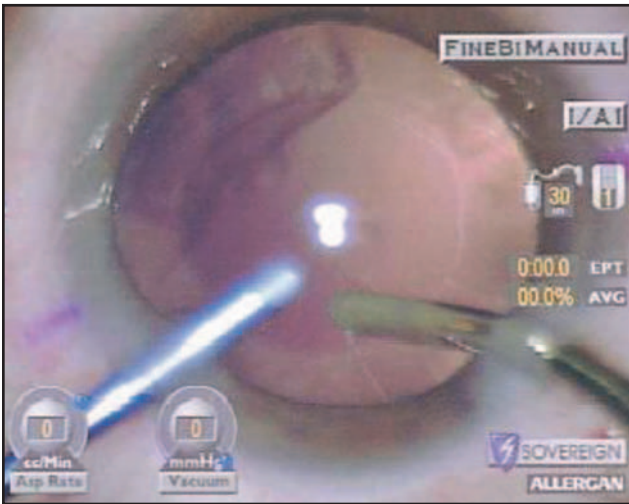
Figure 16-4. Subincisional cortex is easily removed using the Duet System (MST) bimanual irrigation and aspiration handpieces. (Note the Effective Phaco Time EPT=0 and Average Percent Phaco Power AVG=0 following lens removal).

IOL insertion. Eventually, access to microincision lenses in the United States. will afford the ability to eliminate the 2.5-mm incision and perform the entire procedure through two microincisions.

Following IOL insertion, stromal hydration of the 2.5-mm incision is performed to assist in self-sealing of the incision. Bimanual (I/A) is performed to remove all viscoelastic. Following removal of the viscoelastic, the aspiration handpiece is removed while maintaining irrigation of the anterior chamber, and stromal hydration of the empty incision is performed to assist in closure of the microincision. The irrigation handpiece is then removed, followed by stromal hydration of that incision. In this manner, the eye is fully formed and pressurized throughout the procedure avoiding hypotony and shallowing of the anterior chamber.

BIMANUAL FLUIDICS

The greatest criticism of bimanual phaco lies in the fluidics and the current limitations in intraocular lens technology that could be utilized through these microincisions. By nature of the size of these incisions, less fluid flows into the eye than occurs with coaxial techniques. Most current irrigating choppers integrate a 20-gauge lumen that limits fluid inflow. This can result in significant chamber instability when high vacuum levels are utilized and occlusion from nuclear material at the phaco tip is cleared. Thus, infusion needs to be maximized by placing the infusion bottle on a separate IV pole that is set as high as possible. Also, vacuum levels usually need to be lowered below 350.0 mmHg to avoid significant surge flow. Although chopping instruments are generally not necessary for routine RLE, the 20-gauge irrigating choppers and 20-gauge irrigators from Microsurgical Technology (MST, Redmond, Wash) appear to have improved infusion flow compared to other irrigating choppers secondary to their thin-walled construction (Figure 16-5).

Another device that has been helpful for improving fluidics during bimanual surgery has been the Cruise Control (STAAR Surgical, Monrovia, Calif). The Cruise Control has a cylindrical mesh within it designed to capture all lens material and will never become completely occluded by virtue of its large surface area. Fluid will always be

Figure 16-5. Relative infusion rates of various 20-gauge bimanual irrigating choppers (courtesy of MST).
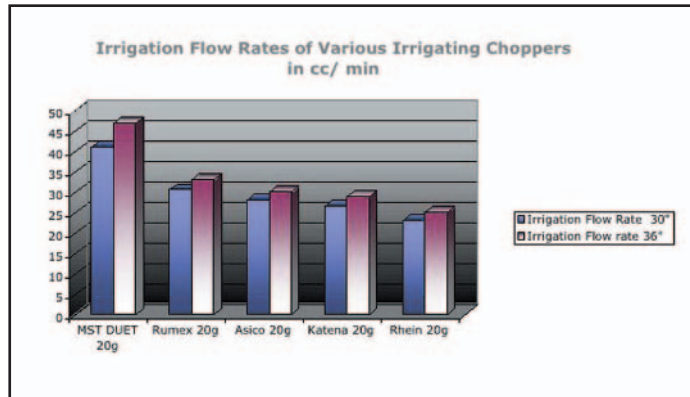
able to pass through some portion of the mesh but is restricted on the downstream side of the device by a small I/A sized exit port. This port restricts flow at high flow rates such as those that occur following consumption of nuclear material at the tip with high vacuum in the aspiration line. The device has been shown to prevent intraocular pressure from dropping below atmospheric pressure, preventing chamber instability and forward movement of the iris and posterior lens capsule. It should allow for safer bimanual surgery by allowing surgeons to utilize higher vacuum levels while maintaining better chamber stability.

Utilization of bimanual microincision RLE as we have described offers an enormous advantage of maintaining a more stable intraocular environment during lens removal. This may be especially important in high myopes who are at a greater risk for retinal detachment following lens extraction.[33-35] By maintaining a formed and pressurized anterior chamber throughout the procedure, there should be less tendency for anterior movement of the vitreous body with a theoretical lower incidence of posterior vitreous detachment occurring from intraoperative manipulations. Vitreous detachments occurring in the postoperative period would obviously not be avoided, however, future lens technology that completely fills the capsular bag may help eliminate posterior vitreous detachments occurring in the postoperative period.

LENS TECHNOLOGY

Microincision Lenses

New lens technologies are currently being developed that will allow surgeons to perform RLEs by means of a bimanual technique through two microincisions. Medennium (Irvine, California) is developing its Smart Lens—a thermodynamic accommodating IOL. It is a hydrophobic acrylic rod that can be inserted through a 2.0 mm incision and expands to the dimensions of the natural crystalline lens (9.5 mm x 3.5 mm) (Figure 16-6). A 1.0-mm version of this lens is also being developed. ThinOptX fresnel lenses (Abingdon, Virginia) will soon be under investigation in the U.S. and will also be able to be implanted through 1.5 mm incisions. In addition, Acri.Tec GmbH (Berlin, Germany) has released the Acri.Smart acrylic IOL that is available outside of the United States. and can be injected through a cartridge injector system through a 1.4-mm incision. Finally, injectable polymer lenses are being researched by both Pharmacia/Pfizer (New York, NY) and Calhoun Vision (Pasadena, Calif).[36,37]
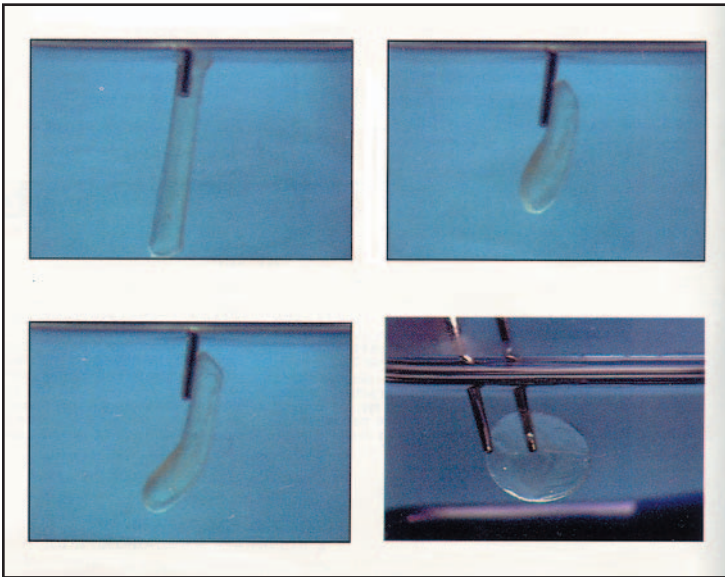
Figure 16-6. Expansion of the Medennium Smart Lens from rod to full size lens after being immersed in a warm saline solution (Courtesy of Medennium).

Multifocal IOLs

Perhaps the greatest catalyst for the resurgence of RLE has been the development of multifocal lens technology. High hyperopes, presbyopes, and patients with borderline cataracts who have presented for refractive surgery have been ideal candidates for this IOL technology.

Historically, multifocal IOLs have been developed and investigated for decades. Newer multifocal IOLs are currently under investigation within the United States. The 3M diffractive multifocal IOL (3M Corporation, St. Paul, Minn), has been acquired, redesigned, and formatted for the 3-piece foldable Acrysof acrylic IOL (Alcon). Alcon is currently completing the US (Food and Drug Administration) FDA clinical trials of their multifocal IOL and will eventually be releasing the lens on their single-piece acrylic platform under the name ReStor (Figure 16-7). Pharmacia/Pfizer has also designed a diffractive multifocal IOL, the CeeOn 811E that has been combined with the wavefront adjusted optics of the Technis Z9000 with the expectation of improved quality of vision[38] in addition to multifocal optics (Figure 16-8).

The only multifocal IOL approved for general use in the United States is currently the Array (AMO). The Array is a zonal progressive intraocular lens with five concentric zones on the anterior surface (Figure 16-9). Zones 1, 3, and 5 are distance dominant zones while zones 2 and 4 are near dominant. The lens has an aspheric design and each zone repeats the entire refractive sequence corresponding to distance, intermediate, and near foci. This results in vision over a range of distances.[39]

A small recent study reviewed the clinical results of bilaterally implanted Array multifocal lens implants in RLE patients.[40] A total of 68 eyes were evaluated, comprising 32 bilateral and four unilateral Array implantations. One hundred percent of patients undergoing bilateral RLE achieved binocular visual acuity of 20/40 and J5 or better, measured one to three months postoperatively. Over 90% achieved uncorrected binocular visual acuity of 20/30 and J4 or better, and nearly 60% achieved uncorrected binocular visual acuity of 20/25 and J3 or better. This study included patients with

Figure 16-7. The Alcon ReStor multifocal IOL (Courtesy of Alcon Laboratories).

Figure 16-8. The Tecnis ZM001 multifocal IOL (courtesy of Pfizer).

preoperative spherical equivalents between 7.0 D of myopia and 7.0 D of hyperopia with the majority of patients having preoperative spherical equivalents between plano and +2.50. Excellent lens power determinations and refractive results were achieved.

Another recent study by Dick et al evaluated the safety, efficacy, predictability, stability, complications, and patient satisfaction after bilateral RLE with the Array IOL.[41] In their study, all patients achieved uncorrected binocular visual acuity of 20/30 and J4 or better. High patient satisfaction and an absence of intraoperative or postoperative complications in this group of 25 patients confirmed the excellent results that can be achieved with this procedure.
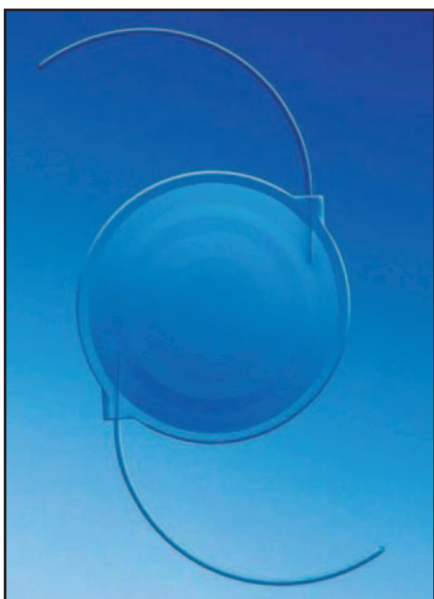
Figure 16-9. The AMO Array Multifocal IOL (courtesy of Advanced Medical Optics).

Accommodative IOLs

The potential for utilizing a monofocal IOL with accommodative ability may allow for RLEs without the potential photic phenomena that have been observed with some multifocal IOLs.[42-44] The two accommodative IOLs that have received the most investigation to date are the Model AT-45 CrystaLens (Figure 16-10) (Eyeonics, Aliso Viejo, Calif) and the 1 CU (Humanoptics, Mannheim, Germany). Both lenses have demonstrated accommodative ability[45,46] although the degree of accommodative amplitude has been reported as low and variable.[47,48]

As clinical investigators for the US FDA clinical trials of the AT-45 CrystaLens, we have had experience with the clinical results of the majority of accommodative IOLs implanted within the U.S. In our practice, 96 AT-45 IOLs were implanted with 24 patients implanted bilaterally. All patients had uncorrected distance vision of 20/30 or better and uncorrected near vision of J3 or better. Eighty-three percent of patients were 20/25 or better at distance and J2 or better at near. And 71% were 20/20 or better at distance and J1 or better at near. These results confirm the potential clinical benefits of accommodative IOL technology for both cataract patients and refractive patients and place accommodative IOLs in a competitive position with multifocal IOL technology.

Newer accommodative models incorporating dual optics for increased accommodative amplitudes are being designed and evaluated. The Sarfarazi elliptical accommodating IOL contains two 5.0 mm optics connected with three flexible haptics and is designed to fill the capsular bag with both optics moving away from each other during accommodative effort. Similarly, the Visiogen Synchrony has a dual optic configuration with a positive powered anterior lens and a negative powered posterior lens designed to separate with an increase in overall functional power during accommodation (Figure 16-11). These dual optic accommodating IOLs may produce greater accommodative amplitudes than single-piece designs, however clinical comparisons are to date lacking.[49]

Figure 16-10. The eyeonics CrystaLens accommodating IOL (courtesy of Eyeonics).
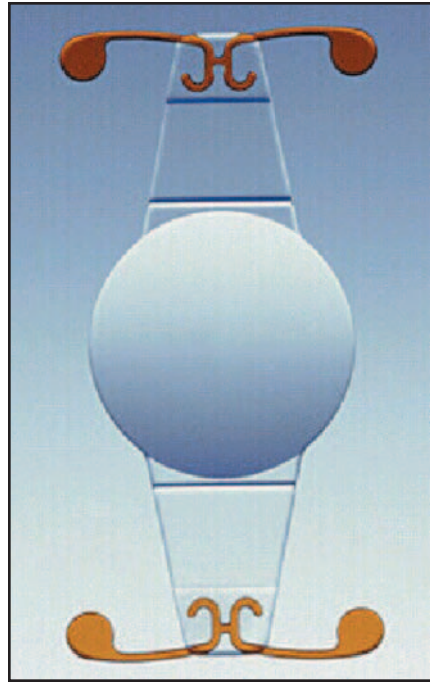
Figure 16-11. Side-view of the Visiogen Synchrony dual optic accommodating IOL (courtesy of Visiogen).

Future Lens Technology

There are lens technologies under development that may also contribute to increased utilization of RLE in the future. One of the most exciting technologies is the light adjustable lens (LAL) (Calhoun Vision). The LAL is designed to allow for postoperative refinements of lens power in situ. The current design of the LAL is a foldable three-piece IOL with a cross-linked silicone polymer matrix and a homogeneously embedded photosensitive macromer. The application of near-ultraviolet light to a portion of the lens optic results in polymerization of the photosensitive macromers and precise changes in lens power through a mechanism of macromer migration into polymerized regions and subsequent changes in lens thickness (Figures 16-12 and 16-13B).
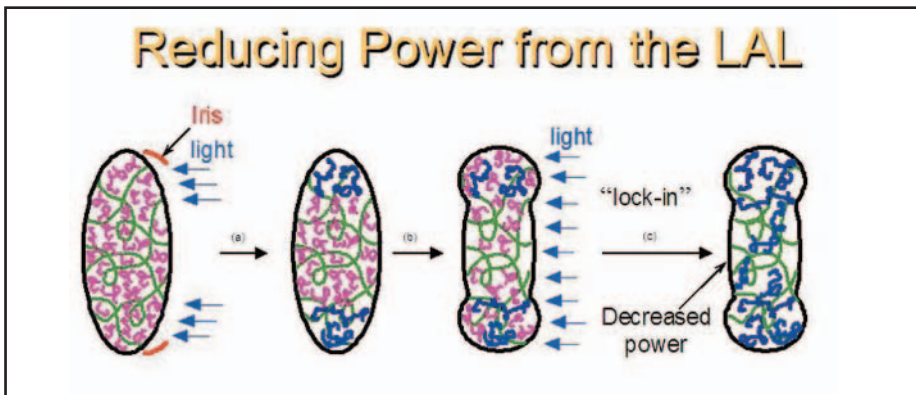
Figure 16-12. The Calhoun Vision Light Adjustable IOL (LAL). Cross sectional schematic illustration of mechanism for treating myopic correction. A) Selective irradiation of peripheral portion of lens polymerizes macromer, creating a chemical gradient between irradiated and non-irradiated regions. B) macromer from the central zone diffuses peripherally leading to swelling of the peripheral lens. C) irradiation of the entire lens polymerizes the remaining macromer and "locks-in" the new lens shape with less power (courtesy of Calhoun Vision).
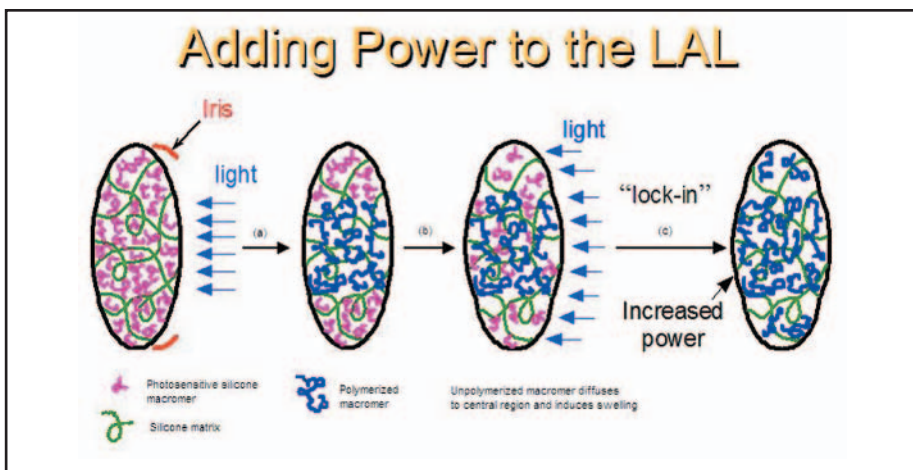
Figure 16-13. Cross sectional schematic illustration of mechanism for treating hyperopic correction. A) Selective irradiation of central portion of lens polymerizes macromer, creating a chemical gradient between irradiated and non-irradiated regions. B) in order to re-establish equilibrium, macromer from the peripheral lens diffuses into the central irradiated region leading to swelling of the central zone. C) irradiation of the entire lens polymerizes the remaining macromer and "locks-in" the new lens shape (courtesy of Calhoun Vision).

Hyperopia, myopia, and astigmatism can be fine-tuned postoperatively and Calhoun Vision is currently working on creating potentially reversible multifocal optics and higher order aberration corrections. This capability would allow for more accurate postoperative refractive results. In addition, it would enable patients to experience multifocal optics after their lens exchanges and reverse the optics back to a monofocal lens system if multifocality was unacceptable. The ability to correct higher order

aberrations could create higher levels of functional vision that would remain stable with increasing age since the crystalline lens, with its consistently increasing spherical aberration, would be removed and replaced with a stable pseudophakic LAL.[50]

As previously stated, Calhoun Vision is currently developing a light adjustable injectable polymer that could be injected through a 1.0-mm incision, completely inflate the capsular bag, and have the capability of light adjustability for lower order and higher order aberrations. If this product can successfully be developed, it will embody the ideal lens for bimanual microincision RLE—allowing for full utilization of the intraoperative benefits of microincision RLE and the postoperative benefits of a LAL that completely fills the capsular bag (theoretically reducing the incidence of postoperative retinal complications).

FINAL COMMENTS

As has long been the history within ophthalmology, IOL technology lags many years behind ophthalmic procedural technique. Three-millimeter incision phacoemulsification once required opening of the incision to 6.0 mm in order to facilitate insertion of 6.0-mm optic PMMA lenses. It took several years before foldable lenses could take full advantage of the 3.0-mm incisions. Similarly, today in the United States, we have the capability of removing crystalline lenses through microincisions but will need to wait for microincision lenses to become available before allowing for the full benefit of this technique.

By virtue of the increased safety of current lens extraction techniques and the ability to accurately address refractive errors and presbyopia, RLE will become a more popular procedure in the future. The current bimanual technique requires opening a new 2.5 mm incision in order to utilize the multifocal and accommodative optics of current lens designs. However, cross-licensing of the numerous lens technologies being developed should ultimately produce microincision IOLs that allow surgeons to address all refractive errors, including presbyopia, while working through the safety of two microincisions.

KEY POINTS

✔ The term bimanual microincision refractive lens exchange appears to best describe the technique of removing the crystalline lens through bimanual phaco and replacing it with a pseudophakic lens in any aged patient for the purpose of reducing or eliminating refractive errors and/or addressing presbyopia.

✔ Removal of the crystalline lens for refractive purposes offers many advantages over corneal refractive surgery.

✔ RLE with bimanual microincision lens extraction offers a potentially safer and more controlled method of crystalline lens removal than standard coaxial phacoemulsification.

✔ Utilization of bimanual microincision RLE offers an enormous advantage of maintaining a more stable intraocular environment during lens removal. This may be especially important in high myopes who are at a greater risk for retinal detachment following lens extraction.

✔ Coaxial phaco is an excellent procedure with low amounts of induced astigmatism but bimanual phaco offers the potential for truly astigmatic neutral incisions. In addition, these microincisions should behave like a paracentesis incision with less likelihood for leakage and theoretically, a lower incidence of endophthalmitis.

✔ Various IOLs in the market are multifocal IOLs, accommodating IOLs and the light-adjustable IOLs

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Three-Port Bimanual Sleeveless Microphacoemulsification Using the "Tilt and Tumble" Technique

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Introduction

The concept of phacoemulsification by Dr. Charles Kelman heralded the era of modern cataract extraction and paved the way for small incision surgery.[1] The evolution from the large incision extracapsular cataract extraction, wherein the lens is removed en bloc, to the small incision required by phacoemulsification has led to quicker visual recovery with less induced astigmatism.[2,3] Further reduction in size of the incision would allow for improved safety intraoperatively by providing a more stable anterior chamber and improved safety postoperatively with more rapid wound healing and less risk of endophthalmitis.[4] Furthermore, smaller incisions may accelerate visual rehabilitation.

Currently, reduction in the size of the incision has been limited by the phacoemulsification probe and in particular the irrigation sleeve, which requires an incision of at least 3.0 mm. Recently the concept of bimanual sleeveless microphacoemulsification, which has been promoted by Amar Agarwal, MD, has led to the development of sub-1.0-mm incision phacoemulsification.[5] Intraocular lenses are being developed in order to realize the full benefits of small incision cataract surgery. At present, the small incisions must be enlarged in order to allow for insertion of the intraocular lens (IOL).[6]

In bimanual microphacoemulsification, the large diameter infusion sleeve is separated from the 0.9- to 1.5-mm titanium phacoemulsification tip, which can then be inserted through a 0.9- to 1.5-mm incision. One of the major concerns of bimanual phacoemulsification include corneal thermal burns from the sleeveless phaco tip.[7] Thus the fluidics must be optimized to: 1) maintain fluid flow through the phaco tip in order to prevent corneal wound burn; and 2) to maintain a stable anterior chamber during surgery. Additionally, the phacoemulsification settings must be optimized to prevent continuous phacoemulsification from causing excessive heat transfer. This is typically done by cycling the ultrasound on and off with the computer software in the phacoemulsification machine.

In order to maintain a stable anterior chamber, the fluidics must be balanced such that the outflow is equilibrated by inflow. The inflow of fluid in current phacoemulsification units is provided by the infusion sleeve of the phacoemulsification handpiece, which also serves to protect the cornea from thermal injuries. With microphacoemulsification, the infusion sleeve is removed, and thus irrigation is provided by a second instrument via a paracentesis port. Various irrigating second instruments, such as irrigating choppers and nucleus rotators, are being developed that allow surgeons to continue phacoemulsification using techniques with which they are accustomed. Current irrigating second instruments incorporate 19- to 21-gauge irrigation devices,[8] and are typically sufficient to maintain a stable anterior chamber. However when the outflow exceeds the inflow, an unstable anterior chamber may occur. The concept of three-port phakonit was devised to reduce the potential of an unstable anterior chamber. A third port allows the insertion of an anterior chamber maintainer that would provide additional inflow and thus stabilize the anterior chamber.[9] This concept is analogous to three-port vitrectomy, where one port is used for the vitrectomy handpiece, a second port is used for the light pipe, and the third port is used for the infusion device.

"Tilt and Tumble" Phacoemulsification

Many of the standard phacoemulsification techniques may be adapted to incorporate microphacoemulsification. The surgeon must be comfortable working through two small paracentesis ports and be able to work with both hands equally. Furthermore, the size of the microincision impedes use of traditional capsulorrhexis forceps. Thus, the capsulorrhexis may be accomplished with a needle, cystotome, or specially designed capsulorrhexis forceps.[10]

We will describe the technique of "tilt and tumble," which is a form of supracapsular phacoemulsification,[11] and how it is modified to incorporate three-port bimanual small incision phacoemulsification. In this technique, the superior pole of the nucleus is tilted above the capsule upon completion of a large capsulorrhexis. Bimanual phacoemulsification is then performed while supporting the lens in the iris plane with an irrigating nucleus rotator.

Because "tilt and tumble" is a supracapsular technique, the risk of endothelial trauma from the instruments or the cataract itself exists. Furthermore with bimanual phaco, the endothelium in the region of the wound is also at risk of damage from transmitted ultrasound energy by the sleeveless ultrasound probe. Thus, the technique of "tilt and tumble" is to be used selectively in cases in which there is a relatively deep anterior chamber and a modestly dense cataract. Because a deep anterior chamber is essential to this technique, the inflow provided by current 20-gauge irrigating second instruments may not be sufficient. An anterior chamber maintainer inserted through a third paracentesis may better ensure a deep and stable anterior chamber. Additional protection to the endothelium may be provided by use of a dispersive viscoelastic such as Viscoat (Alcon, Fort Worth, Tex) prior to phacoemulsification. Eyes that have shallow anterior chambers, low endothelial cell counts, or very dense nuclei should be approached via an endocapsular technique.

There are several distinct advantages to the "tilt and tumble" technique. Firstly, it is easy to learn or teach. It is also quick to perform, thus decreasing surgical time. Risk of capsular rupture may be decreased by working in the iris plane. Stress on the zonules is lessened by working out of the bag, making this technique advantageous in

cases of pseudoexfoliation. A large capsulorrhexis is required and this virtually elimi-
nates development of a capsular contraction syndrome. However, a large capsulor-
rhexis may not be appropriate for newer intraocular lenses such as the Eyeonics
CrystaLens (Eyeonics, Aliso Viejo, Calif).[12]

INDICATIONS

The indications for the "tilt and tumble" phacoemulsification technique are quite
broad. "Tilt and tumble" is especially useful in cases of soft and moderately dense
cataracts because ultrasound time is significantly reduced by nature of the technique
itself. Because of the use of less phaco energy, this technique is well-suited for
microphacoemulsification. For example, no grooving is required as in the divide and
conquer technique. Rather, for moderately dense cataracts, the soft cortical and epin-
uclear material can be "stripped" with high vacuum interspersed with short pulses of
ultrasound. The remaining nugget of nucleus is now substantially reduced in size and
can then be phacoemulsified and disassembled at the iris plane. "Tilt and tumble" also
works very well for softer cataracts, which are often difficult to split or chop and are
also difficult to impale and maneuver. By contrast, in "tilt and tumble", tilting the
cataract allows one to easily impale and maneuver the superior pole.

This technique can also be utilized in either a large or small pupil situation. Some
surgeons favor the technique with small pupils where the nucleus can be tilted up such
that the equator is resting in the center of the pupil and is then carefully emulsified. It
does require a larger continuous tear anterior capsulectomy of at least 5.0 mm. If a
small anterior capsulectomy is achieved, the hydrodissection step of tilting the nucle-
us can be dangerous, and it is possible to rupture the posterior capsule during the
hydrodissection step. If, inadvertently, a small anterior capsulectomy is created, it is
probably safest to convert to an endocapsular phacoemulsification technique or
enlarge the capsulorrhexis. If it is not possible to tilt the nucleus with either hydrodis-
section or a manual technique, the surgeon should convert to an endocapsular
approach. Occasionally the entire nucleus will subluxate into the anterior chamber. In
this setting if the cornea is healthy, the anterior chamber deep, and the nucleus soft,
then the phacoemulsification can be completed in the anterior chamber supporting the
nucleus away from the corneal endothelium. The nucleus can also be pushed back
inferiorly over the capsular bag to allow the iris plane "tilt and tumble" technique to
be completed.

In patients with severely compromised endothelium, such as Fuchs' dystrophy or
previous keratoplasty patients with a low endothelial cell count, endocapsular pha-
coemulsification is preferred to reduce endothelial stress. In a normal eye, corneal
clarity on the first day postoperatively is excellent. Nevertheless, the tilting and tum-
bling maneuvers do increase the chance of endothelial cell contact with lens material
compared to an endocapsular phacoemulsification. Therefore, the endocapsular tech-
nique should be employed in eyes with borderline corneas. The technique is a very
good transition technique for teaching residents, fellows and surgeons who are transi-
tioning to phacoemulsification, because it is easy to convert to a planned extracapsu-
lar cataract extraction with the nucleus partially subluxated above the anterior capsu-
lar flap at the iris plane.

PREOPERATIVE PREPARATION

The preoperative preparation is no different when adapting "tilt and tumble" to a bimanual sleeveless microphacoemulsification technique. The patient enters the anesthesia induction or preoperative area and tetracaine drops are placed in both eyes. The placement of these drops increases the patient comfort during the placement of the multiple dilating and preoperative medications, decreases blepharospasm and also increases the corneal penetration of the drops to follow.

The eye is dilated with 2.5% neosynephrine and 1% cyclopentolate every 5 minutes for three doses. Additionally, preoperative topical antibiotic and anti-inflammatory drops are administered at the same time as the dilating drops. We favor the combination of a preoperative topical antibiotic, topical steroid, and topical nonsteroidal. The rationale for this is to preload the eye with antibiotic and nonsteroidal prior to surgery. The pharmacology of these drugs and the pathophysiology of postoperative infection and inflammation support this approach. An eye that is preloaded with anti-inflammatory drops prior to the surgical insult is likely to have a reduced postoperative inflammatory response. Both topical steroids and nonsteroidals have been found to be synergistic in the reduction of postoperative inflammation. In addition, the use of perioperative antibiotics is supported in the literature as reducing the small chance of postoperative endophthalmitis.[13] Since the patient will be sent home on the same drops utilized preoperatively, there is no additional cost.

Our usual anesthesia is topical tetracaine reinforced with intraoperative intracameral 1% nonpreserved (methylparaben-free) lidocaine. For patients with blepharospasm an O'Brien facial nerve anesthesia block, utilizing 2% lidocaine, can be quite helpful in reducing squeezing of the lids. This block lasts 30 to 45 minutes and makes surgery easier for the patient and the surgeon. Patients are sedated prior to the block to eliminate any memory of discomfort. One way to determine when this facial nerve block might be useful is to ask the technicians to make a note in the chart when they have difficulty performing applanation pressures or A-scan because of blepharospasm. In these patients a facial nerve block can be quite helpful.

In younger anxious patients and in those with difficulty cooperating, we perform a peribulbar or retrobulbar block. Naturally, general anesthesia is used for very uncooperative patients and children. While this is controversial, in some patients where general anesthesia is chosen and a significant bilateral cataract is present, we will perform consecutive bilateral surgery completely reprepping and starting with fresh instruments for the second eye. Again, this is a clinical decision weighing the risk to benefit ratio of operating both eyes on the same day versus the risk of two general anesthetics.

Upon entering the surgical suite the patient table is centered on preplaced marks so that it is appropriately placed for microscope, surgeon, scrub nurse, and anesthetist access. We favor a wrist rest, and the patient's head is adjusted such that a ruler placed on the forehead and cheek will be parallel to the floor. The patient's head is stabilized with tape to the head board to reduce unexpected movements, particularly if the patient falls asleep during the procedure and suddenly awakens. A second drop of tetracaine is placed in each eye. If the tetracaine is placed in each eye, blepharospasm is reduced. A periocular prep with 5% povidone-iodine solution is completed.

An aperture drape is helpful for topical anesthesia to increase comfort. We have noted that when the drape is tucked under the lids this often irritates the patient's eye and also reduces the malleability of the lids, decreasing exposure. Since it is important

to isolate the meibomian glands and lashes, a reversible solid-blade speculum may be used. With temporal and nasal approaches to the eye, the solid blades of the speculum are not in the way. In those cases where a superior approach is planned, a Tegaderm drape is used, tucking it under the lids. In these cases, a Kratz modified Barraquer wire is useful, as this enhances access to the globe. Nevertheless, we have been using a superior approach incision less and less.

Balanced salt solution (BSS) is used in all cases. For the short duration of a phacoemulsification case, BSS plus typically does not provide any clinically meaningful benefit. We place 0.5 cc of the intracardiac non-preserved (sodium bisulfate free) epinephrine in the bottle for assistance in dilation and perhaps hemostasis. We also add 1 mL (1000 units) of heparin sulfate to reduce the possibility of postoperative fibrin. This is also a good anti-inflammatory and coating agent. At this dose, there is no risk of enhancing bleeding or reducing hemostasis.

The lids are separated with the solid-blade speculum. A solid-blade Barraquer speculum or an aspirating speculum, which can be placed temporally or nasally, isolates the lashes. A final drop of tetracaine is placed in the operative eye or the surface is irrigated with the nonpreserved lidocaine. We do not like to utilize more than three drops of tetracaine or other topical anesthetic as excess softening of the epithelium can occur, resulting in punctate epithelial keratitis, corneal erosion, and delayed postoperative rehabilitation.

ADAPTING TO BIMANUAL SLEEVELESS MICROPHACOEMULSIFICATION

New skills must be learned and several alterations in technique must be made when modifying the "tilt and tumble" technique or any other technique to incorporate bimanual sleeveless microphacoemulsification:

1. Three 1.0-mm stab incisions are made to allow for the sleeveless phaco probe, the irrigating second instrument, and the anterior chamber maintainer.

2. Because the smaller incision cannot accommodate current capsulorrhexis forceps, we prefer the use of a cystotome to perform the capsulorrhexis. New designs for microincision capsulorrhexis forceps have recently been developed but typically require a steeper learning curve.

3. The instruments will behave as if they are "oar-locked" by the small incisions and thus the surgeon must adapt to reduced mobility of the instruments.[10]

4. Probably the skill that is most foreign to ophthalmologists is learning how to use the irrigating second instrument and learning how to use the irrigation itself as a tool.[8] Because the irrigating second instrument is no longer coaxial with the phaco probe, it may be used to drive material towards the phaco tip rather than away from the tip as in coaxial irrigation sleeves. Other novel uses of the irrigating second instrument include using the irrigation to flip the epinucleus, as Fine has described.[8] In addition, the irrigation may be used to drive the iris away from the phaco tip as in pseudoexfoliation cases with small pupils.

5. Microphacoemulsification is a truly bimanual procedure where the instruments may be interchanged between any of the incisions. For example, removal of subincisional cortex may be accomplished by interchanging the irrigating and aspirating handpieces in order to obtain better access to the cortical material.

Figure 17-1. Paracentesis port of 1.0 mm is created with a diamond stab knife.
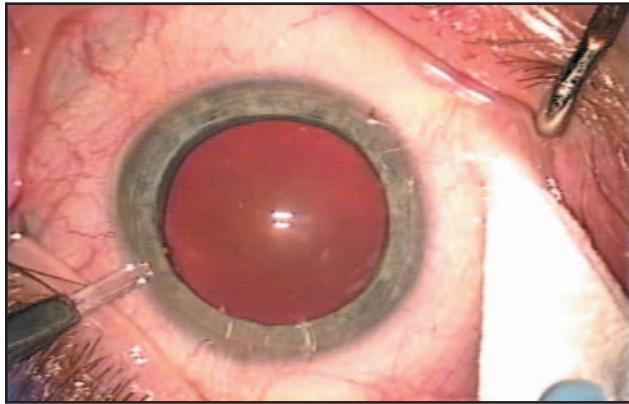
Similarly, interchanging the phaco probe and the irrigating second instrument may necessary in certain situations, such as in cases of zonular dialysis where traction may be relieved by interchanging the instruments. Consequently, right-handed surgeons must learn how to phaco with the left hand and left-handed surgeons must learn how to phaco with the right hand.

OPERATIVE PROCEDURE

Incisions

The patient is asked to look down. The globe is supported with a dry Merocel sponge (Medtronic Xomed, Mystic, Conn), and a counter puncture is performed superiorly at 12 o'clock with a diamond stab knife. (Osher/Storz, Bausch & Lomb Surgical, San Dimas, Calif) The incision is about 1.0 mm in length (Figure 17-1). Approximately 0.25 mL of 1% nonpreserved methylparaben free lidocaine is injected into the eye. We advise the patient that they will feel a "tingling" or "burning" for a second, and then "the eye will go numb". This provides psychological support for the patient that they will now have a totally anesthetized eye and should not anticipate any discomfort. We tell them that while they will feel some touch and fluid on the eye, they will not feel anything sharp, and if they do, we can supplement the anesthesia.

Two additional stab incisions of approximately 1.0 mm in width are created in clear cornea for insertion of the phaco probe and the anterior chamber maintainer. The stab incision for the anterior chamber maintainer is placed inferiorly at 6:00. For the phaco probe, we perform a temporal or nasal anterior limbal or posterior clear corneal incision in a direction that is parallel to the iris plane. The direction of this incision prevents an excessively long tunnel and thereby minimizes "oar-locking," but is shelved enough to be self sealing.[8] Incision size is critical in bimanual phacoemulsification, as a large incision compromises anterior chamber stability while a small incision causes oar-locking of the instruments. Care is taken not to incise the conjunctiva as this can result in ballooning during the procedure. Some surgeons define this as being a posterior clear corneal incision and others as an anterior limbal incision. The anatomical landmark is the perilimbal capillary plexus and the insertion of the conjunctiva. When the incision is made, there will be a small amount of capillary bleeding. Since the incision is into a vascular area, long-term wound healing can be expected to be stronger

than it is with a true clear corneal incision. True clear corneal incisions, such as performed in radial keratotomy, clearly do not have the wound healing capabilities that a limbal incision demonstrates where there are functioning blood vessels present.

In right eyes, the incision that we use in the majority of bimanual phaco cases is temporal; in left eyes it is nasal. This allows the surgeon to sit in the same position for both right and left eyes. The nasal cornea is thicker, has a higher endothelial cell count and allows very good access for phacoemulsification. The nasal limbus is approximately 0.3 mm closer to the center of the cornea than the temporal limbus, and this can, in some cases where there is excess edema, reduce first day postoperative vision more than one might anticipate with a temporal incision. There also, in some patients, can be pooling of irrigating fluid, but this problem is less likely in microphacoemulsification where the incisions are more watertight. An aspirating speculum may be useful in situations of pooling. It is also helpful to tip the head slightly to the left side. Nonetheless, in left eyes a nasal clear corneal approach is an excellent option, particularly for surgeons who find the left temporal position uncomfortable.

Because the incisions are 1.0 mm, they are almost always self sealing and do not require a suture unless oar-locking of the instruments stretches the incisions. If stretching of the wounds does occur, the incisions may need to be hydrated to prevent a wound leak. Furthermore, the 1.0-mm microincisions do not induce astigmatism, whereas incisions of 3.0 mm in length tend to cause an induction of 0.25 ± 0.25 diopters (D) of astigmatism. In select patients an intraoperative astigmatic keratotomy can be performed at the 8.0- to 9.0-mm optical zone. This can be done at the beginning of the operation. The patient's astigmatism axis is marked carefully using an intraoperative surgical keratometer, which allows one to delineate the steeper and flatter meridian and not be concerned about globe rotation. One 3.0-mm incision at an 8.0 to 9.0 mm optical zone will correct 1.0 D of astigmatism and two 3.0 mm incisions will correct 2.0 D of astigmatism in a cataract age patient. Many surgeons have moved to a more peripheral corneal limbal arcuate incision, but we favor the 8.0 to 9.0 mm optical zone because of the decreased length of the incisions necessary to achieve astigmatic correction. There is an increased variation in response to astigmatic correction from patient to patient that is greater than with the excimer laser, but it is unusual to have significant induced astigmatism, or wound related complications with this approach. The outcome goal is 1.0 D or less of astigmatism in the preoperative axis. It is preferable to under-correct rather than over-correct. The key in astigmatism surgery is "axis, axis, axis." If the incision is placed more than 15 degrees off-axis, the astigmatic result is not optimal. It is also important not to cross your astigmatic incisions with any of the limbal incisions which may cause instability and excess ectasia in the area of the incisions.

The anterior chamber is then constituted with a viscoelastic. A dispersive viscoelastic may provide protection to the endothelium. Ocucoat (Bausch & Lomb, Rochester, NY) has proved be an excellent viscoelastic and can also be utilized to coat the epithelial surface during surgery. This eliminates the need for continuous irrigation with BSS. It gives a very clear view. It is also economically a good choice in most settings. Amvisc Plus also works well.

Capsulorrhexis

Next a relatively large diameter continuous tear anterior capsulectomy is fashioned. Because the 1.0-mm incision cannot accommodate traditional capsulorrhexis forceps, the capsulorrhexis may be completed with a cystotome or a bent needle. Alternatively,

Figure 17-2. The nucleus is rotated to face the incision.
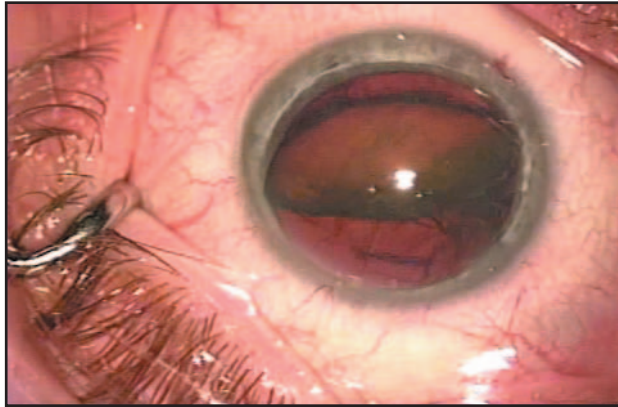
the surgeon may learn how to use the newer forceps specifically designed for microincision phacoemulsification. The optimal size is of the capsulorrhexis is 5.0 to 5.5 mm in diameter and inside the insertion of the zonules (usually at 7.0 mm). Larger is typically better than smaller in the "tilt and tumble" technique, as a larger capsulorrhexis allows the cataract to be more easily prolapsed out of the capsular bag. There is less subcapsular epithelium with a larger capsulorrhexis, which may possibly lower the risk of capsular opacification. On the other hand, some feel that a smaller capsulorrhexis that seals over the edge of the intraocular lens may reduce the chances of posterior capsular opacification.[14] If the capsulorrhexis is larger than the IOL, then the capsule will seal down to the posterior capsule around the loops rather than over the anterior surface of the intraocular lens. Most eyes do extremely well with either approach, yet there is still debate as to whether smaller or larger is preferred.

Hydrodissection

Hydrodissection is then performed utilizing a Pearce hydrodissection cannula on a 3.0-cc syringe filled with BSS. Slow continuous hydrodissection is performed gently lifting the anterior capsular rim until a fluid wave is seen. At this point irrigation is continued until the nucleus tilts on one side, up and out of the capsular bag. If one retracts the capsule at approximately the 7:30 position with the hydrodissection cannula, usually the nucleus will tilt superiorly. If it tilts in another position, it is simply rotated until it is facing the incision (Figure 17-2).

During the hydrodissection, we depress the posterior lip of the wound in order to prevent the anterior chamber from becoming too deep, which may cause excessive stress on the zonules or disrupt the posterior capsule. However, with the small incisions of microphacoemulsification, depression of the posterior lip may not be as easy.

The anterior chamber maintainer is then inserted through the inferior paracentesis. We prefer to use an anterior chamber maintainer designed with screw-type threads on the infusion tip in order to secure the device within the paracentesis.

Phacoemulsification

Once the nucleus it tilted, additional viscoelastic can be injected under the nucleus pushing the iris and capsule back. Also, additional viscoelastic can be placed over the nuclear edge to protect the endothelium. A deep anterior chamber is paramount in
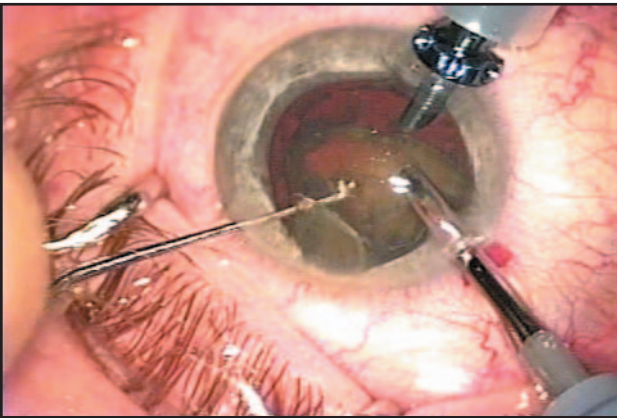
Figure 17-3. The anterior chamber maintainer is inserted into the inferior 1.0-mm paracentesis.
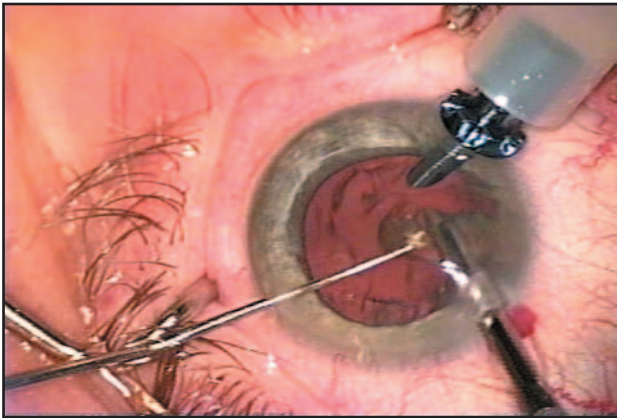
Figure 17-4. Emulsification is completed in the iris plane.

the "tilt and tumble" technique. Thus we prefer using an anterior chamber maintainer inserted through a third port as it provides superior chamber stability over two port techniques that rely solely on the irrigation from current 20-gauge irrigating second instruments. The nucleus is then emulsified from outside-in while supporting the nucleus in the iris plane with the irrigating second instrument, such as a nucleus rotator. In order to minimize the use of ultrasound energy, the soft cortical and epinuclear material may be "stripped" with high vacuum interspersed with short bursts of phaco energy. Once half of the nucleus is removed, the remaining one half is tumbled upside-down and approached from the opposite pole (Figure 17-3). Again, it is supported in the iris plane until the emulsification is completed (Figure 17-4). Alternatively the nucleus can be rotated and emulsified from the outside edge in, in a carousel or cartwheel type of technique. In some cases, the nucleus can be continuously emulsified in the iris plane, if there is good followability, until the entire nucleus is gone.

This a very fast and very safe technique, and as mentioned before, it is a modification of the iris plane technique taught by Richard Kratz, MD in the late-1970s and 1980s. It is basically "back to Kratz" with help from Brown and Maloney in the modern phacoemulsification, capsulorrhexis, hydrodissection and viscoelastic era. Surgery times now range between 5 and 10 minutes with this approach rather than 10 to 15 minutes for endocapsular phacoemulsification. In addition, our capsular tear rate has

now gone under 1%. Therefore, we find this technique to be easier, faster, and safer. It is true that in this technique the phacoemulsification tip is closer to the iris margin and also somewhat closer to the corneal endothelium. There is, however, a significantly greater margin of error in regards to the posterior capsule. Care needs to be taken to position the nucleus away from the corneal endothelium and away from the iris margin when utilizing this approach.

If the nucleus does not tilt with simple hydrodissection, it can be tilted with viscoelastic or a second instrument such as a nuclear rotator, Graether collar button, or hydrodissection cannula.

When utilizing a peristaltic machine, a high flow rate is used, which enhances followability. It is best to maintain a high bottle height in order to maintain a deep anterior chamber, particularly if one chooses to undertake bimanual sleeveless phacoemulsification without an anterior chamber maintainer.

The dual linear Storz Millennium (Bausch & Lomb Surgical, San Dimas, Calif), which uses a Venturi pump, is also excellent for all cataract techniques including "tilt and tumble," as it provides linear control of ultrasound, as well as linear control of vacuum. The foot pedal is arranged such that there is surgeon control over ultrasound on the vertical or pitch motion of the foot pedal, and then on the yaw or right motion foot pedal, there will be vacuum control. This allows very efficient emulsification, and the Millennium is currently our preferred machine. We prefer to set the maximum vacuum in the range of 250.0 to 300.0 mmHg with the bottle height between 120.0 to 130.0, which facilitates maintenance of a deep anterior chamber. The maximum ultrasound power is typically set at 60%, with average use of 11 to 15% depending upon the density of the cataract. With the microphacoemulsification technique, we take care to avoid the use of excessive ultrasound power in order to avoid wound burn from the sleeveless phaco tip. In addition, caution must be exercised with higher vacuum levels as it is possible to core through the nucleus and aspirate the iris margin if very high vacuums are utilized.

Cortical Removal

Following completion of nuclear removal, the cortex is removed with bimanual irrigation and aspiration. In the absence of an anterior chamber maintainer, the irrigating second instrument may provide irrigation through the paracentesis port while the aspiration device is inserted through the main incision. However, in the presence of an anterior chamber maintainer, irrigation from the second instrument is not necessary. Cortical and epinuclear removal is then performed in the usual manner. For subincisional cortical material, the irrigation and aspirating devices may be interchanged through their respective incisions in order to gain better access. If there is significant debris or plaque on the posterior capsule, one can attempt some polishing and vacuum cleaning but not so aggressively as to risk capsular tears. Many times there is an unexpected small burr or sharp defect on the irrigation/aspiration (I/A) tip which results in a capsular tear after a case that was otherwise well done.

IOL Insertion

Although IOLs that can be inserted through small incisions are under development, current IOLs cannot take advantage of microincision surgery. Thus, one of the stab incisions must be enlarged to allow for insertion of the IOL. Alternatively, a new incision may be created, which ensures a well-constructed, self-sealing incision that has

not been previously stretched by oar-locked instruments.[10] After the capsular bag is reconstituted with viscoelastic, the intraocular lens is inserted utilizing an injector system. We prefer the three-piece silicone lenses that are injectable through a 3.0-mm incision.

Excess viscoelastic is removed with irrigation and aspiration. Pushing back on the intraocular lens and slowly turn the irrigation aspiration to the right and left two or three times allows a fairly complete removal of viscoelastic under the intraocular lens.

We favor injection of a miotic and tend to prefer carbachol over Miochol (OMJ Pharmaceuticals, San German, PR) at this time, as it is more effective in reducing postoperative intraocular tension spikes and has a longer duration of action. It is best to dilute the carbachol 5 to 1, or one can obtain an excessively small pupil that results in dark vision for the patient at night for one to two days. The anterior chamber is then refilled through the counter-puncture and the incision is inspected. If the chamber remains well constituted and there is no spontaneous leak from the incision, wound hydration is not necessary. If there is some shallowing in the anterior chamber and a spontaneous leak, wound hydration is performed by injecting BSS peripherally into the incisions and hydrating it to push the edges together. We suspect that within a few minutes these clear corneal microincisions seal, much as a LASIK flap will stick down, through the negative swelling pressure of the cornea and capillary action. It is important to leave the eye slightly firm at 20 mmHg or so to reduce the side effects of hypotony and also help the internal valve incision appropriately seal.

At completion of the procedure another drop of antibiotic, steroid and non-steroidal, is placed on the eye. Additionally, one drop of an antihypertensive such as levobunolol or brimonidine is applied to reduce postoperative intraocular tension spikes. An additional drop of antibiotic is placed in the eye prior to transporting the patient to the postoperative recovery area.

Conclusions

The next step in the evolution of phacoemulsification may lie in bimanual microphacoemulsification. As newer and thinner IOL designs arise to take advantage of microincisions, the procedure will most certainly gain in popularity. Many of the current phacoemulsification techniques can be readily adapted to bimanual microincision surgery thereby allowing a smooth transition for most surgeons. Microincision surgery may herald a new era where intraoperative and postoperative complications may be reduced. Acceptance of these new techniques are likely to be slow until development of the new IOL designs matures. These perpetual advances in cataract surgery will continue to translate into improved safety and ultimately greater patient satisfaction.

KEY POINTS

✔ The concept of three-port bimanual phaco was devised to reduce the potential of an unstable anterior chamber. A third port allows the insertion of an anterior chamber maintainer that would provide additional inflow and thus stabilize the anterior chamber.

✔ This concept is analogous to three-port vitrectomy, where one port is used for the vitrectomy handpiece, a second port is used for the light pipe, and the third port is used for the infusion device.

✔ In the "tilt and tumble" technique, the superior pole of the nucleus is tilted above the capsule upon completion of a large capsulorrhexis. Bimanual phaco is then performed while supporting the lens in the iris plane with an irrigating nucleus rotator.

✔ As the "tilt and tumble" is a supracapsular technique, the risk of endothelial trauma from the instruments or the cataract itself exists. Furthermore, with bimanual phaco, the endothelium in the region of the wound is also at risk of damage from transmitted ultrasound energy by the sleeveless ultrasound probe. So, the technique of "tilt and tumble" is to be used selectively in cases in which there is a relatively deep anterior chamber and a modestly dense cataract.

✔ A deep anterior chamber is essential to this technique and the inflow provided by current 20-gauge irrigating second instruments may not be sufficient. An anterior chamber maintainer inserted through a third paracentesis may better ensure a deep and stable anterior chamber.

✔ If the nucleus does not tilt with simple hydrodissection, it can be tilted with viscoelastic or a second instrument such as a nuclear rotator, Graether collar button, or hydrodissection cannula.

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CHALLENGES AND COMPLICATIONS IN MICROPHACOEMULSIFICATION

Robert H. Osher, MD and Christopher Khng, MD, FRCS

INTRODUCTION

Microphacoemulsification offers new benefits for the patient, but also creates an expanded potential for problems when the surgeon is unprepared.

INCISION

Incision construction is more critical than ever. Too long or too tight an incision will cause severe "oar-locking," while too short or too tight an incision is sure to cause a gape as the tissue molds around the instruments. If the incision is too wide, excessive leakage will make chamber stability more difficult. Location of each incision is also important since intracameral maneuvering is more limited than during coaxial phaco. Instrument insertion and injection of viscoelastic must be carefully accomplished in order to prevent damage to Descemet's membrane. Proper construction and care are more likely to result in a watertight closure at the end of the procedure.

RHEXIS

Performing the capsulorrhexis through a microincision requires both the proper choice of instrumentation and a meticulous technique. Most companies offer a capsulorrhexis forceps specifically designed for a sub-2.0-mm incision, although a bent needle is very effective, especially when the chamber has been filled with a viscoelastic agent.

HYDRODISSECTION

The act of hydrodissection or hydrodelineation is not innocuous because fluid is less able to escape through these incisions. In order to prevent excessive deepening of the chamber and a zonular stress test, placing a second instrument in the second incision allows fluid to more easily escape.

Challenges

Microphacoemulsification is associated with three distinct challenges. These include *chamber stability*, *nuclear chip management*, and *thermal damage*. Since most irrigating choppers permit less infusion than coaxial phaco, there is a more delicate balance that the surgeon must consider between vacuum, aspiration rate, and infusion. Increasing the aspiration rate and vacuum enough to efficiently emulsify must be balanced against the reduced infusion and chamber instability. Flow restricting devices have been designed to improve this balance and some machines offer forced infusion, which may also improve fluidics.

The smaller phaco needle in combination with a lower vacuum may be conducive to nuclear chips. By filling the anterior chamber with a viscoelastic such as Healon 5 (AMO, Santa Ana, Calif), the emulsification may be performed entirely within the posterior chamber while the viscoelastic retards nuclear chip access to the anterior chamber angles.

A laboratory study was undertaken at the Alcon research facility aimed at determining which parameters had the greatest potential for thermal injury during microphacoemulsification. This invitro study was conducted with the Infiniti Vision System (Alcon, Fort Worth, Tex) using bank-eye cadaver eyes and pig eyes measuring the maximum incision temperature with a Flir Systems ThermaCAM P60 Infrared camera. Other studies have also been conducted studying the thermal consequences of small incision surgery.[1-4]

Incision Size

We evaluated incision sizes between 1.2 mm and 1.6 mm using a 0.9-tip and continuous 100% power with a low aspiration rate of 12.0 cc/minute. We found that the larger the incision size relative to the tip size, there was less tendency for "oar-locking," there seemed to be less friction, and there was a greater tendency for leakage around the tip. Therefore, the larger the incision size the less likely it was for a temperature rise to occur.

Duty Cycle

This is the modulation of ultrasound, which means the on/off cycle. We found that this may be the most important single parameter to reduce the risk of thermal injury. The less the ultrasound is working, then there is a lower risk of temperature rise within the incision. With the 25% on time, microphacoemulsification becomes very safe with the Infiniti.

Power

The greater the power, the greater the stroke, which means more friction in the incision and more generation of heat. Continuous power generates more heat and this is why a longer off time (lower duty cycle) allows cooling, which equates to a safer procedure.

Aspiration Rate

Previous laboratory studies have confirmed that there is a greater cooling effect when fluid passes through the inside of the ultrasound tip rather than from fluid pass-

ing outside around the tip. Therefore, the greater the aspiration rate, the more cooling of the tip occurs. Yet in microphacoemulsification there is a delicate balance between the reduced infusion through the irrigating chopper and the aspiration rate, which is removing fluid from the eye. Therefore, the surgeon must be vigilant to maximize the aspiration without challenging the infusion volume and causing chamber shallowing. A higher aspiration rate without compromising the chamber is ideal.

Vacuum

Intuitively, it would seem that vacuum would not be important until there is occlusion of the tip. This is probably not the case since a vacuum set too low will impede the aspiration flow rate. Even if the aspiration rate is set at 25.0 cc/minute, a vacuum of 50.0 mmHg will reduce the actual aspiration rate into the teens and a vacuum of 0 will reduce the flow rate even lower.

Vacuum becomes very important when the tip is occluded. Low vacuum is more conducive to a temperature rise since the occlusion cannot be cleared. On the other hand, higher vacuum will create more "grasping and holding," which could also mean that the tip is occluded more often, although a higher vacuum will also facilitate clearing of the occlusion.

Pulses

Insignificant changes in the incision temperature were observed in relation to the ultrasound pulse frequency. This is because the actual power applied over time is equal.

Temperature of BSS

This had a very minimal effect even though one might have expected otherwise. We are dealing with such a small infusion volume especially when viscoelastic material is in the chamber that the small change in temperature between room temperature (22° C) and refrigerated temperature (7° C) is not enough in such a tiny chamber to be an effective coolant.

Bottle Height

This parameter also had little effect probably because of the very small volume of fluid passing through the irrigating chopper into the eye and out the incision even when the bottle is raised maximally. For example, when the bottle is raised from 60.0 to 120.0 cm, there are only several additional drops that flow through the eye.

Viscoelastic Agent

The more viscous the viscoelastic agent, the more vacuum is required to clear the occlusion. Visco-obstruction is probably one of the most common causes of thermal injury. The vacuum must be set high enough to clear the viscoelastic and allow fluid to enter the phaco tip and cool the needle. On the Infiniti, a higher rise time is an advantage since occlusion will initiate a faster race to the vacuum limit. Yet even with viscoelastic occlusion or complete clamping of the vacuum tubing with a hemostat, there is a safe period before the temperature becomes dangerous if the surgeon is using a lower power with a 25% duty cycle.

Tip Design

Since it has been established that there is a greater cooling from within rather than outside the tip, it is not intuitive that a 0.9 tip would have a safer temperature profile than a 1.1 tip. Even though the larger tip has more flow internally, there is greater friction in the incision, which is the dominant variable. The 0.9-tip with less flow through it, allows more leakage around the tip for a given incision size, as well as less friction (the dominant variable). Therefore, in microphacoemulsification the 0.9 tip has a greater safety profile with temperature, yet the disadvantages include that it takes smaller bites slowing the procedure and its holding power creates more nuclear chip management.

SUMMARY

In summary, whenever the surgeon introduces a modification in technique and the required instrumentation, new challenges and complications may occur. Careful study and preparation will help the inexperienced surgeon to avoid making the same mistakes as those made by the pioneers in microphacoemulsification.

KEY POINTS

✔ Incision construction in microphacoemulsification is more critical than phaco. Too long or too tight an incision will cause severe "oar-locking," while too short or too tight an incision is sure to cause a gape as the tissue molds around the instruments. If the incision is too wide, excessive leakage will make chamber stability more difficult.

✔ The act of hydrodissection or hydrodelineation is not innocuous because fluid is less able to escape through these incisions.

✔ The reduced infusion of the irrigating chopper may influence the vacuum and aspiration rate resulting in chamber instability.

✔ The smaller phaco needle in combination with a lower vacuum may be conducive to nuclear chips. By filling the anterior chamber with a viscoelastic such as Healon 5, the emulsification may be performed entirely within the posterior chamber while the viscoelastic retards chip access to the anterior chamber angles.

✔ Hyperpulsed ultrasound with a duty cycle of 25% on and 75% off offers a very safe thermal profile.

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COMPLICATIONS OF BIMANUAL PHACO

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INTRODUCTION

More complications[1-5] may be encountered by a surgeon who has just begun to do bimanual phaco, as a longer learning curve is often associated with this technique in comparison to other methods.

WOUND CONSTRUCTION

The importance of a perfectly constructed wound in bimanual phaco surgery cannot be overstated. A well-constructed wound is the key to achieving a flawless self-sealing wound that requires no sutures. A well-constructed wound can be closed by any method with good results. A poorly-constructed wound can be a continued source of astigmatism, filtration, irritation, hemorrhage, and corneal trauma despite a satisfactory wound closure.

COMPLICATIONS RELATED TO NUCLEUS (EMULSIFICATION TECHNIQUE)

While manipulating with the micromanipulator, great care should be taken not to sink it through the soft nuclei and especially into the posterior capsule. Phacoemulsification energy must be substantially reduced when fragments are small, or they will bounce off the tip when the power is activated.

When removing the nuclear chips, it is advisable to shift to pulse mode to reduce the "chattering" of the chip. Moreover, the posterior capsule is covered during the entire emulsification process by the outer nucleus which acts as a thick layer of foam rubber separating the firm inner nucleus from the capsular bag.

If the phacoemulsification tip does not emulsify the nucleus properly, correction of one or more of the following responsible conditions is required:

Figure 19-1. Capsular phimosis. One can see the anterior capsular rim in the central pupillary zone. The treatment of this complication is enlargement of the opening with the YAG laser (courtesy of Dr. Prakash, DP).
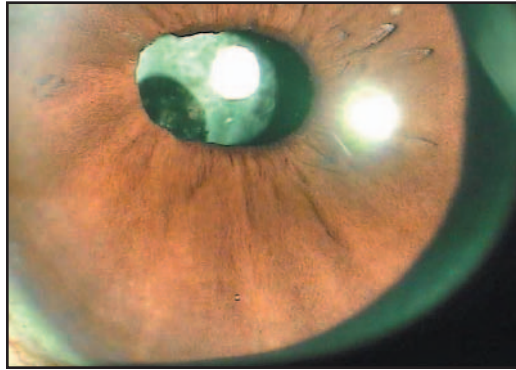
1. The titanium needle is not tightly screwed to the handpiece.
2. The aspiration system is partially blocked by a piece of nucleus.
3. The ultrasound setting is too low for a particular piece of nucleus.

Moreover, the handpiece temperature should be monitored at all times, and it should not be allowed to become too warm. After cortical aspiration, meticulous anterior capsular vacuuming should be performed to eliminate residual lenticular periequatorial epithelial cells that could lead to capsular phimosis (Figure 19-1).

CORNEAL COMPLICATIONS

Many corneal complications may occur especially with beginners. They are summarized in Table 19-1.

Transient postoperative superior corneal edema is usually present in cases of bimanual phaco for the beginners (Figure 19-2). Moreover, adequate incision construction, proper instrumentation, and avoidance of false passages reduce the occurrence and hasten the resolution of corneal edema. Incisional burns can be averted by avoiding too tight an incision, using cold balanced salt solution (4° C) as irrigating fluid, and minimizing the phaco time.

Moreover, diffuse corneal haze (Figure 19-3) or loss of corneal clarity is a common problem encountered during bimanual phaco surgery for the beginners. Topical medications should be used judiciously, as their prolonged and frequent instillation may induce superficial punctate keratopathy.

Descemet's detachment and Descemet's tears may also occur occasionally. The anterior tip of the incision should be lifted up when the instruments are inserted. Descemet's tears can also be prevented by using sharp instruments. The probe tip should be inserted with the bevel down. The side-port entry should also be made with a beveled instrument in a similar fashion, and any mechanical damage to the Descemet's membrane should be avoided.

Corneal endothelium damages can be further prevented by decreasing the effective emulsification time and confining the procedure to the nucleus with the minimal required ultrasonic energy in the posterior chamber. Only high-quality ophthalmic fluids (eg, sodium hyaluronate and other similar viscoelastics, and balanced salt solution. etc) should be used.

TABLE 19-1		
CORNEAL COMPLICATIONS OF BIMANUAL PHACO		
1.	Epithelial	• Abrasions • Filamentary Keratitis • Toxic keratopathy
2.	Corneal burns	• Thermal • Cautery
3.	Infection	• Bacterial wound infection • Fungal wound infection • Herpetic keratitis
4.	Sterile ulcerations and stromal melting	• Rheumatoid arthritis • Collagen vascular disease • Keratoconjunctivitis sicca
5.	Sterile Descement's membrane	• Blunt blade injury • Oblique instrument insertion • Incomplete insertion of instruments • Injection of viscoelastic, air, or irrigation fluids

6.	Endothelial damage	• Poor endothelial preoperative cell count
		• Intraocular mechanical damage
		  a. Anterior chamber collapse
		  b. Instruments
		  c. Irrigating fluid disturbances
		  d. Anterior chamber emulsification
		  e. Lens/nucleus/nucleus fragment touch
		  f. IOL touch
		  g. Foreign matter
		• Toxicity
		  a. Irrigating solutions
		  b. Povidone iodine
		• Chronic endothelial touch
		  a. IOL
		  b. Vitreous
		• Faulty IOL
		  a. Closed loop anterior chamber IOL
		  b. Iris-supported IOL
		  c. Poorly coated surfaces
		• Ingrowth of cells
		  a. Epithelial
		  b. Fibrous

7.	Corneal complications—postoperative	• Endothelial decompensation • Striate keratopathy • Bullous keratopathy

Figure 19-2. Corneal edema (courtesy of Dr. Prakash, DP).
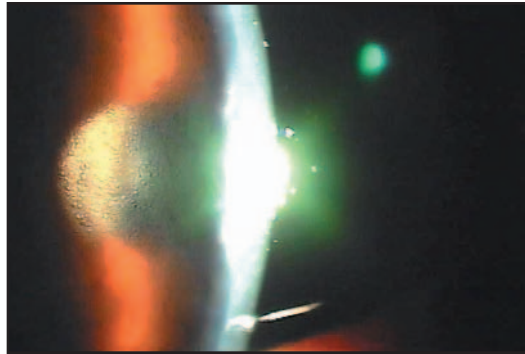
Figure 19-3. Striate keratitis (courtesy of Dr. Prakash, DP).

In the event of postoperative corneal decompensation, anti-inflammatory and cycloplegic agents should be applied to counteract the associated inflammation and achieve cycloplegia respectively. Hyperosmotics may also be useful for decongesting microcystic corneal edema. In the event of irreversible corneal endothelial damages, however, penetrating keratoplasty may be undertaken.

IRIS INJURY

Injury to both the superior and inferior portions of the iris may occur during bimanual phaco. Iris fluttering should always be prevented during phacoemulsification. While performing phacoemulsification, the bevel of the phaco needle should be pointed upwards and maintained parallel to the iris plane throughout the process.

VITREOUS LOSS

The closed system inherent with the ultrasmall incisional wound of bimanual phaco limits vitreous loss and enhances the surgeon's ability to perform an adequate vitrectomy. The constant pressure in the anterior chamber due to the closed system associated with Bimanual phaco reduces the tendency of anterior vitreous prolapse. The small incision also limits the amount of vitreous extrusion from the eye. Zonular dehiscence may occur if an attempt is made to rotate the nucleus after an inadequate hydrodissection, partially due to the lack of capsular flexibility upon stress.
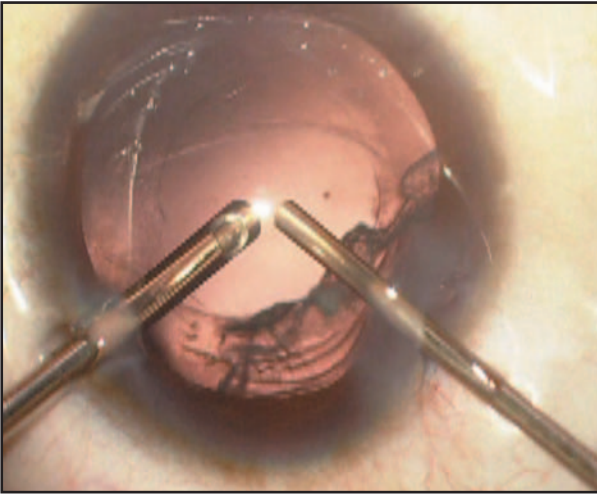
Figure 19-4. Bimanual vitrectomy. Please note separate vitrectomy probe and infusion cannula.

Unplanned posterior capsulotomy that violates the anterior vitreous hyaloid face tends to induce vitreous loss. Factors which inhibit early recognition of a posterior capsular rent by the surgeon (ie, obstruction of view by a large and opaque nuclear fragment, may increase the tendency for greater vitreous loss).

In the event of a posterior capsular rent with no vitreous loss, vitrectomy may not be required. Nevertheless, the flow rate and infusion should be decreased to avoid subsequent anterior vitreous herniation. However, a vitrectomy is mandatory when vitreous loss is confirmed. A single vitrectomy probe with a coaxial cannula should generally be avoided in favor of a bimanual vitrectomy technique using separate infusion cannula and vitrectomy probe (Figure 19-4). A coaxial infusion probe may require enlargement of the original incisional wound. Coaxial infusion also tends to open up the posterior capsular flap and hydrate the vitreous more than a separate infusion cannula, thus permitting more anterior vitreous prolapse. With the bimanual technique, a limited anterior vitrectomy is performed and the main body of the vitreous is not disturbed. During the procedure, vitreous should be aspirated downward below the plane of the posterior capsule. Irrigation should be gentle and limited to the anterior chamber. Following vitrectomy, a posterior intraocular lens (IOL) may be inserted in front of the anterior capsule in the ciliary sulcus, if an adequate capsular rim is present. Vitreous loss can be prevented or minimized by avoiding phacoemulsification on the posterior surface of the nucleus. Improper vitrectomy can result in postoperative malpositioning of the IOL (Figure 19-5) and severe intraocular inflammation (Figure 19-6).

NUCLEAR DISLOCATION

If the posterior capsular rent is large, the nucleus may migrate into the posterior vitreous cavity. Since an exposed nucleus is strongly antigenic and may cause a severe ocular phacoanaphylactic or phacotoxic reaction, its removal is mandatory. A soft nucleus can be removed with a vitrectomy probe alone, but a hard one requires posterior phacofragmentation, usually via a pars plana approach. An alternative method for removing a large and hard nuclear fragment is floating it anteriorly with perfluorocarbon liquids (PFCL) after a posterior vitrectomy (see Chapter 20). The anteriorly displaced lens fragment can then be delivered out of an enlarged corneal-scleral limbal

Figure 19-5. Haptic of an IOL in the anterior chamber (courtesy of Dr. Prakash, DP).
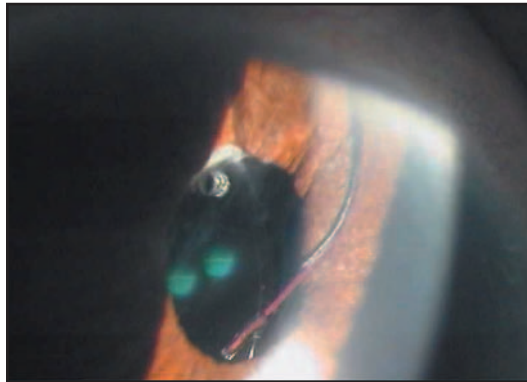
Figure 19-6. Severe inflammatory reaction in the anterior chamber (courtesy of Dr. Prakash, DP).
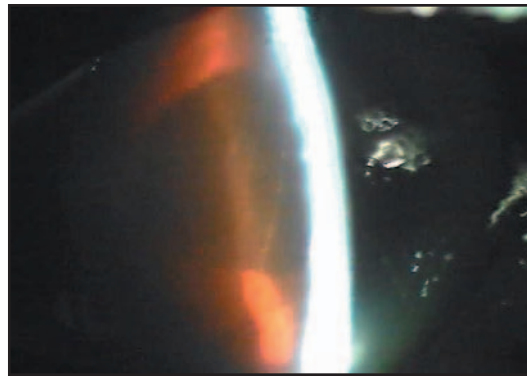
wound. One can also use the FAVIT technique (see Chapter 20) for removing dropped nuclear pieces.[6]

Expulsive Hemorrhage

Expulsive suprachoroidal hemorrhage rarely occurs in conjunction with a 1.0-mm incision associated with bimanual phaco. This small beveled incision is self-sealing, and therefore, usually prevents extrusion of intraocular contents associated with the suprachoroidal hemorrhage. In the event of a hemorrhagic choroidal detachment, the performance of a posterior sclerotomy to allow posterior release of the suprachoroidal hemorrhage and a rapid closure of the wounds minimize the chance of an expulsive hemorrhage.

Conversion to Extracapsular Cataract Extraction

Upon the first sign of excessive corneal clouding or anterior vitreous prolapse, the surgeon should consider converting bimanual phaco to extracapsular cataract extraction (ECCE), in order to enhance the likelihood of achieving good functional visual outcome. Conversion should be undertaken preferably before excessive corneal endothelial damages and capsular rupture occur.

Planned conversion to ECCE is better than forced conversion. The surgeon should enlarge the limbal wound for extracapsular delivery of the nucleus from the posterior chamber, upon the first sign of anterior vitreous herniation. A lens loop or equivalent instrument may be inserted under the nucleus for its expression out of the eye. After the nucleus is out, an irrigation/aspiration handpiece with a 0.5-mm tip is employed with low vacuum for lenticular cortical clean-up. However, lens fragments dislocated into the vitreous cavity are left alone for subsequent management with vitreoretinal techniques. The cataract surgeon unfamiliar with vitreoretinal techniques should refer the patient to a vitreoretinal surgeon. Attempts in removing posteriorly dislocated lens fragments without proper vitreoretinal techniques tend to cause retinal complications. In the event of vitreous loss, cortical aspiration may be difficult, and a vitrectomy probe is usually a better tool for completing the cortical clean-up.

MANAGEMENT OF A MALPOSITIONED IOL

Disturbing visual symptoms such as diplopia, metamorphopsia, and hazy images are associated with a dislocated IOL (Figure 19-7). If not properly managed, a malpositioned IOL may also induce sight-threatening ocular complications, including persistent cystoid macular edema, intraocular hemorrhage, retinal breaks, and retinal detachment. Contemporaneous with advances in bimanual phaco microsurgical techniques for treating cataracts, a number of highly effective surgical methods have been developed for managing a dislocated IOL (Figure 19-8). They include IOL manipulation with perfluorocarbon liquids, scleral loop fixation, use of a snare, employing 25-gauge IOL forceps, temporary haptic externalization, as well as managing the single plate implant and two simultaneous intraocular implants. One excellent method is the use of a diamond tipped forceps to hold the IOL and bring it anteriorly after vitrectomy (Figure 19-9). The primary aim of such methods is to reposition the dislocated IOL close to the original site of the crystalline lens in an expeditious manner whenever possible, and with minimal morbidity, enhancing the chance of good visual outcome.

PERFLUOROCARBON LIQUIDS

Chang popularized the use of perfluorocarbon liquids for the surgical treatment of various vitreoretinal disorders. Due to their heavier-than-water properties and their ease of intraocular injection and removal, perfluorocarbon liquids are highly effective for flattening detached retina, tamponading retinal tears, limiting intraocular hemorrhage, insulating the retina from damages, as well as floating dropped crystalline lens fragments and dislocated IOLs. The anterior displacement of a dislocated IOL by perfluorocarbon liquids facilitates its removal or repositioning.

Types of Perfluorocarbon Liquids

Four types of perfluorocarbon liquids are frequently employed for intraocular surgery. They include:

1. Perfluoro-N-Octane.
2. Perfluoro-Tributylamine.
3. Perfluoro-Decaline.
4. Perfluoro-Phenanthrene.

Figure 19-7. Dislocated plate haptic IOL on the retina.
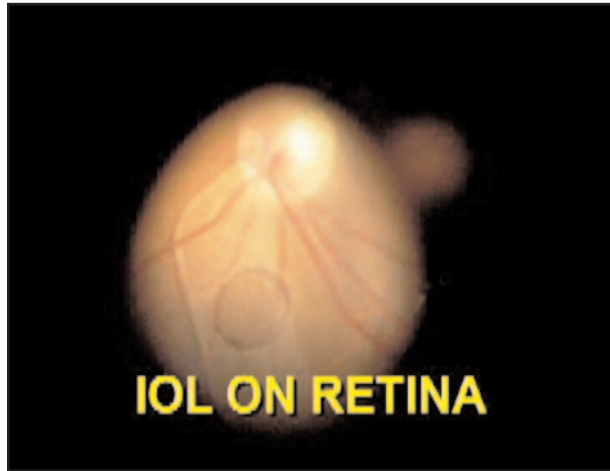
Figure 19-8. IOL lying over the disc.
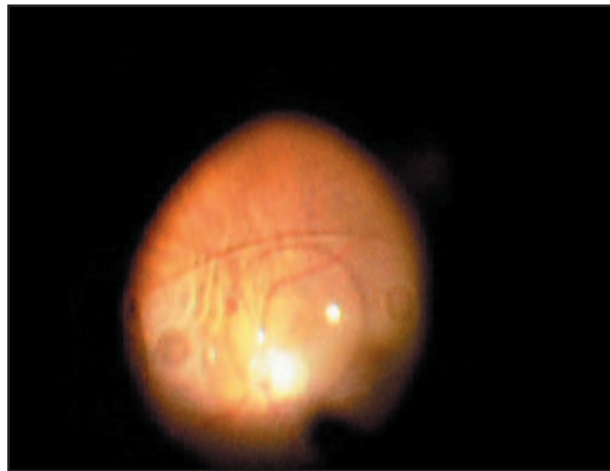
Figure 19-9. Diamond tipped forceps lifting a looped IOL lying on the retina after a vitrectomy.
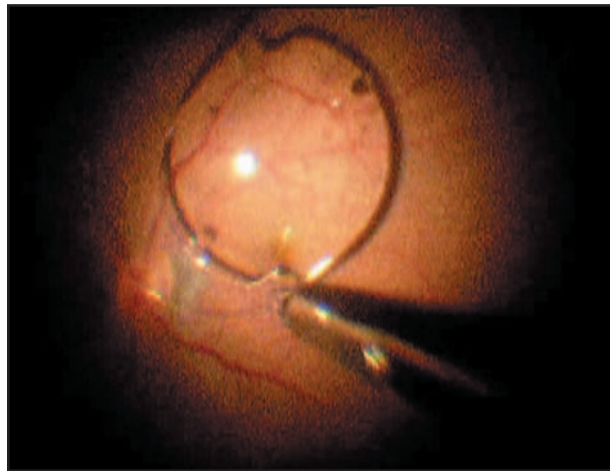
TABLE 19-2			
PROPERTIES OF PERFLUOROCARBON LIQUIDS			
Characteristic	*Perfluoro-N Octane*	*Perfluoro-Tributylamine*	*Perfluoro-Decaline*	*Perfluoro-Phenanthrene*
Chemical formula	C3F18	C12F27N	C10F18	C14F24
Molecular weight	438	671	462	624
Specific gravity	1.76	1.89	1.94	2.03
Refractive index	1.27	1.29	1.31	1.33
Surface tension (Dyne/cm 25°C)	14	16	16	16
Viscosity (Centistokes: 25°C)	0.8	2.6	2.7	8.03
Vapor pressure (mmHg at 37°C)	50	1.14	13.5	< 1

Their physical properties are outlined in Table 19-2.

THE SNARE

Grieshaber first manufactured a snare that was designed by Packo in the early 1990s. It consists of a 20-gauge tube and a handle with a movable spring-loaded finger slide for adjusting the size of a protruding polypropylene loop. The distal portion of the tube with the polypropylene loop is inserted through an anterior sclerotomy for engaging a dislocated haptic in the vitreous cavity. Once the looped haptic is pulled up against the anterior sclerotomy, the external portion of the polypropylene loop is cut free and guided through a 30-gauge needle for anchoring by the anterior sclerotomy (Figure 19-10).

TEMPORARY HAPTIC EXTERNALIZATION

Chan first described this method in 1992. Its main features involve temporary haptic externalization for suture placement after a pars plana vitrectomy, followed by re-internalization of the haptics tied with 9-0 or 10-0 polypropylene sutures for secured anchoring by the anterior sclerotomies. The details of this technique include the following:[5]

1. A three-port pars plana vitrectomy is performed for the removal of the anterior and central vitreous adjacent to the dislocated IOL, in order to prevent any vitreoretinal traction during the process of manipulating the IOL.

2. Two diametrically opposed limbal-based partial thickness triangular scleral flaps are prepared along the horizontal meridians at 3 and 9 o'clock. Anterior sclerotomies within the beds under the scleral flaps are made 1.0 to 1.5 mm from the limbus (Figure 19-11A). As an alternative to the scleral flaps, the anterior sclerotomies may be made within scleral grooves at 1.0 to 1.5 mm from the horizontal limbus.

Figure 19-10. The Grieshaber snare consists of a 20-gauge tube and handle with a movable spring-loaded finger slide for adjusting the amount of a protruding polypropylene suture loop. The suture loop is inserted posteriorly to engage a dislocated haptic. The external portion of the suture loop is then cut free and guided through a 30-gauge needle for anchoring at the sclera, after the engaged haptic is pulled up against the anterior sclerotomy.
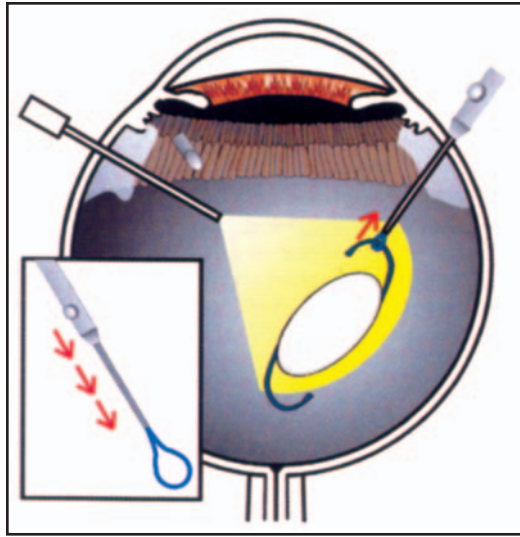
3. .A fiberoptic light pipe is inserted through one of the posterior sclerotomies, while a pair of fine non-angled positive action forceps (eg, Grieshaber 612.8) is inserted through the anterior sclerotomy of the opposing quadrant to engage one haptic of the dislocated IOL for temporary externalization (Figure 19-11B). A double-armed 9-0 (Ethicon TG 160-8 plus, Somerville, NJ) or 10-0 polypropylene suture (Ethicon CS 160-6, Somerville, NJ) is tied around the externalized haptic to make a secured knot. The same process is repeated for the other haptic after the surgeon switches the instruments to his opposite hands.

4. The externalized haptics with the tied sutures are re-internalized through the corresponding anterior sclerotomies with the same forceps (Figure 19-11C). The surgeon anchors the internalized haptics securely in the ciliary sulcus by taking scleral bites with the external suture needles on the lips of the anterior sclerotomies. By adjusting the tension of the opposing sutures while tying the polypropylene suture knots by the anterior sclerotomies, the optic is centered behind the pupil, and the haptics are anchored in the ciliary sulcus.

ONE-PIECE PLATE IOL

The surgeon may extend the tip of a lighted pick under the edge of the silicone plate implant to gently elevate it off the retinal surface. The elevated edge is then grasped with the intraocular forceps for the repositioning or removal of the implant. Alternatively, the plate implant may be brought anteriorly by hooking the lighted pick through one of its positioning holes, and then grasped with forceps at the anterior or mid-vitreous cavity (Figure 19-12).
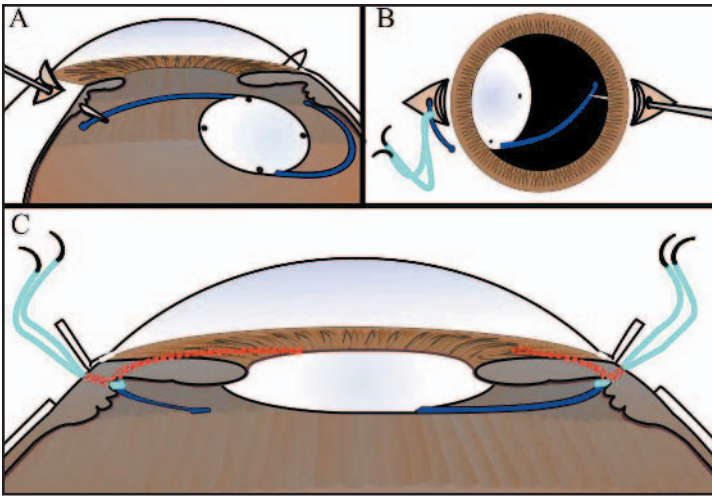
Figure 19-11. Temporary haptic externalization.
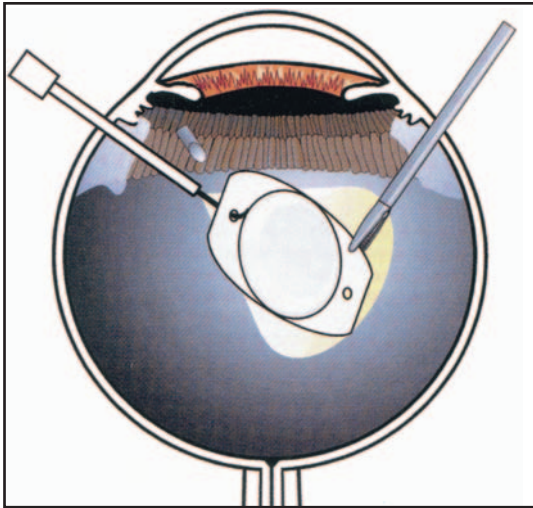
Figure 19-12. The slippery plate implant may be lifted on its edge or hooked through a positioning hole with a lighted pick, and then grasped with intraocular forceps for its repositioning or removal.

MISCELLANEOUS IOL PROBLEMS

A number of problems may be associated with the IOL itself. For instance, a defective IOL due to improper manufacturing may cause increased tendency for opacification of the IOL (Figure 19-13). The IOL may also decenter or tilt (Figure 19-14), and extrude (Figure 19-15).

ENDOPHTHALMITIS

Introduction

Despite numerous recent advances in its treatment, infectious endophthalmitis continues to be one of the most serious complications in ophthalmology. The infectious organism associated with endophthalmitis causes prominent ocular inflammation and

Figure 19-13. IOL opacification.
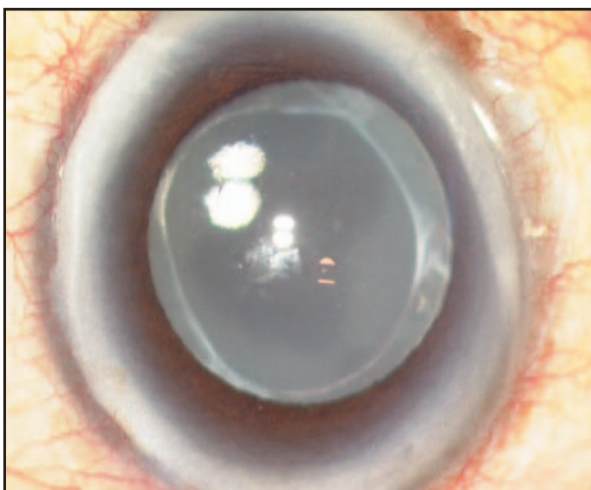
Figure 19-14. IOL decentration.
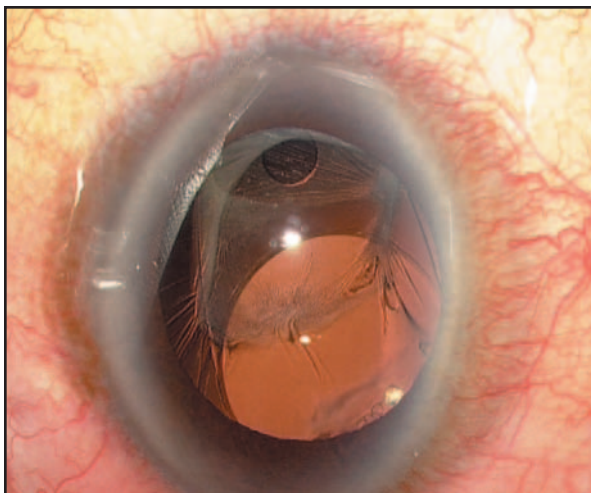
Figure 19-15. IOL extrusion.
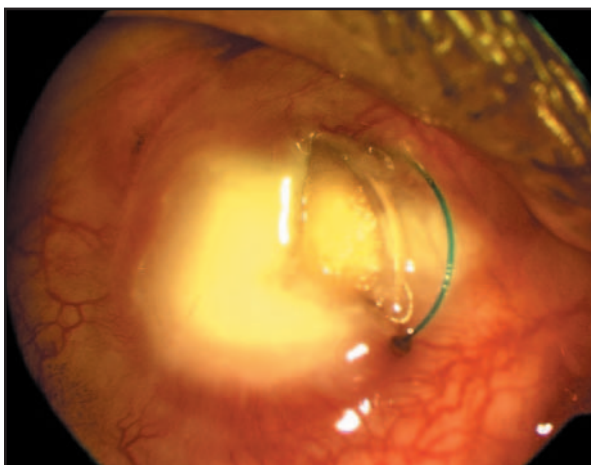
toxic reactions, leading to severe intraocular tissue damages and the consequential marked visual loss.

Techniques of Specimen Collection

Aqueous and vitreous specimens may be obtained in an office setting or at the time of a vitrectomy. In the former situation, careful administration of local anesthesia (topical, subconjunctival, peribulbar, or retrobulbar) and sterile prepping with 5% povidone-iodine solution are recommended. A small volume of aqueous specimen (0.1 to 0.2 mL) is then carefully withdrawn via a 27- or 30-gauge needle at the limbus into a tuberculin syringe. The vitreous specimen may be obtained with one of the following two methods:

1. Needle tap: A 22- to 27-gauge needle attached to a tuberculin syringe is inserted through the pars plana into the vitreous cavity for gentle aspiration of 0.1 to 0.3 ml of liquid vitreous. Excessive force must be avoided to prevent vitreoretinal traction. A "dry tap" requires the conversion to a mechanized biopsy.

2. Mechanized vitreous biopsy: A one-, two-, or three-port pars plana vitrectomy with a mechanized 20-gauge vitrectomy probe is employed for the biopsy. A small volume of undiluted specimen (up to 0.3 mL) from the anterior vitreous is collected into a sterile syringe connected to the aspiration line of the vitrectomy probe through gentle manual suction by a surgical assistant during the vitrectomy.

Diluted specimens collected into a larger syringe or into a vitrectomy cassette may also be concentrated either with the suction filtered technique or the centrifuged method (Figure 19-16A). The former involves passing the diluted specimens in an upper sterile chamber through a membrane filter with 0.45-µm pores into a lower chamber connected to suction. With the aid of sterile forceps and scissors or knives, the membrane filter containing the concentrated specimens is then cut into small pieces for direct inoculation on solid and into liquid media for cultures (Figure 19-16B). Concentrated specimens scraped off the surface of the membrane filter are also applied on slides for preparation of various stains. The alternative centrifuged method requires the transfer of the diluted specimens into a sterile centrifuge tube for high-speed centrifuge. The sediments from the centrifuged tube are then processed for microbiological stains and cultures (Figure 19-16C).

Treatment of Endophthalmitis

The two fundamental therapeutic modalities for treating infectious endophthalmitis in the modern world comprise of antimicrobial therapy and vitrectomy (Figure 19-17). When appropriate, they may be supplemented with anti-inflammatory therapy for reducing damages induced by the infection. Applying effective strategies for antimicrobial therapy constitutes the most critical aspect of the management of endophthalmitis. The intravitreal dosage of drugs is shown in Table 19-3.

Figure 19-16. Methods of collecting specimens in endophthalmitis. A) Undiluted aqueous and vitreous specimens may be directly inoculated onto culture media and used for smear preparation. B) Diluted vitreous specimen collected into a syringe or a cassette is either first concentrated by vacuuming the diluted fluid in a sterile upper chamber through a 0.45-µm membrane filter into a lower sterile chamber (suction filter method). C) Concentrated in a sterile centrifuge tube after performing high-speed centrifuge (centrifuge method). Small cut segments of the membrane filter with the concentrated specimens or the sediments from the centrifuged tube are inoculated into culture media and applied on slides for smear preparation.
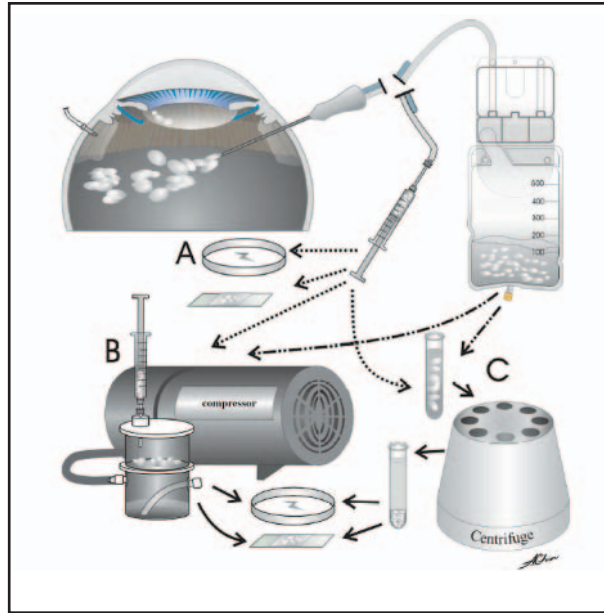
Figure 19-17. Anterior chamber washout before vitrectomy. The technique of eliminating cloudy fibrin deposits, membranes, and hyphema from the anterior chamber is illustrated. A microsurgical hook or pick inserted at the limbus is used to scrape off the cloudy material from the IOL and iris surface before removing them with a vitrectomy probe from the anterior chamber. A separate probe also inserted at the limbus for anterior chamber infusion is often necessary to prevent chamber collapse. The posterior infusion fluid is not turned on until adequate media clarity is achieved to ascertain the proper location of the tip of the posterior infusion cannula.
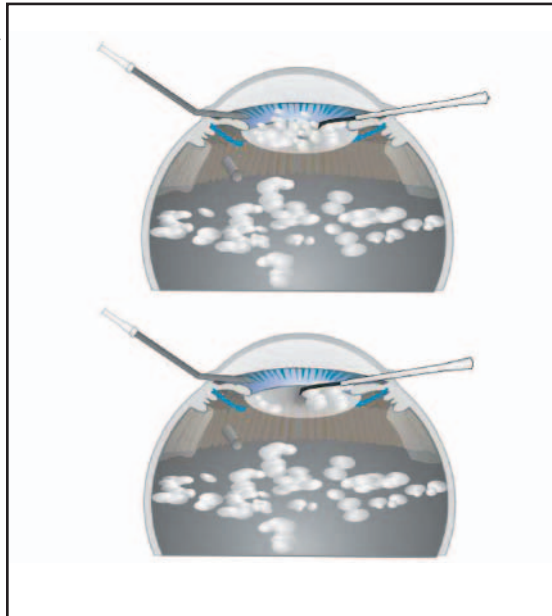
TABLE 19-3
PROTOCOL FOR INTRAVITREAL ANTIBIOTIC PREPARATION

Vancomycin Hydrochloride: 1.0 mg in 0.1 mL

1. Add 10.0 mL of diluent to 500.0 mg powder in vial, resulting in 50.0 mg/mL concentration.
2. Insert 2.0 mL (100.0 mg) or reconstituted drug into a 10.0-mL sterile empty vial, and add 8.0 mL of diluent, resulting in a final solution of **10 mg/mL.***

Ceftazidime Hydrochloride: 2.25 mg in 0.1 mL

1. Add 10.0 mL of diluent to 500.0 mg powder in vial to result in a 50.0 mg/mL-concentration.
2. Insert 1.0 mL (50.0 mg) of reconstituted drug into a 10.0-mL sterile empty vial and mix with 1.2 mL of diluent, for a final solution of **22.5 mg/mL.***

Cefazolin sodium: 2.25 mg in 0.1 mL

1. Add 2.0 mL of diluent to 500.0 mg powder in vial to result in concentration of 225.0 mg/mL.
2. Insert 1.0 mL (22.5 mg) of reconstituted drug into a 10.0 mL sterile empty vial and mix with additional 9.0 mL of diluent, for a final solution of **22.5 mg/mL***

Amikacin sulfate: 0.2 to 0.4 mg in 0.1 mL

1. Original vial contains 500.0 mg in 2.0 mL (250.0 mg/mL) solution.
2. Add 0.8 mL (200.0 mg) solution into a 10.0-mL sterile empty vial and mix with additional 9.2 mL of diluent, to achieve a concentration of 200.0 mg in 10.0 mL (20.0 mg/mL).
3. Withdraw 0.2 mL (4.0 mg) and mix with 0.8 mL of diluent in a second sterile empty vial to achieve final solution of **0.4 mg/mL***; or withdraw 0.1 mL (2.0 mg) and mix with 0.9 mL of diluent to achieve a final solution of **0.2 mg/mL.***

Gentamicin sulfate: 0.1 to 0.2 mg in 0.1 mL

1. Original vial contains 80.0 mg in 2.0 mL (40.0 mg/mL) solution.
2. Add 0.1 mL (4. mg) solution into a 10-mL sterile empty vial, and mix with 3.9 mL of diluent to achieve a solution of 4.0 mg in 4.0 mL or **1 mg/mL***; or add 0.2 mL (8.0 mg) solution into a 10.0-mL sterile empty vial, and mix with 3.9 mL of diluent to achieve a solution of 8.0 mg in 4.0 mL or **2 mg/mL.***

Clindamycin phosphate: 1.0 mg in 0.1 mL

1. Original vial contains a 600.0 mg in 4.0 mL solution (15.0 mg/1.0 mL)
2. Add 0.2 mL (30.0 mg) solution into a 10.0-mL sterile empty vial and mix with 2.8 mL of diluent to achieve a solution of 30.0 mg in 3.0 mL or **10.0 mg/mL.***

TABLE 19-3 (CONTINUED)
PROTOCOL FOR INTRAVITREAL ANTIBIOTIC PREPARATION

Chloramphenicol sodium succinate: 2.0 mg in 0.1 mL

1. Original vial contains 1000.0 mg powder.
2. Add 10.0 mL of diluent to reconstitute 1000.0 mg powder for a concentration of 100 mg/mL.
3. Withdraw 1.0 mL of reconstituted drug (100.0 mg) and mix with 4.0 mL of diluent in a 10.0-mL sterile empty vial to achieve a final solution of **20 mg/mL.***

Amphotericin B: 0.005 mg in 0.1 mL

1. Original vial contains 50.0-mg powder.
2. Add 10.0 mL of diluent to reconstitute the 50.0 mg powder into a concentration of 5.0 mg/mL.
3. Add 0.1 mL (0.5 mg) of reconstituted solution into a 10.0-mL sterile empty vial, and mix with 9.9 mL of diluent to achieve a final solution of **0.05 mg/mL.***

Miconazole: 0.025 mg in 0.1 mL

1. Original ampule contains 20.0 mL of 10.0 mg/mL solution.
2. Remove glass particles and impurities by passing solution into a 5.0-µm filter needle.
3. Add 0.25 mL (2.5 mg) of filtered solution into a 10.0-mL sterile empty vial, and mix with 9.75 mL of diluent to achieve a final solution of 2.5 mg in 10.0 mL or **0.25 mg/mL.***

Recommendation: For optimal results, the drug dilution and preparation should be performed by trained personnel in the controlled environment of a hospital pharmacy. Nonbacteriostatic sterile water is used as the diluent for Vancomycin and Amphotericin B. For all others, nonbacteriostatic sterile water or 0.9 % sodium chloride solution is used as the diluent.

*For all medications, the volume from the final solution for intravitreal injection is 0.1 mL drawn into a tuberculin syringe and delivered with a 27-or 30-gauge needle at the pars plana.

KEY POINTS

✔ A poorly constructed wound can be a source of astigmatism, filtration, irritation, hemorrhage, and corneal trauma despite a satisfactory wound closure.

✔ The handpiece temperature should be monitored at all times, and not allowed to become too warm.

✔ In the event of postoperative corneal decompensation, anti-inflammatory and cycloplegic agents should be applied to counteract the associated inflammation and achieve cycloplegia respectively. Hyperosmotics may also be useful for decongesting microcystic corneal edema. However, In the event of irreversible corneal endothelial damages, penetrating keratoplasty may be undertaken.

✔ A single vitrectomy probe with a coaxial cannula should generally be avoided in favor of a bimanual vitrectomy technique using separate infusion cannula and vitrectomy probe.

✔ A true expulsive suprachoroidal hemorrhage through the 1.0-mm incision associated with bimanual phaco is rare.

✔ Due to their unique physical properties, perfluorocarbon liquids are well-suited for floating dropped lens fragments and dislocated IOL, in order to insulate the underlying retina from damages.

✔ The two fundamental therapeutic modalities for treating infectious endophthalmitis in the modern world comprise of antimicrobial therapy and vitrectomy.

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Managing Dislocated Lens Fragments

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Introduction

Dislocation of lens fragments into the vitreous cavity occurs in a small percentage of cases of cataract extraction with conventional or bimanual phacoemulsification but continues to be encountered on an intermittent basis with potentially serious consequences in the modern setting.[1] Small lens fragments consisting of mostly cortical material may gradually resolve with conservative medical management alone. However, large lens fragments with a sizeable nuclear component do not resolve easily, and may elicit a phacoantigenic response from the host.[2-5] The released lens proteins may not only induce persistent intraocular inflammation, but also block the trabecular meshwork, resulting in phacolytic (or lens particle) glaucoma.[6,7] In time, other serious anatomical complications with poor visual consequences may develop in the absence of appropriate management of the lens fragments (eg, peripheral anterior synechiae of the iris, pupillary or vitreous membranes, cystoid macular edema, retinal breaks or detachment, and phacoanaphylaxis, etc).[1,2-5] Therefore, most retained and dislocated lens fragments with a substantial nuclear component require surgical removal.[1,5,8-10] Earlier clinical studies advocated the immediate removal of dislocated lens fragments.[11,12] In Blodi's report, those eyes undergoing surgery within 7 days had a lower incidence of long-term glaucoma.[11] However, subsequent reports by Gilliland et al and Kim et al demonstrated no difference in visual outcome and glaucoma development between those eyes undergoing lens fragment removal within 7 days and those after 30 days following the dislocation.[13,14] Despite such conclusions, expeditious surgical management of retained lens fragments within a limited time frame is the current standard of care that allows rapid visual rehabilitation and prevention of serious complications mentioned above.[1,11,12,14]

The Responsibility of the Cataract Surgeon

In the event of a rupture of the posterior lens capsule or zonular dehiscence leading to posterior migration of lens fragments, the cataract surgeon must avoid any uncontrolled and forceful surgical maneuvers in the vitreous cavity in an attempt to

retrieve the sinking lens fragments. Any retrieval technique that does not provide for the appropriate management of the vitreous first creates the potential of immediate or subsequent retinal complications. Thus, the cataract surgeon must refrain from the temptation of passing a sharp instrument or lens loop into the mid- or posterior vitreous cavity to engage the sinking lens fragments, or passing forceful irrigation fluid into the vitreous cavity to float the lens fragments.[1,15,16] Such maneuvers usually generate vitreoretinal traction resulting in retinal breaks and detachment. Instead, he should finish the clean up of the remaining cortical debris within the capsular bag and its vicinity, and then also perform a limited anterior vitrectomy in the event of vitreous prolapse into the anterior chamber and at the cataract wound.[1,5,11-14,16,17] An intraocular lens (IOL) may also be implanted in the absence of significant anterior segment complications (eg, corneal decompensation, iridodialysis, hyphema, anterior chamber angle injury, etc).[1,13,14,16,17] An anterior chamber lens (ACIOL) can usually be safely implanted, but it may induce postoperative corneal pathology, chronic cystoid macular edema, and even glaucoma under certain circumstances.[18] Frequently, a posterior chamber implant (PCIOL) can be safely inserted at the ciliary sulcus or even into the capsular bag with the aid of a capsular tension ring for cases with limited capsular or zonular damages.[18-20] The surgeon should avoid the implantation of an IOL made of silicone material due to its potential of interfering with subsequent vitreoretinal surgery, particularly in the event of fluid-gas exchange or long term silicone oil tamponade.[21] The moisture condensation on the posterior surface of a silicone IOL due to its hydrophobic properties leads to a loss of visibility during fluid-gas exchange,[21] and silicone oil may erode into the silicone IOL with long term silicone oil tamponade subsequently. In addition, the surgeon should avoid the implantation of an IOL altogether in the presence of a rock-hard dislocated lens fragment, which may need to be removed intact through a limbal incision subsequently (see sections on cryoextraction and perfluorocarbon liquid).[1,17] Finally, a watertight wound closure is important in anticipation of postoperative intraocular pressure fluctuation and subsequent posterior surgical maneuvers for the lens fragments.[1,17] With the completion of the anterior segment maneuvers described above, the cataract surgeon is now ready to consider various options for managing the posteriorly dislocated lens fragments. In case of familiarity with vitreoretinal techniques, he may convert over to a posterior segment setup and utilize one of the methods described in the following sections for removing the lens fragments. Otherwise, a prompt referral of the patient to a vitreoretinal surgeon is recommended. At the same time, medical management with topical anti-inflammatory, antibiotic, as well as cycloplegic medications should be instituted. If necessary, hypotensive agents are also utilized.

Techniques for Removing Posteriorly Dislocated Lens Fragments

FAVIT

This innovative method was introduced by Agarwal et al.[22] Its major advantage is that it allows the cataract surgeon familiar with vitreoretinal techniques to quickly convert over to posterior segment surgery with a limited amount of additional setup of instrumentation for removing the lens fragments (Figures 20-1 and 20-2). One can per-
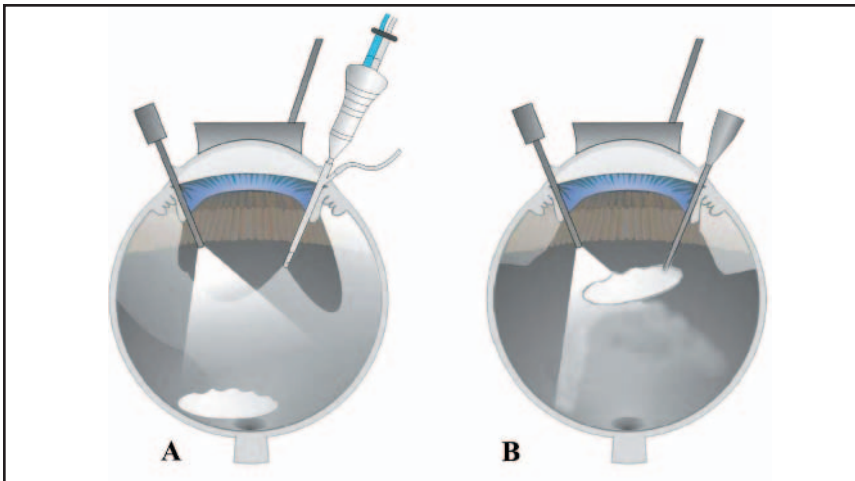
Figure 20-1. FAVIT technique. A) After completing the anterior lenticular cortical clean up and anterior vitrectomy, a two-port posterior vitrectomy is performed. The vitrectomy probe and endoilluminator are inserted through separate clear corneal or scleral tunnel incisions created at the start of cataract surgery, and a vitrectomy contact lens is applied firmly on the cornea by surgical assistant to allow adequate viewing of the posterior fundus for the surgeon. B) The vitrectomy probe is replaced with a phacoemulsification probe after completion of a posterior vitrectomy to engage the posteriorly dislocated nuclear lens fragment. Suction-only mode is activated to elevate the lens fragment, and the phaco tip is then embedded into the elevated lens fragment with a small burst of ultrasonic energy. One can alternatively fix an infusion and thus do a three-port FAVIT.

form a two-port FAVIT (FA-fallen/VIT-vitreous)—a technique to remove fragments fallen into the vitreous. First, a vitrectomy probe with an infusion sleeve is passed through the same clear corneal or scleral-tunnel cataract incision into the anterior chamber and the anterior vitreous cavity for removal of anterior lenticular cortical material and an anterior vitrectomy respectively. The peristaltic pump of the same phacoemulsification machine is used to drive the vitrectomy probe, and the microscope light may be used for illumination for this part of the procedure. A bimanual (two-port) technique is then required for the rest of the procedure. A fiberoptic endoilluminator is passed through a separate limbal incision and a vitrectomy contact lens is applied on the cornea to provide for appropriate visualization of the posterior vitreous cavity. The surgical assistant should apply the right amount of tension with the vitrectomy contact lens on the cornea to allow an adequate view for the surgeon, on account of the temporary disturbance of the normal corneal curvature induced by the two instruments passing simultaneously through separate clear corneal incisions. Next, the surgeon performs a thorough posterior vitrectomy including the elimination of the vitreous fibers surrounding the retained lens fragments, in order to prevent subsequent vitreoretinal traction (see Figure 20-1A). After the completion of the posterior vitrectomy, the surgeon replaces the vitrectomy probe with a phacoemulsification probe through the same incision (see Figure 20-1B). With the ultrasonic power at 50% and the aspiration intensity at moderate setting, the surgeon activates the suction-only mode to elevate the lens fragment from the retinal surface. The surgeon quickly applies a small burst of ultrasonic energy to embed the probe tip into the elevated lens fragment, and then lifts the entire fragment anteriorly. The endoilluminator is also used at the same time to guide
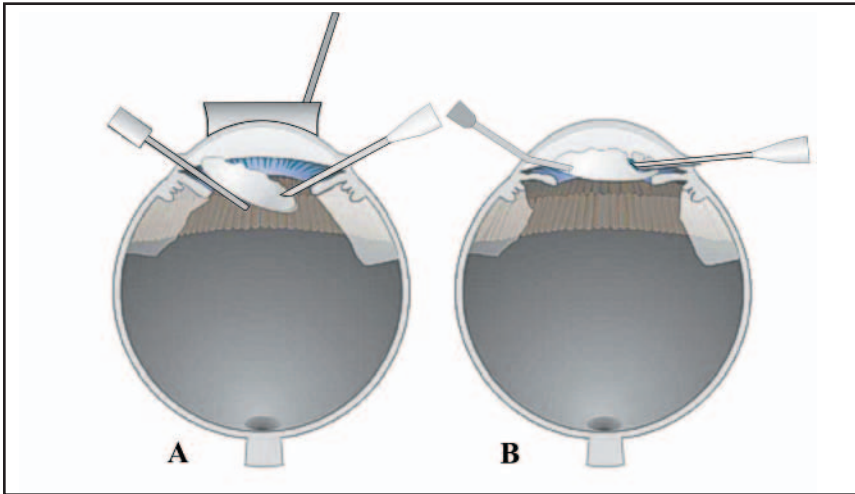
Figure 20-2. FAVIT technique. A) The lens fragment is lifted anteriorly with the phaco probe while the endoilluminator is used at the same time to guide the lens fragment above the iris and into the anterior chamber. B) Emulsification is performed on the lens fragment in the anterior chamber, while chopping and pulsing are avoided to prevent dropping smaller lens fragments back into the vitreous cavity.

the lens fragment above the iris plane and into the anterior chamber (see Figure 20-2A). Finally, the lens fragment is gradually removed with continuous phacoemulsification in the anterior chamber without pulsing or chopping to avoid dropping small fragments back into the vitreous cavity (see Figure 20-2B). The endoilluminator can be exchanged with a cannula for infusion into the anterior chamber and prevention of chamber collapse. An excessively large or hard nuclear fragment may be removed through an enlarged limbal incision.[22]

Alternatively, one can do a three-port FAVIT. First, an infusion cannula is fixated through the first port. This is fixed 3.0 to 3.5 mm from the limbus. An endoilluminator is then inserted through a second port, and a vitrectomy probe without an infusion sleeve is inserted through a third port. These incisions are also 3.0 to 3.5 mm from the limbus in the pars plana. A phacofragmentation tip (phaco probe without a sleeve as in bimanual phaco) is exchanged for the vitrectomy probe subsequently. One may use an air pump to drive the irrigation through the infusion cannula so that no collapse of the eye occurs while removing the nucleus, and a precise intraocular pressure level is maintained at all times. Three-port FAVIT is safer, although it may be difficult for a surgeon who is inexperienced in fixing an infusion cannula and is hesitant to enter through the pars plana. In this situation, one can do two-port FAVIT.

Vitrectomy and Phacofragmentation Techniques

The standard three-port pars plana vitrectomy approach is the most frequently employed method for the removal of posteriorly dislocated lens fragments in a safe and effective manner.[1,5,8-14,16,17] The first step involves the insertion of a posterior infusion cannula at the inferior temporal pars plana. In the event of a localized concomitant choroidal detachment in the inferior temporal quadrant, an alternative quadrant (eg, inferior nasal) may be chosen for the infusion cannula. Frequently, cloudy media resulting from dense lens fragments or in some cases hyphema and fibrin deposits sur-

rounding the implant, may prevent an adequate view of the tip of the pars plana infusion cannula. In that situation, the surgeon may ascertain the proper intravitreal location of the infusion cannula tip by inserting a microvitreoretinal blade through one of the superior pars plana sclerotomies to rub against the cannula tip, before turning on the infusion fluid. Utilizing a longer infusion cannula (eg, 4.0- or 6.0-mm) is also advantageous in avoiding inadvertent subretinal or choroidal infusion.

Managing the Anterior Chamber Opacities and Herniated Vitreous

Cloudy lens material, hemorrhagic infiltrates, and fibrin deposits in the anterior chamber must be first eliminated before the performance of a posterior vitrectomy and phacofragmentation.[1,5,16,17] For the anterior chamber washout, a separate infusion cannula (eg, a 20- or 22-gauge angled rigid or flexible soft cannula) may be inserted at the limbus for anterior chamber infusion and prevention of chamber collapse. Microsurgical picks, hooks, bent needle tips, or forceps may be used to remove opaque membranes from the anterior and posterior surfaces of the implant.[1] Vitreous herniated into the anterior chamber and vitreous strands attached to the iris or the limbal surgical wound must be excised with a vitrectomy probe in order to reduce the chance of postoperative cystoid macular edema and other types of vitreoretinal complications. To further enhance anterior media clarity, intracameral viscoelastic substances can be injected to coat the corneal endothelium for reducing striate keratopathy, displace blood from the visual axis, or to achieve hemostasis associated with a persistent hyphema.[1,5] Unwanted residual lenticular capsular remnants may also be eliminated with the vitrectomy probe. Pupillary dilation may be maintained throughout surgery with the administration of topical and subconjunctival mydriatics or intracameral epinephrine.[1,5] If necessary, temporary iris retractors can be inserted via multiple limbal incisions to maintain pupillary dilation during surgery.

Posterior Vitrectomy and Phacofragmentation

After completing the core vitrectomy, it is important for the surgeon to carefully remove all of the vitreous fibers surrounding the posterior lens fragments before proceeding with phacofragmentation, in order to prevent the occlusion of the phaco tip by formed vitreous elements during the phacofragmentation process and also prevent traction on the retina.[1,5,8-14,16,17] In fact, the surgeon should remove as much of the vitreous as he can safely achieve before performing phacoemulsification, in order to avoid unwanted vitreoretinal traction.[16] Perfluorocarbon liquid may be infused into the eye to serve as a cushion for protecting the underlying retina from the bouncing lens fragments during the process of lens emulsification (Figure 20-3). Only a limited amount of perfluorocarbon liquid should be injected, since excessive perfluorocarbon liquid with a convex meniscus tends to displace the lens fragments away from the central visual axis and toward the peripheral fundus and the vitreous base.[1] In case of peripheral displacement of the lens fragments, a layer of viscoelastic may be applied on top of the perfluorocarbon liquid to neutralize its convex meniscus, resulting in recentering of the lens fragments toward the visual axis, a simple maneuver described by Elizalde (Figure 20-4).[23]

At the start of the pars plana phacoemulsification process, each lens fragment is first engaged at the phaco tip with the machine set at the aspiration mode and then brought to the mid vitreous cavity for emulsification.[16,17,24] During the emulsification of the lens fragments, the ultrasonic power is kept at a low or moderate setting in order to

Figure 20-3. Insulating the retina with perfluorocarbon. A small amount of perfluorocarbon liquid may be infused on the retinal surface to protect it from dropped lens fragments during the process of lens emulsification. Excessive perfluorocarbon is avoided to decrease the propensity of peripheral displacement of the floating lens fragments toward the vitreous base due to the convex meniscus of the perfluorocarbon. During phacoemulsification, the ultrasonic power of the phaco probe is kept at a low to medium setting to reduce the tendency of blowing the lens fragments from the phaco tip toward the retina.
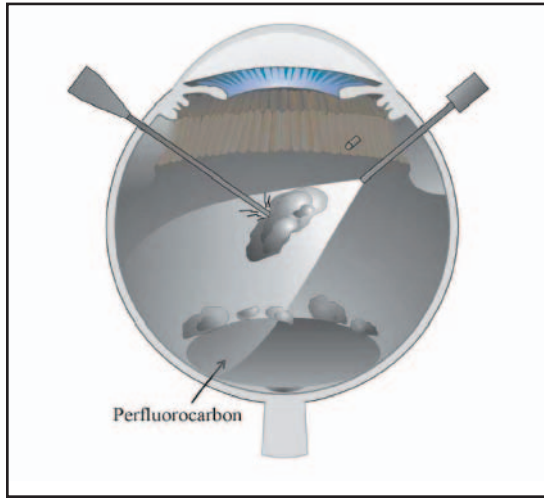
Figure 20-4. Recentering lens fragments on top of perfluorocarbon with viscoelastic. A layer of viscoelastic is applied on top of the perfluorocarbon liquid to neutralize its convex surface meniscus for recentering a peripherally displaced lens fragment toward the visual axis (courtesy of J. Elizalde; modified and published with permission).
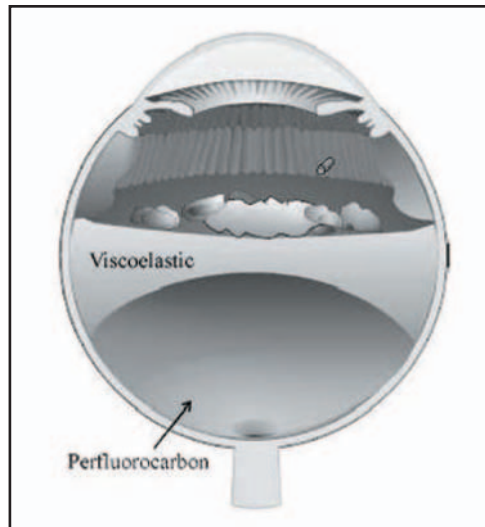
decrease the tendency of blowing the fragments from the phaco tip and repeatedly dropping them on the retina (see Figure 20-3).[16,17] The more advanced phacofragmentation units with sophisticated linear (proportional) ultrasonic and aspiration controls tend to reduce the erratic movements of the lens fragments at the phaco tip during the fragmentation process. The surgeon may also stabilize a large lens fragment in the mid vitreous cavity by using his other hand to spear the fragment with an endoilluminator with a hook or pick at its tip for emulsification (Figure 20-5).[1,12] As an alternative, he may utilize the bimanual "crush" or "chopstick" technique, which involves the use of his other hand to methodically crush each lens fragment with the tip of an endoilluminator against the phaco tip before aspirating it from the eye through the phaco tip (Figure 20-6).[1,16] After emulsifying and removing the bulk of the lens fragments, the surgeon eliminates any remaining vitreous with the vitrectomy probe. He also carefully searches for and removes residual small lens fragments embedded at the
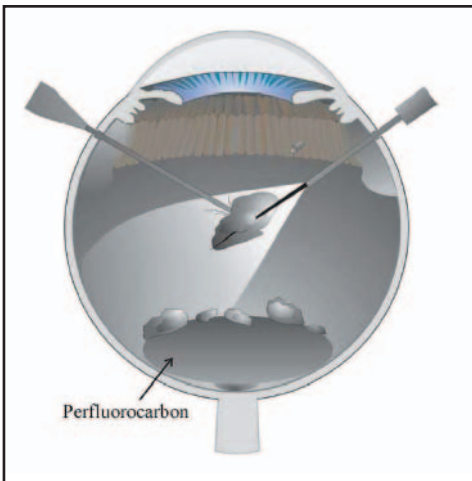
Figure 20-5. Stabilizing the lens fragment with a sharp instrument for emulsification. The surgeon may stabilize a lens fragment in the mid vitreous cavity by using his other hand to spear the fragment with an endoilluminator probe with a hook or pick at its tip for emulsification.
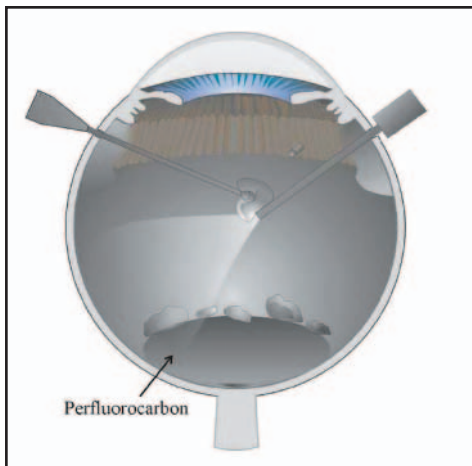
Figure 20-6. Crush method. The surgeon may also use his other hand to methodically crush each lens fragment with the endoilluminator tip against the phaco tip, before aspirating it from the eye through the phaco tip.

vitreous base, as well as inspects the peripheral fundus with indirect ophthalmoscopy.[1] Retinal breaks and peripheral retinal detachment discovered during the inspection are then promptly treated with the appropriate modality (eg, laser, cryotherapy, scleral buckling, fluid-air, or gas exchange, etc). Residual perfluorocarbon liquid is removed before closure. The postoperative therapy includes the application of topical steroidal or nonsteroidal anti-inflammatory medications, antibiotics, and cycloplegics.

Previous studies utilizing the phacoemulsification methods similar to the above description reported favorable visual outcome (ie, a final visual acuity of 20/40 or better with 52% to 87% of treated eyes.) [12,13,14,25]

Endoscopic Technique

The endoscopic approach is best suited for removing dislocated lens fragments from eyes with an opacified cornea, a miotic or occluded pupil, persistent hyphema, or a cloudy IOL, etc.[26-33] It also provides a clear and unimpeded view of lens fragments trapped at the vitreous base. It allows the surgeon to scrutinize peripheral fundus

Figure 20-7. Principle of an ophthalmic endoscopic system. A) The image acquired at the tip of an endoscopic handpiece is transmitted through an optical pathway (GRIN solid-lens or a fiberoptic bundle). The image magnification and coupling to the CCD camera system take place at the proximal portion of the handpiece and the CCD camera unit. B) GRIN endoscope: The image acquired at the probe is transmitted along the length of a cylindrical pathway of the solid lens with a gradient index (index of refraction varies with the distance from the

central axis) in a sinusoidal mode to a CCD camera unit. C) Fiberoptic endoscope: The image acquired with a GRIN lens at the distal end of a handpiece is transferred through a bundle of microfibers (via total internal reflection within each fiber) to a CCD camera unit
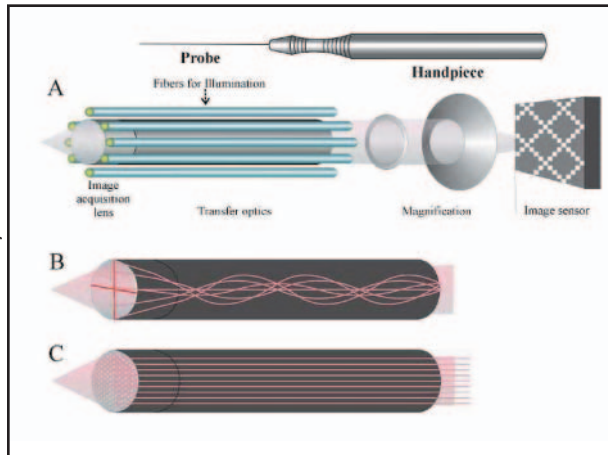
details and appreciate the precise anatomical relationship of various retro-irideal structures (eg, irido-capsular interface, haptic-ciliary junction, vitreous base, etc.) The magnified and undistorted images of the peripheral intraocular structures provided by the endoscope cannot be obtained through other methods. The endoscopic system includes an endoscopic hand piece with a probe, connected to a fiberoptic light source, a charged coupled device (CCD) video camera system and recorder, coupled with a high-resolution color video monitor.[26-33] For optimal viewing, a bright light source such as Xenon is preferred, although halogen lights can be used.[26-33] The two types of ophthalmic endoscopic systems that are commercially available include the gradient Index (GRIN) solid-rod endoscopes first developed by Eguchi,[26,27] and the fiberoptic endoscopes subsequently developed by Uram and Fisher.[27-31] Both types of devices share the principle of image acquisition and optics transfer through the distal probe , and then image magnification and coupling in the handpiece or the remote CCD camera unit (Figure 20-7A).[27] The GRIN solid rod endoscope employs a single long, slender, glass lens for optics transfer. The image acquired at the probe is transmitted along the length of a cylindrical pathway of the solid lens with a gradient index in a sinusoidal mode to a CCD camera unit (Figure 20-7B).[26,27] The index of refraction of the lens varies with the distance from the central axis. In the case of a fiberoptic endoscope, the image acquired with a GRIN lens at the distal end of a handpiece is transferred through a bundle of microfibers (via total internal reflection within each fiber) to a CCD camera unit (Figure 20-7C).[27-32] The fiberoptic endoscope allows for a lighter handpiece. However, its image resolution is limited by the pixel density of the CCD camera as well as the density of the microfibers, and its depth of field is less than the GRIN single-rod endoscope.[27] Besides vitrectomy and phacoemulsification, other surgical maneuvers including laser photocoagulation can be performed in conjunction with the endoscopic system.[27-29] Laser componentry can be built into the endoscopic system.[27-29] For instance, the endoscopic hand piece may contain an optical path for viewing, besides separate fibers for endoillumination and photocoagulation. Thus a single endoscopic handpiece can be constructed with the capability of performing

multiple tasks simultaneously: viewing, endoillumination, and photocoagulation.[27-29] Even a channel for infusion can also be incorporated into the endoscope.[27] However, the multiple functions increase the bulk and weight of the handpiece. One commercially available fiberoptic endoscopic system offers a 20-gauge endoscopic handpiece with a 3000-pixel fiberoptic bundle allowing a 70-degree field of view and a depth of focus from 0.5 to 7.0 mm, or an 18-gauge handpiece with a 10 000-pixel fiberoptic bundle allowing a 110-degree field of view and a depth of focus from 1.0 to 20.0 mm.[28,29] Drawbacks of the endoscopic method include the lack of a stereoscopic or three-dimensional view, and an initially steep learning curve for the surgeon.[1,33] Excellent surgical results can be achieved with this technique. In their study published in 1998, Boscher and associates reported consistently successful outcome in the use of the endoscopic method for managing a consecutive series of 30 eyes with dislocated lens fragments or IOLs.[33]

Further development in ophthalmic endoscopic systems holds the promise of providing unparalleled microscopic images of intraocular structures (even on a cellular level) that are not possible through conventional surgical instrumentation (eg, viewing of sensory retinal, retinal pigment epithelial, and choroidal components in the subretinal space during vitreoretinal surgery).[27] The construction of stereoscopic endoscopes is also technically feasible.

Removal by Cryoextraction

This method is reserved for removing an entire dislocated lens or a large and particularly hard lens nucleus that would otherwise require application of excessive intraocular ultrasonic energy and time-consuming manipulation with the conventional phacoemulsification approach.[24,34,35] When properly performed, it allows rapid delivery of a hard lens nucleus from the retinal surface to the anterior chamber and then out of the eye through a limbal incision, in the absence of an intraocular implant obstructing the passage of the lens nucleus. It is critical that the surgeon first performs a meticulous vitrectomy to eliminate all vitreolenticular and vitreoretinal traction. A fluid-air exchange is also required immediately before the insertion of the endocryoprobe to engage the dislocated lens nucleus.[1,24] The surgeon's failure to eliminate sufficient vitreous fluid from the eye before activation of the endocryoprobe may result in spreading of the freezing ice-ball throughout the residual vitreous fluid and the adjacent retina. Thus this seemingly simple surgical approach is associated with multiple potential hazardous complications. While delivering the hard lens nucleus anteriorly, the surgeon must apply a continuous freeze of sufficient intensity on the lens fragment to prevent its fall from the probe, but at the same time, avoid an excessive freeze that may damage the surrounding vital intraocular structures, including the retina, iris, and cornea, etc. This delicate balance and the intrinsically unpredictable behavior of the expanding ice-ball present a difficult challenge to the surgeon, particularly in the presence of poor visibility through a hazy cornea frequently encountered in such cases made even worse by the intraocular air.[1,35] Due to its potential of inducing retinal necrosis, vitreous hemorrhage, and even severe choroidal and expulsive hemorrhage, it is the author's opinion that posterior cryoextraction should be limited to select cases of large dislocated hard lens nuclei and performed with extreme caution by an experienced surgeon.

Manipulation with Perfluorocarbon Liquid

High density, inert behavior, and low viscosity are unique properties of perfluorocarbon liquid (see Chapter 19) that allow its use as an elegant surgical tool for removing dislocated lens fragments with minimal instrumentation in a safe and consistent manner.[35-38] As described in the previous section, perfluorocarbon liquid is frequently used to insulate the retina from injury by dropped lens fragments during phacoemulsification.[1] Perfluorocarbon is particularly effective when the surgeon is faced with the adverse condition of poor visibility through a hazy cornea and a dislocated nucleus with a rock-hard consistency.[1,35] In that situation, he may use perfluorocarbon alone without phacoemulsification to deliver the lens fragment anteriorly for its extraction through a limbal wound. Employing conventional phacoemulsification techniques to retrieve a hard lens nucleus may be time consuming and hazardous, particularly in the presence of marked ocular inflammation and a cloudy media with poor visibility.[35] Historically, several methods of removing a dislocated hard nucleus were utilized in the past.[35,39,40] With the exception of cryoextraction, these methods have been largely abandoned due to their technical difficulties and associated potential complications. They include trapping the lens nucleus with two needles passed across the globe with the patient in a prone position and buoying the lens nucleus anteriorly with sodium hyaluronate.[35,39,40] The needle-trapping technique is inherently difficult to apply and is associated with many potential hazards.[35,39] Although sodium hyaluronate is well tolerated by the eye, its relatively low density in comparison to perfluorocarbon does not allow the buoying of the lens nucleus on a consistent basis.[35] In contrast to perfluorocarbon liquid, clear visibility is required for the precise placement of the sodium hyaluronate with a cannula under the dislocated nucleus in order for it to float the nucleus. To avoid the premature dilution and extrusion of the sodium hyaluronate from the globe, the infusion fluid must also be turned off temporarily during the placement of the sodium hyaluronate. Such a maneuver may lead to hypotony and miosis with potentially serious consequences during surgery.[35,40] For the above reasons, perfluorocarbon liquid is superior to sodium hyaluronate and is currently the agent of choice for floating a posteriorly dislocated lens fragment for removal.[35-38]

Shapiro and associates reported the removal of dislocated hard lens nuclei with perfluoro-n-octane in 1991 (Figure 20-8).[35] Their technique includes an initial vitrectomy to eliminate vitreoretinal traction after a thorough clean up of the anterior lenticular cortical and capsular remnants. The subsequent intraocular infusion of perfluoro-n-octane floats the hard lens nucleus anteriorly toward the vitreous base. The nuclear fragment is displaced peripherally due to the convex meniscus of the perfluorocarbon, and temporarily wedged at the vitreous base between the surface of the perfluorocarbon and the iris and ciliary processes. No attempt is made to directly expulse the dislocated lens fragment into the anterior chamber and out of the limbal wound with the perfluorocarbon liquid, due to potential mechanical injury of the corneal endothelium and the iris by the hard lens nucleus with such a maneuver. Instead, a soft-tipped cannula is inserted through a sclerotomy to recenter the lens nucleus behind the pupil (see Figure 20-8A). The lens nucleus is then gently floated further anteriorly with slow infusion of balanced salt solution on top of the perfluorocarbon, and carefully brought into the anterior chamber for delivery out of the eye with a lens loop through a limbal incision (see Figure 20-8B). In the absence of poor integrity of the cornea and the iris, a secondary IOL can be conveniently implanted through the same limbal incision before
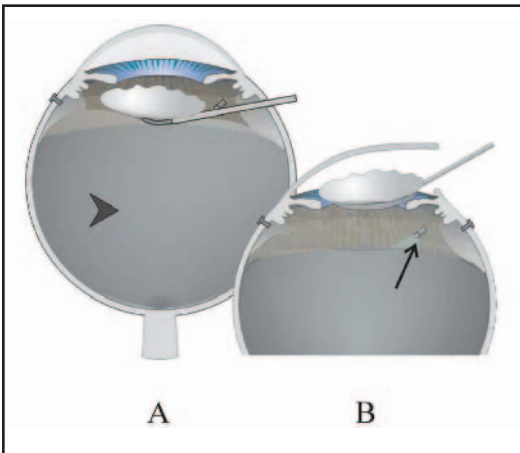
Figure 20-8. Removal of entire hard lens fragment with perfluorocarbon. After a thorough clean up of the anterior lenticular remnants and a posterior vitrectomy to eliminate vitreoretinal traction, perfluorocarbon liquid (arrow head) is infused via a pars plana sclerotomy into the vitreous cavity to float the hard lens fragment, until it is lodged at the vitreous base between the surface of the perfluorocarbon and the iris as well as the ciliary processes. A) Soft-tipped cannula is inserted through a sclerotomy to recenter the lens fragment behind the pupil. B) Slow infusion of BSS (arrow) on top of the perfluorocarbon allows the gentle floating of the lens fragment further anteriorly. A lens loop is then used to carefully bring the lens fragment into the anterior chamber for delivery out of the eye through a limbal incision (modified and reprinted from *Am J Ophthalmol*, Vol 112, Shapiro et al, Management of the dislocated crystalline lens with a perfluorocarbon liquid, Pages 401-405, Figures 3 and 4, 1991, with permission from Elsevier Science.)

closure. Due to its low viscosity and tendency for posterior pooling, the surgeon can easily remove the perfluorocarbon liquid with a small aspiration cannula after the closure of the limbal wound at the end of surgery. Besides Shapiro's report, there have been a series of reports by multiple surgeons in the effective use of a variety of perfluorocarbon liquids to remove dislocated intraocular lens fragments. Similar to cryoextraction, this method of removing lens fragments is not appropriate for an eye with an IOL, unless the IOL is explanted first or at the time of the lens fragment removal.

The special properties of perfluorocarbon liquid make it especially suitable as an intraocular tool for atraumatic tissue manipulation when the surgeon encounters the situation of posteriorly dislocated lens fragments in conjunction with retinal breaks and a retinal detachment.[1,41] In the presence of a giant retinal tear or a large retinal dialysis, perfluorocarbon frequently becomes indispensable for a successful surgical outcome.[36] The retinal complications may be related to pre-existing retinal pathology, elicited by vitreoretinal traction associated with attempts to remove the lens fragments during the primary cataract surgery, or retinal injury from the dropped lens fragments subsequently.[1,5] The retinal breaks may also enlarge and a retinal detachment may progress during the process of lens fragment removal. In such a situation, perfluorocarbon liquid serves the dual purpose of stabilizing the retinal complications and preventing more retinal injury, while the lens fragments are floated anteriorly for phacoemulsification or removal through a limbal incision.[1,35,41] Any posterior hemorrhage from the retinal breaks may also be displaced anteriorly by the perfluorocarbon liquid for removal. With the retina held down by the perfluorocarbon liquid, standard vitreoretinal techniques are employed to repair the retinal breaks and detachment following the vitrectomy and elimination of the lens fragments. After the application of laser or cryotherapy and possible placement of a scleral buckle, fluid-air or gas exchange is performed to replace the perfluorocarbon liquid and to achieve appropriate retinal tamponade. In case of proliferative vitreoretinopathy, silicone oil may be required as the agent for prolonged retinal tamponade. Utilizing perfluorocarbon liquid in a man-

ner similar to the above description, Lewis and others reported favorable outcome in managing dislocated lens fragments and IOLs.[41] Improved care and methods in the management of dislocated lens fragments during the primary cataract extraction and the subsequent surgery may be responsible for the much lower prevalence of associated retinal breaks and detachment in recent reports in contrast to earlier studies (3% to 5% versus 7% to 50%.)[42] In a recent study, Moore and colleagues reported a combined incidence of 13.4% for retinal detachment associated with retained lens fragments and their subsequent surgical management (6.4% before pars plana vitrectomy and 7.0% after pars plana vitrectomy).[43]

Conclusion

Modern vitreoretinal surgery offers a variety of effective techniques in the safe removal of posteriorly dislocated lens fragments. Besides the standard three-port pars plana vitrectomy with phacoemulsification, FAVIT is an expedient alternative for the cataract surgeon familiar with vitreoretinal techniques to promptly remove the lens fragments with minimal additional setup during the primary surgery. Perfluorocarbon liquid is a highly valuable intraoperative tool in managing the dislocated lens fragments and underlying associated retinal complications at the same time. Although cryoextraction provides a simple and direct means of removing a large and hard lens nucleus from the posterior segment, severe ocular complications may be associated with this technique. Its use should be limited to select cases by an experienced surgeon familiar with its potential hazards. Under the adverse condition of markedly poor visibility due to various causes, endoscopy can provide unparalleled viewing of the retro-irideal structures to allow safe removal of dislocated lens fragments irrespective of the degree of transparency of the anterior segment of the eye. Employing one or more of the techniques described in this chapter, favorable visual outcome can be achieved for the majority of eyes with dislocated lens fragments.

KEY POINTS

✔ Small lens fragments consisting of mostly cortical material may gradually resolve with conservative medical management alone. However, large lens fragments with a sizeable nuclear component do not resolve and may elicit a phacoantigenic response from the host and so have to be removed.

✔ In the event of a rupture of the posterior lens capsule or zonular dehiscence leading to posterior migration of lens fragments, the cataract surgeon must avoid any uncontrolled and forceful surgical maneuvers in the vitreous cavity in an attempt to retrieve the sinking lens fragments.

✔ Any retrieval technique that does not provide for the appropriate management of the vitreous first has the potential of causing immediate or subsequent retinal complications.

✔ The cataract surgeon must refrain from the temptation of passing a sharp instrument or lens loop into the mid- or posterior vitreous cavity to engage the sinking lens fragments, or passing forceful irrigation fluid into the vitreous cavity to float the lens fragments. Such maneuvers usually generate vitreoretinal traction resulting in retinal breaks and detachment.

✔ In case of familiarity with vitreoretinal techniques, one may convert over to a posterior segment setup and utilize one of the methods described in the following sections for removing the lens fragments. Otherwise, a prompt referral of the patient to a vitreoretinal surgeon is recommended.

✔ Medical management with topical anti-inflammatory, antibiotic, as well as cycloplegic medications should be instituted. If necessary, hypotensive agents can also be utilized.

✔ Modern vitreoretinal surgery offers a variety of effective techniques in the safe removal of posteriorly dislocated lens fragments. Besides the standard three-port pars plana vitrectomy with phacoemulsification, FAVIT is an expedient alternative for the cataract surgeon familiar with vitreoretinal techniques to promptly remove the lens fragments with minimal additional setup during the primary surgery.

✔ Perfluorocarbon liquid is a highly valuable intraoperative tool in managing the dislocated lens fragments and underlying associated retinal complications at the same time.

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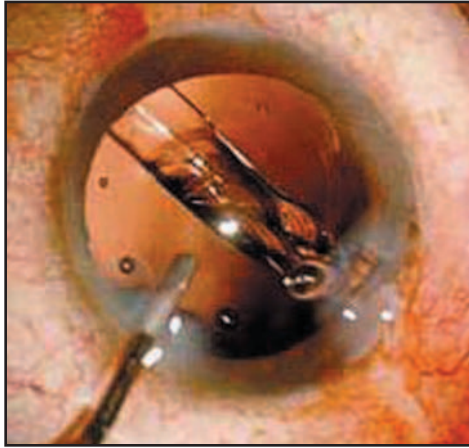
ULTRASMALL INCISION IOLs

THE ACRI.SMART IOL (ACRI.TEC GMBH)

Christine Kreiner, PhD

HISTORY OF THE FIRST IOL FOR BIMANUAL PHACO

There are many reasons to reduce incision sizes during cataract surgery. Small incisions help to reduce risks like endophthalmitis, induce less astigmatism, and the phaco procedure can be performed in a closed system, which again enhances the safety of the procedure. Over the last 25 years, phacoemulsification using ultrasound driven handpieces represented the standard in small incision cataract surgery.

Phacoemulsification incision sizes were limited by the fact that the phaco tips had to be covered by sleeves. The balanced salt solution (BSS) that is commonly used in cataract surgery was used to cool the tips for prevention of corneal burns and for replacing the already aspirated volume. Even tips with smaller diameters and improved sleeve technology did not allow smaller incisions below 2.0 mm.

Finally, in the year 2000, Kanellopoulos reported on one of the first prospective multicenter studies on the use of a Nd:YAG laser photolysis system by Dodick (ARC Laser, Salt Lake City, Utah) for cataract removal through reduced incision sizes.[1] The application of laser generated shock-waves to remove the lens, the so-called ARC Dodick Laser photolysis allowed cataract surgery through a 1.4-mm incision for the first time. Through a fiber embedded within the aspiration handpiece, laser pulses are shot onto a titanium target. The laser energy is absorbed and transformed into a mechanical shock wave. The major advantage of this new technology is that no intraocular heat is generated.

Kanellopoulos introduced two 1.4-mm paracenteses followed by capsulorrhexis and hydrodissection. High aspiration of up to 400.0 mmHg was applied and a bimanual technique to emulsify the cortex with touch-pulse aspiration was used. The nucleus was hollowed with the irrigator. Subsequently, the laser/aspiration probe was used to divide and remove the natural lens. Since the acoustic wave will only propagate over a short distance from the probe end, it is essential to bring the lens material as closely as possible to the probe's mouth.

Figure 21-1. The first prerolled bimanual phaco inside the eye.
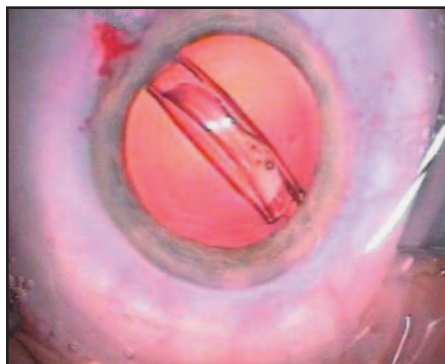
In 1998, Agarwal[2] separated the phaco tip from the infusion sleeve to further reduce incision sizes. These studies led one step further towards the bimanual phaco. The operation was performed via two paracenteses of 19-gauge (1.1 mm). For lens implantation one of the incisions had to be enlarged.

A distinctive problem of the approach to perform bimanual phaco was the fact that no intraocular lens was available in the market to allow an implantation through this very small incision. For Acri.Tec this situation was a driving force to develop suitable intraocular lenses to be used in bimanual phaco. There are two possible ways of achieving this:

1. Development of a very thin lens compromising a coherent micro-structure at the optic rim, as already realized by the Acri.Twin intraocular lenses (IOLs) from Acri.Tec (patent pending, market introduction in 1999).

2. Development of a special cartridge injector-system (Acri.Smart System) by which a lens with a standard geometry can be injected through a 1.4-mm incision. This task required a very stable, homogeneous, flexible lens material.

Because standard IOL geometries already proved their long-term stability within the capsular bag, the more reliable concept was chosen by Acri.Tec. Further reasons to decide for the use of the Acri.Smart System were the predictability of the outcomes and the enhanced safety for both patients and surgeons.

The first bimanual phaco IOL, developed by Acri.Tec, was implanted by Kanellopoulos in the year 2000. It was the first cataract surgery and IOL implantation worldwide that was performed through an incision less than 2.0 mm.

This lens was a single piece acrylic lens with an overall length of 11.0 mm and a 5.5-mm optic that was dehydrated and pre-rolled (Figure 21-1). The design of this first bimanual phaco IOL is shown in Figure 21-2.

Although the clinical results are very satisfying, the handling of the pre-rolled lens was difficult. Therefore, Acri.Tec revised the system and was able to introduce in 2002 an improved IOL (Acri.Smart 48S). This intraocular lens was a major step forward in bimanual phaco.

The geometry as well as the material of the Acri.Smart 48S is identical to the first Acri.Smart. However the abandonment of the fenestrations altered the performance during implantation of the lens dramatically. Figure 21-3 shows the Acri.Smart 48S. This bimanual phaco IOL now allows a safe minimal incision implantation.

Figure 21-2. Design of first bimanual phaco-IOL developed by Acri.Tec.

Figure 21-3. Actual design of Acri.Smart 48S.
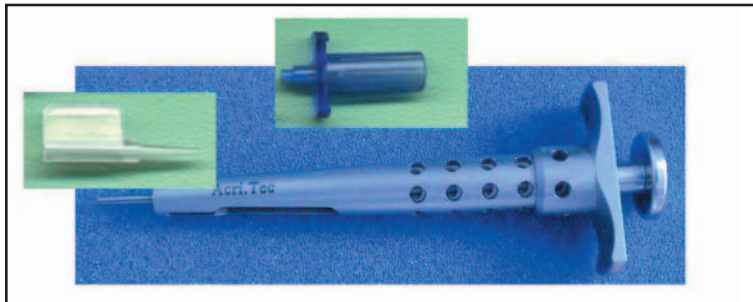
Figure 21-4. Acri.Smart Glide system (Acri.Shooter A2, Acri.Smart Glide cartouche, Tip 2).

This lens, which is comparable to any other single piece acrylic IOL with plate haptics as far as design is concerned, can be easily implanted through a 1.4- to 1.5-mm incision with a special designed cartridge-system. No somewhat troublesome pretreatment like warming-up or prerolling is necessary. Figure 21-4 shows the Acri.Smart Glide system.

The clinical results prove that this bimanual phaco IOL is stable in the capsular bag and the optical performance after implantation is perfect, despite the fact that the lens is heavily stressed during pushing through the very tiny inner diameter of the cartridge.

These very good results are due to two factors:

1. The extraordinary mechanical stability of the lens material.

2. The specific technique of the hydraulic acting injector-system.

The first Acri.Smart IOL was introduced into the European market in 2001.

TABLE 21-1 MATERIALS USED IN FOLDABLE IOLs		
Silicone	*Dry Acrylic Material*	*Wet Acrylic Material*
Dimethylsiloxane (eg, B&L) (Dimethyldiphenyl)-siloxane (eg, Allergan, Pharmacia)	Phenylethyl-methacrylate (Alcon) (Trifluor)-Ethylmeth-acrylate (Allergan)	Hydroxyhexylmeth-acrylate/HEMA Ethylmethylacrylate/HEMA (eg, corneal) MMA/HEMA (eg, Morcher, Ciba/IOLTECH) Ethoxyethyl-methacrylate/ HEMA (Acri.Tec) HEMA

SURVEY ON IOL MATERIALS

The first IOL was implanted by Ridley in 1949. His observation that bomber pilots did not show any inflammatory reaction towards the polymethylmethacyrylate (PMMA) fragments in their eyes determined his choice of PMMA for manufacturing of the first IOL.

Until 1996, PMMA was the material of choice. PMMA belongs to the family of cross linked acrylmethacrylate-polymers. It exhibits thermoplastic behavior (hard and brittle at room temperature) and becomes soft only when heated up (>100°C).

Although PMMA exhibits a very good biocompatibility and chemically inert behavior, the requirements of modern cataract surgery have changed and now require foldable IOL.

New materials have been developed. The most important requirements are optical transparency, biocompatibility and elasticity. Currently four different groups of materials are used for manufacturing of foldable IOLs (Table 21-1):

1. Silicone elastomer
2. Dry foldable acrylic material
3. Wet foldable acrylic material (Hydrogel)
4. Collamers

The choice of silicone elastomers or dry foldable material is limited. Wet foldable acrylic material offer a much greater choice of various copolymers. Copolymers consist of one polymer that can incorporate water (HEMA) and a second polymer that can not contain any water (PMMA). Dry acrylic materials gain their elasticity by introduction of softening agents into their matrix (chemically).

Wet acrylic materials when kept dry exhibit the behavior known from PMMA. They are hard and brittle when not hydrated. These materials achieve their elasticity by hydration. One major advantage compared with dry acrylic materials is the possibility for the covalent integration of an UV-block.

Chemically, wet acrylic materials belong to the group of hydrogels. Due to this fact these materials are commonly known as hydrophilic materials. However the conclusion that also the surfaces of hydrogels must exhibit hydrophilic properties can be misleading. Even though containing a certain amount of water, hydrogels can have hydrophobic surfaces.

<table>
<tr><th colspan="4">TABLE 21-2
CHARACTERISTICS OF ACRI.LYC-BASED ACRI.SMART IOLs</th></tr>
<tr><th></th><th>*Acri.Smart 48S**</th><th>*Acri.Smart 46S***</th><th>*Acri.Smart 36A****</th></tr>
<tr><td>Optic diameter</td><td>5.5 mm</td><td>6.0 mm</td><td>6.0 mm</td></tr>
<tr><td>Overall length</td><td>11.0 mm</td><td>11.0 mm</td><td>11.0 mm</td></tr>
<tr><td>Haptic angulation</td><td>0 degrees</td><td>0 degrees</td><td>0 degrees</td></tr>
<tr><td>Design</td><td>Haptic and optic with squared edges</td><td>Haptic and optic with squared edges</td><td>Haptic and optic with squared edges</td></tr>
<tr><td>Optic</td><td>Biconvex, symmetric</td><td>Biconvex, symmetric</td><td>Biconvex, symmetric; aberration corrected-aspheric</td></tr>
<tr><td>Material</td><td>Foldable acrylate with hydrophobic surface, 25% water content, and UV-absorber</td><td>Foldable acrylate with hydrophobic surface, 25% water content, and UV-absorber</td><td>Foldable acrylate with hydrophobic surface, 25% water content, and UV-absorber</td></tr>
<tr><td>Sterilization method</td><td>Autoclave</td><td>Autoclave</td><td>Autoclave</td></tr>
<tr><td>Diopter available</td><td>Between 0.0 and +32.0 D</td><td>Between 0.0 and +32.0 D</td><td>Between 0.0 and +32.0 D</td></tr>
<tr><td>Recommended A-constant</td><td>Acoustic: 118
Optical: SRK/T: 118.3</td><td>Acoustic: 118
Optical: SRK/T: 118.3</td><td>Acoustic: 118
Optical: SRK/T: 118.3</td></tr>
</table>

* 5.5 mm optics for bimanual phaco one piece
** 6.0 mm optics for bimanual phaco one piece
*** 6.0 mm aberration corrected optics for bimanual phaco one piece

All Acri.Lyc IOLs are hydrogels with hydrophobic surfaces. Collamers are based on the same polymers as hydrophilic acrylic materials but contain approximately 0.25% collagen.

CHARACTERISTICS OF ACRI.LYC-BASED ACRI.SMART IOL

Acri.Smart IOL are processed in dry environment. Their refractive index (dry, 25°C) is 1.505. When the lens is hydrated the refractive Index is lowered to 1.460.

In Table 21-2, all details are listed for the different models currently available.

Compared to other acrylate materials the advantages of the copolymer of the Acri.Lyc IOL are:

- Low water content
- Better mechanical properties (eg, tensile strength and modiolus)
- Quick orientation of the IOL in the capsular bag
- Extremely good folding and unfolding behavior
- Easy injection through newly developed cartridges

The Acri.Smart intraocular lens is a one-piece, hydrophobic acrylic lens with a water content of 25%. It is stored in BSS to facilitate the implantation. The high purity

of the material, which is exposed to a specific cleaning process, the excellent surface design and also the sharp edge design result in a significant decrease in secondary cataract formation.

An in vivo opacification or glistenings, as observed in a series of other acrylic lenses, can be excluded for this lens. Regarding stability inside the capsule, optical performance and physiological compatibility, the Acri.Smart has the characteristics of a standard IOL.

Physical Conditions of Polymers

Polymers can be differentiated according to their molecular structure:
- Crystalline: Regular, three-dimensional arrangement of the chains.
- Amorphous: Statistical distribution of the chains.
- Norm: Partially crystalline.

The differentiation into three groups mentioned above is important due to the properties the different modifications are exhibiting.

The physicochemical properties that determine whether a polymer is useful for IOL manufacturing are:
- Optical transparency
- Elasticity
- Hardness
- Mechanical properties

For the manufacturing of IOLs that can be used in bimanual phaco only small amounts of crystalline areas are allowed. However the resulting reduction in optical transparency and a lower refractive index have to be considered.

A further important factor is the glass transition temperature Tg. Again for the manufacturing of a bimanual phaco IOL, there are certain requests. First, the material should be as homogeneous as possible, and second, no intrinsic softening should occur.

The glass transition temperatures for different materials used for manufacturing of intraocular implants are varying within a broad range.
- Polymers: Between -100°C and +250°C
- PMMA: +160°C/@room temperature (RT)—brittle
- Silicone elastomer: -80°C/@RT—rubber elasticity

To adapt the materials to be foldable at room temperature the decrease of the glass transition temperature becomes necessary. This goal is achieved either by adding softeners (components boiling at high temperature or simply water) or by increasing the movement of the chains. The higher movement can be achieved by cross linking with rotating chains, by binding loops and branchings which easily rotate or by mixing polymers with different Tg ("intrinsic softening").

Thorough investigations have shown that the best suitable softener for foldable IOL is water.

Optical Requirements

The most important feature is a strong structural memory of the material used for the optics. The material should not change optical power when the curvature of the optic is altered. Further requirements are that no induced astigmatism occurs due to rolling

or folding of the material. This claim becomes even more important when injectors and cartridges are used for implantation. During the injection process the IOL is subsequently compressed and stretched, and therefore, should not alter its optical properties in any case.

A further demand is that the surface of the IOL should not be damaged during injection.

CHEMICAL REQUIREMENTS

Three major parameters determine whether an acrylic material could be used for manufacturing of high quality implants:

- Content of monomers
- Purity of the copolymers
- Content of the UV absorber

The past has shown that the chemical purity of acrylic materials containing water is essential. Do the base materials exhibit impurities which were left during the synthesis (mainly free methacrylic acid) there is a risk that the IOL may become clouded or colored. Such problems can also occur if the material is wrongly treated during further processing.

Extraction tests (ISO 11979-5 and ISO 10993-10) have demonstrated that for the Acri.Lyc material no loss of substance can be measured. Thus it can be demonstrated that low molecular volatile components do not exist within the Acri.Lyc material.

Opacities at temperatures below 10°C, at which the Acri.Lyc material passes through a phase of reduced transparency, are connected to the osmotic equilibrium of the water content. This transition is totally reversibly at room temperature and can be repeated infinitely.

PORE SIZE

The pore size of the material determines the surface properties as well as the velocity to incorporate water molecules. The smaller the pores are the slower an equilibrium is reached. Simultaneously reduced pore sizes increase the hydrophobic character of the surface.

HYDROPHOBIC SURFACE

The hydrophobic properties of a material can be determined by measuring its surface tension. To prove the hydrophobic character of the Acri.Lyc material an acrylic IOL with a rotational symmetric, sharp outer edge and hydrophobic surface characteristics was investigated. The Acri.Lyc 53N IOL model exhibits a water content of 25%.

The hydrophobic surface characteristics of the Acri.Lyc-type 53N IOLs were affirmed by measuring the contact angle in comparison to hydrophobic and hydrophilic polysiloxane screens.

Whether next to the hydrophobic characteristics of the surface also "chemical" factors are responsible for the rolling-off of cells and the declined cell vitality, cannot be checked with standardized cell culture experiments. In order to exclude an overlapping of the hydrophobic and chemical influences, a chemical analysis would be necessary. The examiner tends to make the hydrophobic characteristics responsible for the death of cells, which occurs sporadically.

SUMMARY

Both clinical and biocompatibility studies have proved the advanced properties of the Acri.Lyc material of which the Acri.Smart IOL is made. Not only the hydrophobic surface of the acrylic material but also the geometry and edge design are greatly contributing to the outstanding performance of the Acri.Smart.

All surgeons agreed that the Acri.Smart System, that consists of the Acri.Smart IOL, the Acri.Shooter A2, and the Acri.Smart Glide Cartouche can be easily applied in all standard situations. The very small incision allows for controlled injection and supports the new technologies of Dodick Laser Phaco and bimanual phaco.

The good centration, the gain of vision and the extremely low rate of PCO really are making the Acri.Smart an IOL of choice.

Because of the big success of the Acri.Smart design all over the world, the Acri.Smart IOL family is expanded with new innovative products.

The following products are available right now:

- Acri.Smart 48S (5.5 mm diameter optic)
- Acri.Smart 46S (6.0 mm diameter optic)
- Acri.Smart 36A (6.0 mm diameter optic, with aberration correction)

KEY POINTS

✔ The first bimanual phaco IOL, developed by Acri.Tec was implanted by Kanellopoulos in the year 2000. It was the first cataract surgery and IOL implantation worldwide which was performed through an incision less than 2.0 mm.

✔ The Acri.Tec lens is comparable to any other single piece acrylic IOL with plate haptics, as far as design is concerned, can be easily implanted through a 1.4-to 1.5-mm incision with a special designed cartridge-system.

✔ Chemically, wet acrylic materials belong to the group of hydrogels. Due to this fact these materials are commonly known as hydrophilic materials. However the conclusion that also the surfaces of hydrogels must exhibit hydrophilic properties can be misleading. Even though containing a certain amount of water, hydrogels can have hydrophobic surfaces.

✔ All Acri.Tec Acri.Lyc IOLs are hydrogels with hydrophobic surfaces. Collamers are based on the same polymers as hydrophilic acrylic materials but contain additionally approximately 0.25% collagen.

✔ The Acri.Smart IOL is a one-piece, foldable acrylate with a hydrophobic surface with a water content of 25%. It is stored in BSS to facilitate the implantation. The high purity of the material, which is exposed to a specific cleaning process, the excellent surface design and also the sharp edge design result in a significant decrease in secondary cataract formation.

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BIMANUAL PHACO
WITH THE ACRI.TEC GMBH IOL

Sunita Agarwal, MS, DO

HISTORY

On August 15, 1998, Amar Agarwal performed the first sub-1.0-mm cataract surgery using a technique called bimanual phaco (or Phakonit).[1,2,3] I also worked on laser cataract surgery and achieved cataract removal through the Paradigm laser phaco machine (Salt Lake City, Utah). Today, companies have started manufacturing IOLs that can pass through ultrasmall incisions of 1.5 mm or less. One such IOL is the Acri.Lyc IOL made by the Acri.Tec GmbH company (Berlin, Germany).

TECHNIQUE OF BIMANUAL PHACO FOR CATARACTS

After enlarging the side port, a 20- or 21-gauge irrigating chopper (Geuder, Heidelberg, Germany or MST, Redmond, Wash) connected to the infusion line of the phaco machine is introduced with foot pedal on position 1. The phaco probe is connected to the aspiration line and the phaco tip without an infusion sleeve is introduced through the incision (Figure 22-1). Using the phaco tip with moderate ultrasound power, chopping the nucleus is done. The whole nucleus is finally removed (Figure 22-2). Note in Figure 22-2 no corneal burns are present. Cortical wash-up is then done with the bimanual irrigation aspiration technique (Figures 22-3 and 22-4).

ACRI.TEC IOL

The Acri.Lyc IOL is a sterile foldable intraocular lens made of hydrophobic acrylate. The IOL consists of highly purified biocompatible hydrophobic acrylate with a chemically bonded UV-absorber. It is a single-piece foldable IOL like a plate-haptic IOL. The lens is sterilized by autoclaving. The lens comes in a sterile vial filled with water, and is wrapped in a sterile pouch.
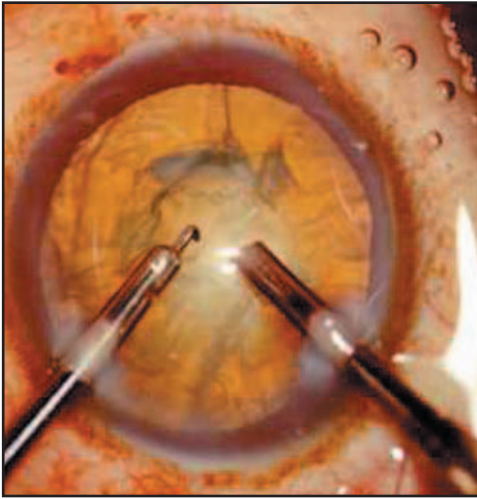
Figure 22-1. Phakonit irrigating chopper and phako probe without the sleeve inside the eye.
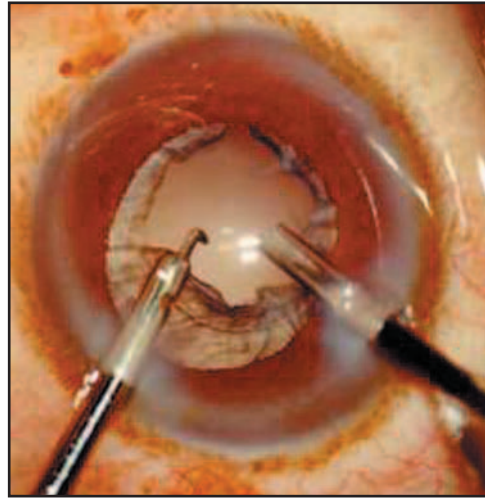
Figure 22-2. Bimanual phaco completed. Note the nucleus has been removed and there are no corneal burns.
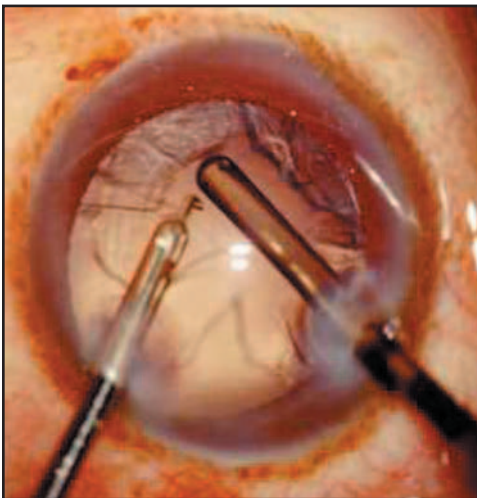
Figure 22-3. Bimanual irrigation aspiration started.
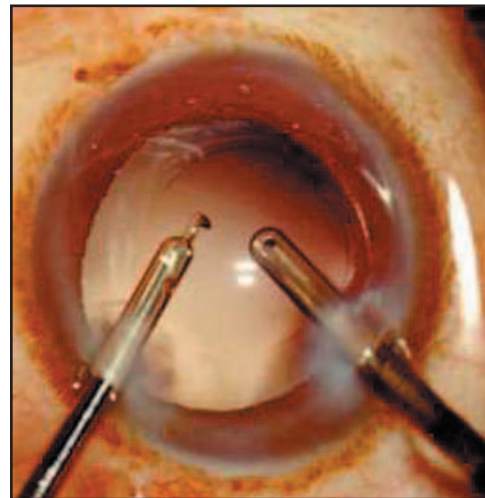
Figure 22-4. Bimanual irrigation aspiration completed.

Lens Loading Technique

To remove the IOL, one should open the Medipeel pouch at the defined spot. The lens vial or bottle is then taken out and placed on the sterile tray. The lens is shaped like a plate haptic IOL (Figure 22-5). The next step is to prepare the injector (Figure 22-6). The injector tip is fitted with a sponge tip (Figures 22-7 and 22-8) which is provided with the cartridge. This prevents the injector tip from damaging the lens while inserting it inside the eye. The lens is then taken out from the bottle/vial. Holding the lens with a forceps, it is placed in the cartridge. Viscoelastic is injected in the cartridge,

Figure 22-5. The Acri.Lyc foldable IOL.

Figure 22-6. The Acri.Tec injector.
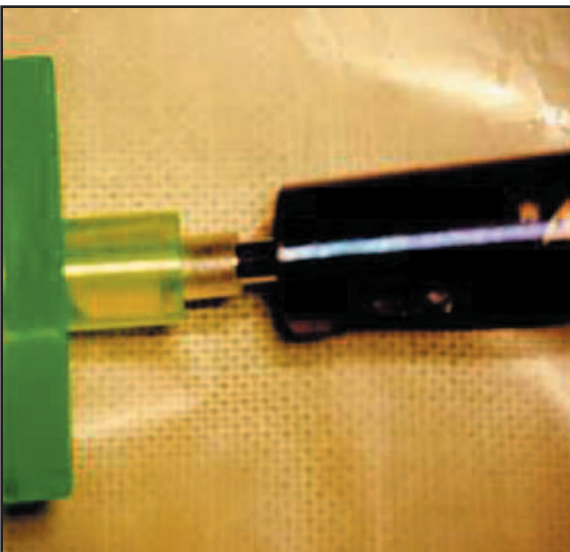
Figure 22-7. The soft sponge tip being fixed onto the tip of the Acri.Tec injector.

Figure 22-8. Tip of the injector with the sponge tip. This will prevent any damage to the lens when inserting the lens.

Figure 22-9. The tip of the injector with the sponge tip ready in place to push the IOL.
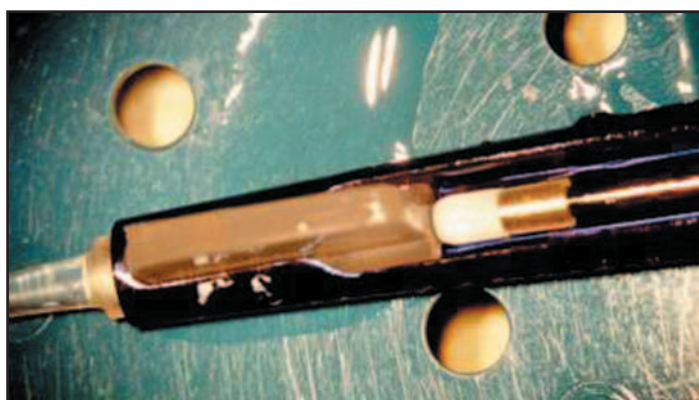
and once the flanges of the IOL are in the groove of the cartridge, the cartridge is closed and then inserted in the injector. Once the cartridge is fixed onto the injector, the injection of the lens is done by the spongy tip (Figure 22-9) until one can see the lens coming into the nozzle of the cartridge.

LENS INSERTION TECHNIQUE

After the bimanual phaco procedure is completed, the incision is increased to 1.5-mm. Then the tip of the cartridge is kept at the site of the incision. Remember the cartridge is not inserted inside the anterior chamber. Now, the lens is gradually inserted through the incision (Figure 22-10). One can watch the lens unfolding inside the capsular bag. The inferior haptic goes into the bag and the superior haptic is gradually tucked inside the capsular bag. Viscoelastic is then removed with the bimanual irrigation aspiration probes (Figure 22-11).

LASER BIMANUAL PHACO

Laser phakonit uses laser energy (coupled with ultrasound energy in hard nuclei) to remove the nucleus. The laser machine used is the Paradigm Laser Photon. In these cases, two ports are used. One port has fluid (BSS) flowing through a 20-gauge irrigating chopper and in the other hand is the phaco probe without a sleeve. In the center of the phaco probe, the laser probe is passed. The diameter of the phaco probe is 900.0
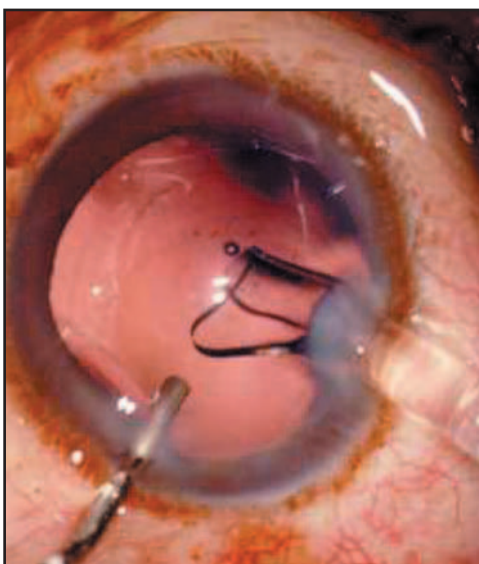
Figure 22-10. The IOL inserted through a 1.5-mm incision.
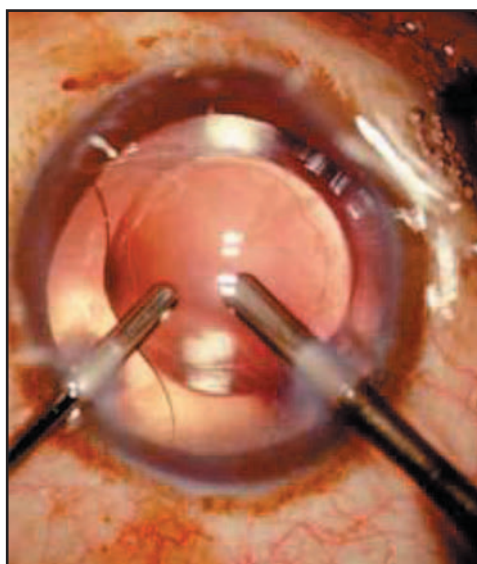
Figure 22-11. Viscoelastic removed using bimanual irrigation aspiration probes.

µm. The laser probe reduces the orifice opening to 550.0 µm. Thus, the nucleus can be removed through a very small opening.

Summary

With the advent of bimanual phaco, the size of the incision has drastically reduced. Now with more companies moving into manufacturing ultrasmall incision IOLs that can pass through 1.5 mm incisions or less, the advantage of bimanual phaco becomes greater. With time, more surgeons will move into this technology thus benefiting more patients.

Key Points

✔ Companies have started manufacturing IOLs that can pass through ultrasmall incisions of 1.5 mm or less. One such IOL is the Acri.Lyc IOL made by Acri.Tec GmbH.

✔ This lens is a sterile foldable IOL made of hydrophobic acrylate.

✔ The injector tip for the Acri.Tec IOL is fitted with a sponge tip that prevents the injector tip from damaging the lens while it is being inserted inside the eye.

✔ The tip of the cartridge is kept at the site of the incision and the cartridge is not inserted inside the anterior chamber.

✔ Laser bimanual phaco uses laser energy (coupled with ultrasound energy in hard nuclei) to remove the nucleus. This can also be used instead of bimanual phaco alone.

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Bimanual Phaco With the ThinOptX Rollable IOL

Virgilio Centurion, MD; Augusto Cezar Lacava, MD; and Juan Carlos Caballero, MD

Introduction

Phacoemulsification is considered the best technique for the treatment of cataract. Modern technique considers a 3.0- to 3.2-mm[1,2] corneal incision as standard for performing surgery and implantation of foldable intraocular lens with injector,[3] as it is astigmatically neutral,[3] providing a closed and safe system and allowing the incision to cool.[1]

Innovations in the technique, such as a 1.5-mm incision by bimanual phaco, and technological innovations such as the use of less ultrasonic energy (cold phaco) or phaco laser (Erbium[4,5] or NdYag laser) or sonic energy (Starwave) associated with ultra-thin lenses (ThinOptX [Abingdon, Va] or Acri.Smart [Acri.Tec GmbH, Berlin, Germany][6]) are considered, as a whole, the new trend in cataract surgery.

With the development of equipment that uses laser energy to emulsify the nucleus where there is no production of heat, there was an incentive to use bimanual techniques, where irrigation is separate from aspiration-emulsification. In August of 1998, Agarwal[7] proposed bimanual surgery using ultrasonic energy equipment, and performed it live during a congress; in the occasion, he used a 18-gauge bent needle for irrigation through the paracentesis, the tip without irrigation sleeve, Universal I (Alcon, Fort Worth, Tex) equipment, and the assistant irrigated the cornea constantly to avoid burns. He called the technique Phakonit (phaco done with needle incision technology) and published the first results. In this series of 306 eyes, there were no incisional burns.

Bimanual Phaco

We began the technique making 1.4-mm incisions. (Figures 23-1 through 23-4). They are performed with disposable blades of 20-gauges (1.4 mm) adequate for scle-rotomies in posterior vitrectomy surgeries via pars plana. With the improvement in the instruments, we reduced the size of incisions, and now perform surgeries using a 1.2-

Figure 23-1. A lateral auxiliary corneal incision is created at 2 clock using a 20-gauge sclerotome.
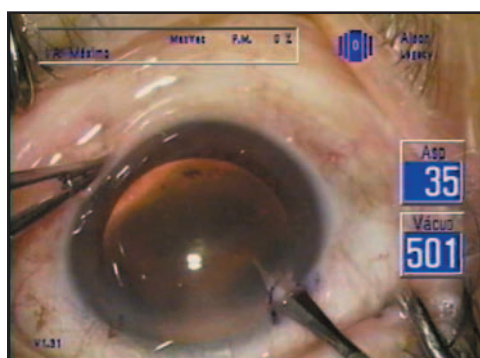
Figure 23-2. An oblique main incision is created at 11 clock using the same instrument to make the 1.5 mm clear-corneal incision.

Figure 23-3. The main incision size is verified with calipers.
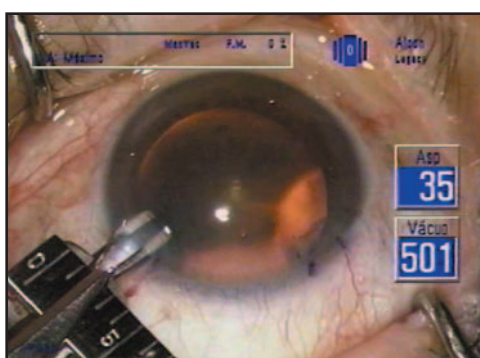
Figure 23-4. The auxiliary incision size is verified with calipers.

mm diamond blade from Accutome (Malvern, Pa). Several disposable blades already exist in the market that can be used.

The next step is to perform the capsulorrhexis. We tried several forceps until we found the ones that were best for our technique. They are the Fine forceps model from MST (Redmond, Wash). With these forceps, one can open up the anterior capsule directly. Their "legs" are short and with this it is not necessary to exit and enter the eye whenever one needs to regrasp the anterior capsule.

To perform bimanual technique (Figures 23-5 through 23-7), it is necessary to remove the silicone sleeve, and with this separate the irrigation from aspiration/emulsification. Irrigation is, then, performed through an accessory instrument, an irrigating nucleus manipulator—a chopper. In the beginning, we did not find a chopper that could adapt to our chop technique. We then decided to design one that would be appropriate for our technique. At that time, what we considered important was for the chopper to have good irrigation, and be adequate for vertical chopping technique. The irrigating ports were closer to the end of the chopper to avoid shallowing of the anterior chamber with the maneuvers. At present, this chopper is being remodeled and will be marketed by MST in its Duet system. In our opinion, four aspects should be considered in an irrigating chopper: *irrigation, width, followability,* and *adaptation to one's phacoemulsification technique.*
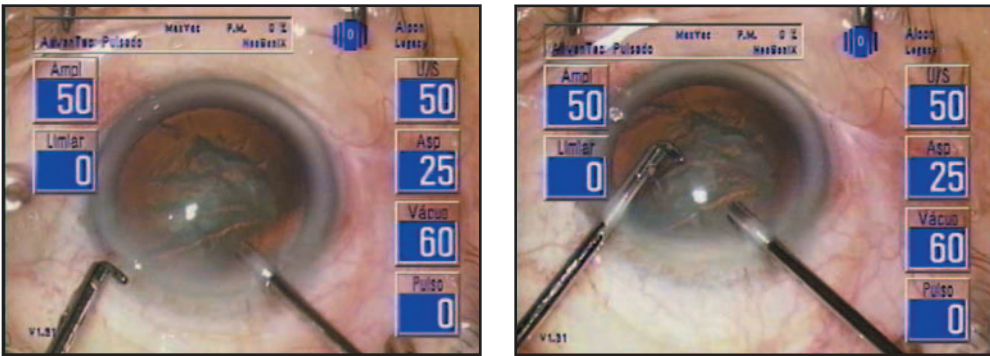
Figure 23-5 and 23-6. For nuclear fragmentation, a Crema irrigator-chopper is inserted through the lateral incision and a standard ABS microtip or 21-gauge/30 degrees flare tip, without a sleeve, through the main incision.
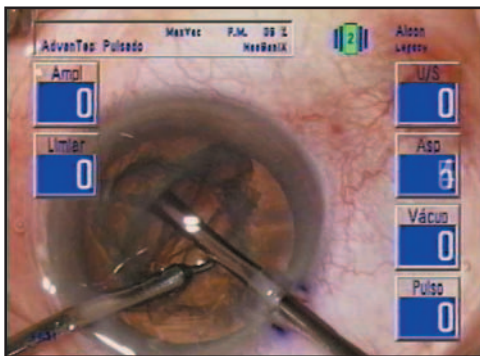
Figure 23-7. Nuclear fragmentation is carried out using a stop-and-chop technique with the irrigator-chopper and the 21-gauge flare tip.

Irrigation

At present, the biggest difficulty that we still face in the technique is the incapacity to keep aspiration parameters that we use as a routine in coaxial technique. As the irrigation of the choppers is always smaller than the coaxial, we will always have a "surge" if we use very high aspiration parameters. The biggest challenge, then, in the making of an irrigating chopper is to make it have a lot of irrigation, maintaining a width that allows its insertion through a 1.2-mm incision. As these choppers irrigate less, we should adjust aspiration parameters for the chopper that we will use, to avoid oscillations of the anterior chamber during the procedure.

Width

It is important that the chopper be fine enough to enter easily through an incision less than 1.4 mm. To reduce the diameter, maintaining a high irrigation is one of the great challenges in making an irrigating chopper. The use of high quality instruments, that allows the making of a thin and at the same time resistant wall, maintaining a big internal diameter is one of the secrets. The irrigation also seems to be more intense in those choppers where the irrigation port is end opening.

TABLE 23-1
PARAMETERS FOR THE LEGACY 20000

	Vacuum (mmHg)	Flow (cc/min)	Phaco Power (%)	Height (cm)	Objective	Technique
Phaco I	50	25	≤50 linear	110	Sculpt sulcus	Chop
Phaco II	250	45	≤50 cont. burst	110	Hold	Chop
Phaco III	250	45	Pulse	110	Capture fragments	Chop
Phaco IV	250	60	≤20 pulse	110	Suction	Epinucleus or flip for soft nucleus
I/A$_1$	300 linear	60		90	Cortex	Aspiration
I/A$_2$	10 linear	60		70	Capsular polishing	Aspiration
I/A$_3$	300 linear	60		90	Viscoelastic	Aspiration

Followability

Many surgeons tell that followability is bigger in the bimanual technique than in the traditional coaxial. This seems to be related to the irrigation being done by a separate way of aspiration. It is very difficult to measure followability quantitatively, however it seems to me that it is more efficient when the irrigation of the irrigating chopper is lateral (two ports) and not end opening.

Adaptation to Chop Technique

Obviously, there is no manipulator of the irrigating nucleus that is ideal for every surgeon, as each one has his or her technique and form of operating. Some surgeons prefer to use technique of sculptures and break, and in these cases the ideal would be a manipulator of the nucleus of the spatula type. Others prefer to use technique of horizontal chop, and for these the chopper should be rounded inferiorly. We preferred to perform techniques of vertical chop, and for this the chopper that we used have a inferiorly sharp format; at present we are using Crema-MST chopper that is part of the Duet system. In this system we have the advantage of being able to change only the tips of the choppers.

The equipment we use is the Legacy 20000 with NeoSonix handpiece and Advantec system, adopting the parameters shown in Table 23-1.

As we have already shown, irrigation using the irrigating choppers is smaller than the conventional co-axial irrigation of the equipment, and for us to avoid surge of anterior chamber, we should adapt our aspiration parameters with the amount of irrigation given by our chopper. To avoid these surges, there are also devices that increase the irrigation or reduce the possibility of oscillation of anterior chamber.

To increase the irrigation, it is proposed to use the air pump, where air is injected in the bottle of BSS. The same effect can be achieved with the Accurus (Alcon) equipment, where the intraocular pressure wanted can be controlled during posterior vit-
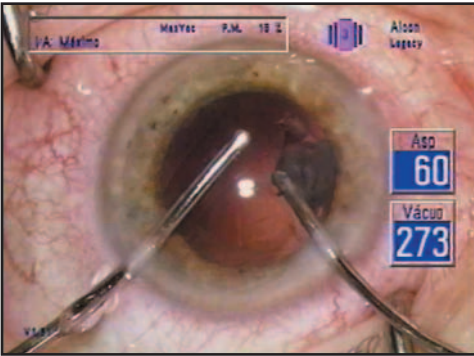
Figure 23-8. Bimanual irrigation aspiration.
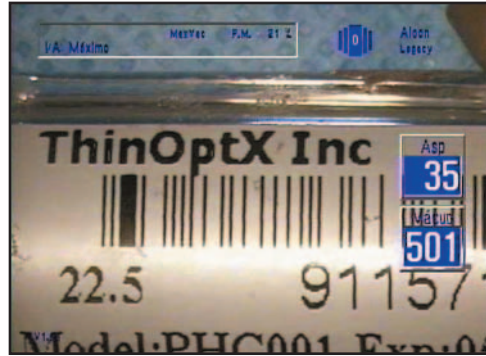
Figure 23-9. The ThinOptX IOL comes in sterile balanced solution in a tightly closed vial.
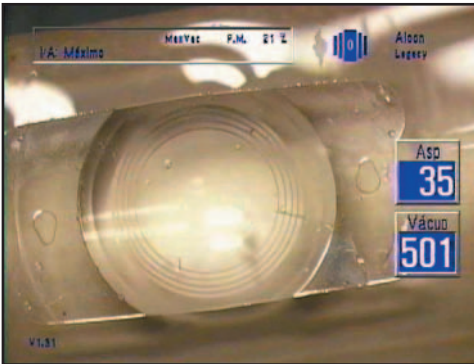
Figure 23-10. The UltraChoice IOL is a single-piece, plate-haptic hydrophilic acrylic lens with an overall length of 11.2 mm, and an optical diameter of 5.5 mm. Note the drop-shaped holes at the haptic level indicate which way the lens should be implanted.

rectomy. Another form of increasing the irrigation in the anterior chamber is using an anterior chamber maintainer through a third incision. To reduce the oscillation of the anterior chamber, an antichamber collapser called Cruise Control, is marketed by STAAR Surgical (Monrovia, Calif), to be coupled in the aspiration tube of any phacoemulsification equipment.[5] Finally, bimanual irrigation aspiration is done for the cortex (Figure 23-8).

ThinOptX Rollable IOL

Thinoptx intraocular lens uses the Fresnel principle. It is in the shape of a meniscus and has concentric rings of different thicknesses in its posterior surface that work as independent units (but in a cooperative way), focusing in a point of incident light, similar to the pinhole (Figure 23-9). Its thickness varies from 50.0 to 400.0 μm and this enables the intraocular lens to roll, and thus it can be injected through an extremely small incision (1.5 mm) and be astigmatically neutral.

In the region of the haptic there is a hole in the shape of a drop, indicating the correct position of the implant when it points in the clockwise direction (Figure 23-10). The anterior surface is not flat, with multiple optic areas (3 to 5), that give the dioptric power. With this technology, they can be manufactured with very fine thickness, most of them 100.0 μm.
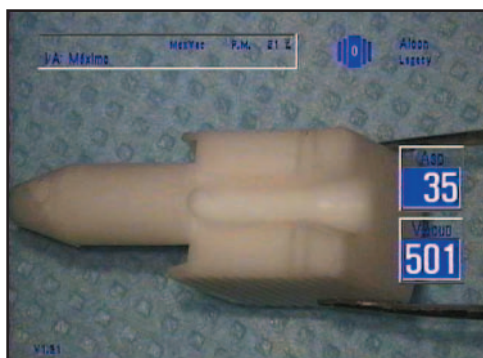
Figure 23-11. The Geuder injector is composed of two parts: a plastic, autoclaveable cartridge into which the rolled IOL is placed. This is where the IOL is mounted or rolled.

Figure 23-12. The metallic injector portion of the injector. This is the metallic injector body which is quite similar to other lens injectors, in that it holds the folded lens within the cartridge as a piston-type injector pushes the lens into the eye.

THINOPTX INJECTOR

The injector has two parts:
1. The cartridge (Figure 23-11), made of plastic and reusable, where the IOL is mounted or rolled.
2. The metallic injector (Figure 23-12), where the cartridge is adapted for the implant to be carried out pressing the piston. The injector is marketed by Geuder (Heidelberg, Germany).

THE ASSEMBLY OF THE IOL AND THE IMPLANT

The ThinOptX IOL comes in sterile balanced solution in a tightly closed vial. Our routine for the assembly is as follows:
1. Remove the IOL from the vial with a delicate atraumatic forceps without teeth (Figure 23-13).
2. Check if the drop-shaped holes at the haptic level indicate the clockwise position.
3. Fix the IOL in the right longitudinal edge of the cartridge (Figure 23-14).

IOL INSERTION

The injector is placed in the border of the incision, trying to half-open the corneal incision with the aid of an atraumatic forceps (Figure 23-15) .The lens is then injected (Figure 23-16). Once the implant is inside the capsular bag, follow the opening or unrolling of the IOL that takes approximately 15 to 20 seconds (Figure 23-17). It is not advisable to rotate the lens inside the capsular bag. Then the viscoelastic is removed (Figure 23-18) followed by stromal hydration.
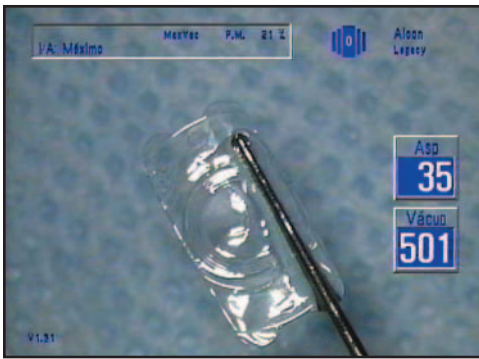
Figure 23-13. IOL held with a delicate atraumatic forceps without teeth. The IOL is held on the right longitudinal edge with holding forceps and submerged in warm saline for 20 seconds.

Figure 23-14. The IOL is placed in the cartridge and rolled counter-clockwise. When the lens is fully rolled, it is held with forceps in the center and introduced into the cartridge, previously moistened with saline.
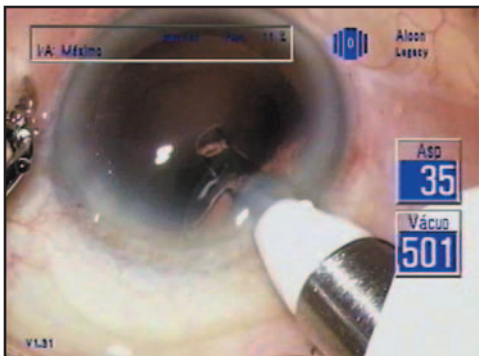
Figure 23-15. IOL Insertion started. Note the tip of the cartridge is at the tip of the incision.
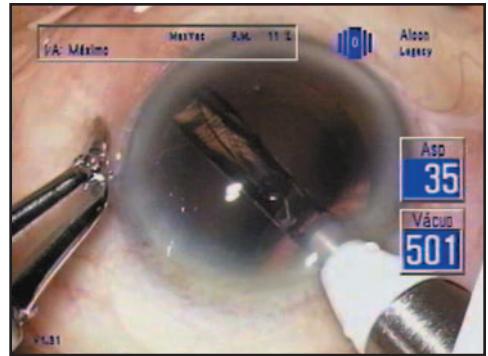
Figure 23-16. IOL inserted inside the capsular bag.
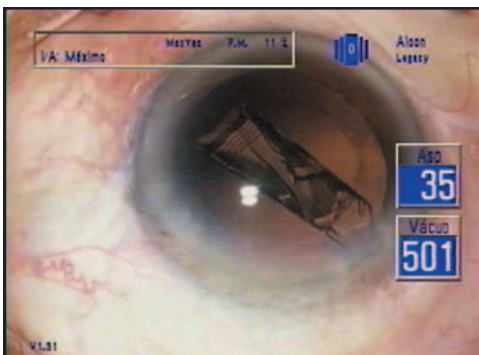
Figure 23-17. IOL unrolls inside the capsular bag. The lens unrolls in about 15 to 20 seconds.
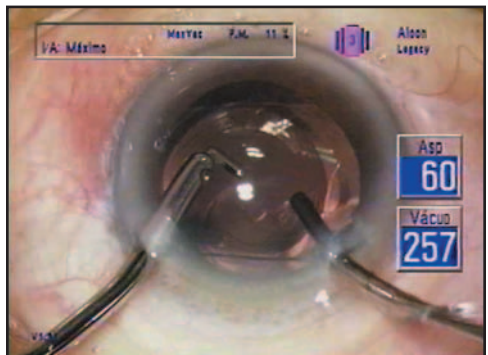
Figure 23-18. The trailing haptic can then be pronated into the capsular bag. Viscoelastic is aspirated, and the case is closed as usual.

Discussion

Significant advances during the last three decades following the evolution of surgical treatment of cataract is a result of the technical and technological development and the high number of surgeries carried out annually all over the world due to the increase in the number of senior citizens. The current objective is to perform the technique and to use technologies that are less aggressive to the eyes, and this can be achieved through several factors:

1. Surgical technique: Basically it is the "final evolution" in relation to the incision, breaking the 3.0-mm barrier and using an incision that varies from 0.9 up to 1.5 mm.[7,8,9]

2. Our experience using Crema[9] irrigating chopper for the auxiliary incision and microtip flared without irrigation glove or sleeve maintains a good stability of the anterior chamber as long as smaller parameters are used than those used in incisions larger than 2.75 mm.

3. In the fracturable nuclei, we prefer the use of stop and chop technique and in the soft nuclei, the flip technique with previous hydrodelamination.

Pearls/Difficulties With the Technology

1. The reduction of the parameters does not increase surgical time when we compare bimanual microincision technique with the traditional phaco, but it requires a learning curve.

2. For the one-handed surgeon, more active use of the nondominant hand with the chopper and irrigation generates a certain difficulty.

Pearls/Difficulties Related to the Technique

1. Difficulty in performing capsulorrhexis due to smaller incisions.

2. Flared tips are difficult to insert through 1.5 mm, but it has an escape of liquid that is more and more constant, enabling irrigation and cooling of the incision

3. Difficulty to handle soft nuclei with chopper.

4. In the stage of cortical aspiration the bimanual tips available in the market are extremely narrow in their external diameter and this facilitates the escape of liquid for the incisions, shallowing the anterior chamber.

Pearls/Difficulties With IOL

1. A considerable advance is the concept of implanting the lens rolled and not folded and this requires an experienced curve.

2. The IOL can be implanted through 1.5 mm, but in our hands it becomes easier and more predictable when we enlarge it to 2.0 mm. In this way, the incision keeps the funnel format, and allows the entrance of the injector in a less traumatic way.

SUMMARY

In conclusion, the experience of using the microincision technique associated to the implant of ultrathin IOL is a reality, with real benefits, an evolution, when we compare it with the routine phacoemulsification.

The popularization of the technique and long follow up of the intraocular lens will be of fundamental importance in the future of this modality of cataract surgery.

KEY POINTS

✔ The ThinOptX intraocular lens uses the Fresnel principle.

✔ Four aspects should be considered in an irrigating chopper: irrigation, width, followability, and adaptation to one's phacoemulsification technique.

✔ The lens thickness varies from 50.0 to 400.0 µm and this enables the intraocular lens to roll, and thus it can be injected through an extremely small incision (1.5 mm) and be astigmatically neutral.

✔ Flared tips are difficult to insert through 1.5 mm, but it has an escape of liquid that is more and more constant, enabling irrigation and cooling of the incision.

✔ In the stage of cortical aspiration the bimanual tips available in the market are extremely narrow in their external diameter and this facilitates the escape of liquid for the incisions, shallowing the anterior chamber.

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Corneal Topography After Bimanual Phaco With a 5.0-mm Optic Rollable IOL

Amar Agarwal, MS, FRCS, FRCOphth

Introduction

Cataract surgery and intraocular lenses (IOL) have evolved greatly since the time of intra capsular cataract extraction and the first IOL implantation by Sir Harold Ridley.[1] The size of the cataract incision has constantly been decreasing from the extremely large ones used for intracapsular cataract extraction (ICCE) to the slightly smaller ones used in extracapsular cataract extraction (ECCE) to the present day small incisions used in phacoemulsification. Phacoemulsification and foldable IOLs are a major milestone in the history of cataract surgery. Large postoperative against-the-rule astigmatism were an invariable consequence of ICCE and ECCE. This was minimized to a great extent with the 3.2-mm clear corneal incision used for phacoemulsification but nevertheless some amount of residual postoperative astigmatism was a common outcome. The size of the corneal incision was further decreased by bimanual phaco.[2,3,4] The only limitation to thus realizing the goal of astigmatism neutral cataract surgery was the size of the foldable IOL as the wound nevertheless had to be extended for implantation of the conventional foldable IOLs.

Rollable IOL

With the availability of the ThinOptX rollable IOL (Abingdon, Va) that can be inserted through a sub-1.4-mm incision, the full potential of bimanual phaco could be realized. This lens, designed by Wayne Callahan, uses the Fresnel principle to make the lens thinner. Subsequently, I modified the lens by making the optic size 5.0 mm so that it could go through a smaller incision. ThinOptX later manufactured these, and we implanted the first five lenses.

Surgical Technique

Five eyes of five patients underwent bimanual phaco with implantation of an ultra-thin 5.0-mm optic rollable IOL at Dr. Agarwal's Eye Hospital and Eye Research Centre, Chennai, India.

Figure 24-1. Agarwal's bimanual phaco irrigating chopper and sleeveless phaco probe inside the eye**.**
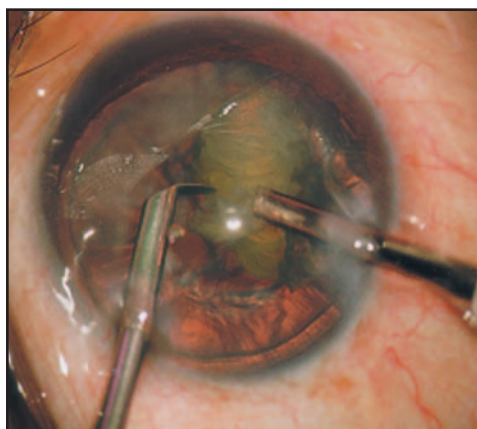
A specially designed keratome, irrigating chopper, straight blunt rod, and 15-degree standard phaco tip without an infusion sleeve form the main prerequisites of the surgery. Viscoelastic is injected with a 26-gauge needle through the presumed site of side port entry This inflates the chamber and prevents its collapse when the chamber is entered with the keratome. A straight rod is passed through this site to achieve akinesia and a clear corneal temporal valve is made with the keratome. A continuous curvilinear capsulorrhexis (CCC) is performed followed by hydrodissection and rotation of the nucleus. After enlarging the side-port, a 20-gauge irrigating chopper connected to the infusion line of the phaco machine is introduced with foot pedal on position 1. The phaco probe is connected to the aspiration line and the phaco tip without an infusion sleeve is introduced through the main port. (Figure 24-1). Using the phaco tip with moderate ultrasound power, the center of the nucleus is directly embedded starting from the superior edge of rhexis with the phaco probe directed obliquely downward towards the vitreous. The settings at this stage are 50% phaco power, flow rate 24.0 mL/min and 110.0 mmHg vacuum. The machine used was the Alcon Universal II (Fort Worth, Tex). When nearly half of the center of the nucleus is embedded, the foot pedal is moved to position 2 as it helps to hold the nucleus due to vacuum rise. To avoid undue pressure on the posterior capsule, the nucleus is lifted slightly and with the irrigating chopper in the left hand, the nucleus is chopped. This is done with a straight downward motion from the inner edge of the rhexis to the center of the nucleus and then to the left in the form of a laterally-reversed "L" shape. Once the crack is created, the nucleus is split to the center. The nucleus is then rotated 180 degrees and cracked again so that it is completely split into two halves. With the previously described technique, three pie-shaped quadrants are created in each half of the nucleus. With a short burst of energy at pulse mode, each pie-shaped fragment is lifted and brought at the level of the iris where it is further emulsified and aspirated sequentially in pulse mode. Thus the whole nucleus is removed. Cortical wash-up is then done with the bimanual irrigation aspiration technique.

The lens is taken out from the bottle and placed in a bowl of BSS solution of approximately body temperature to make the lens pliable. It is then rolled with the gloved hand holding it between the index finger and the thumb. The lens is then inserted through the incision carefully. (At present, ThinOptX have also made a roller/injector for their lenses—see Figure 12-14.) The teardrop on the haptic should be pointing in a clockwise direction so that the smooth optic lenticular surface faces posteriorly. The
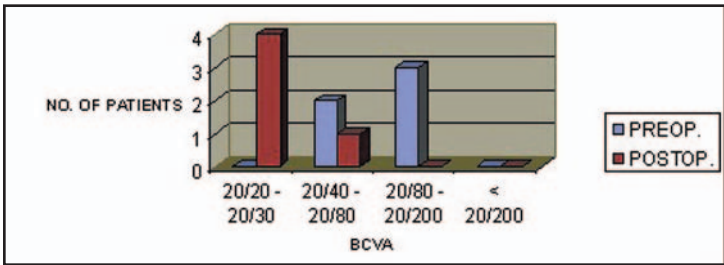
Figure 24-2. Comparison of pre- and postoperative BCVA.
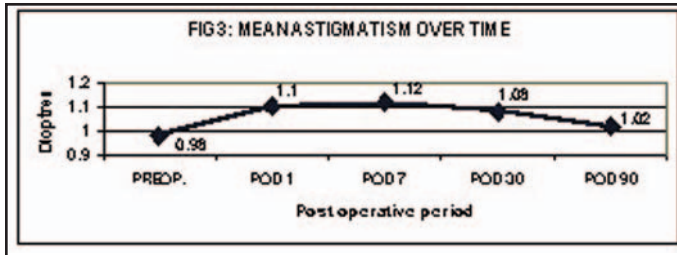
Figure 24-3. Mean astigmatism over time.

TABLE 24-1					
PRE- AND POSTOPERATIVE MEAN ASTIGMATISM					
Time	*Eyes*	*Mean*	*Std. Dev.*	*Minimum*	*Maximum*
Preop	5	0.98	0.62	0.5	1.8
POD 1	5	1.1	0.61	0.6	1.9
POD 7	5	1.12	0.58	0.5	1.7
POD 30	5	1.08	0.62	0.5	1.8
POD 90	5	1.02	0.64	0.3	1.7

natural warmth of the eye causes the lens to open gradually. Viscoelastic is then removed with the bimanual irrigation aspiration probes.

TOPOGRAPHIC ANALYSIS AND ASTIGMATISM

The preoperative best corrected visual acuity (BCVA) ranged from 20/60 to 20/200. The mean preoperative. astigmatism as detected by topographic analysis was 0.98 D ± 0.62 D (range 0.5 to 1.8 D).

The postoperative course was uneventful in all cases. The IOL was well-centered in the capsular bag. There were no corneal burns in any of the cases.

Four eyes had a best-corrected visual acuity (BCVA) of 20/30 or better. One eye that had dry ARMD showed an improvement in BCVA from 20/200 to 20/60. Figure 24-2 shows a comparison of the pre and postoperative BCVA. The mean astigmatism on postoperative day 1 on topographic analysis was 1.1 ± 0.61 D (range 0.6 to 1.9 D) as compared to 0.98 D ± 0.62 D (range 0.5 to 1.8 D) preoperatively. The mean astigmatism was 1.02 ± 0.64 D (range 0.3 to 1.7 D) by 3 months postoperatively. Figures 24-3 and Table 24-1 shows mean astigmatism over time. Figures 24-4A and 24-4B show a comparison of the astigmatism over the pre- and postsurgical period.

Figure 24-4A. Comparison of pre- and postoperative day 1 cylinder.
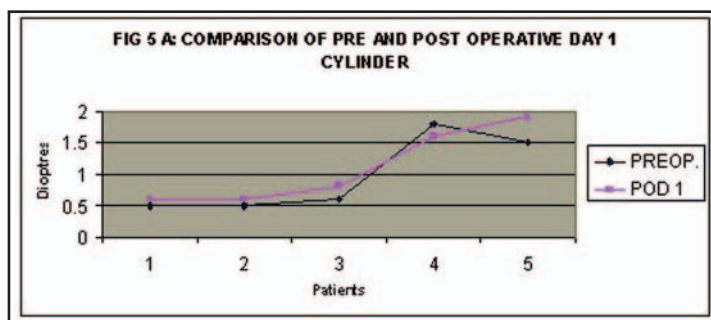
Figure 24-4B. Comparison of 1 day postoperative and 3 months postoperative astigmatism.
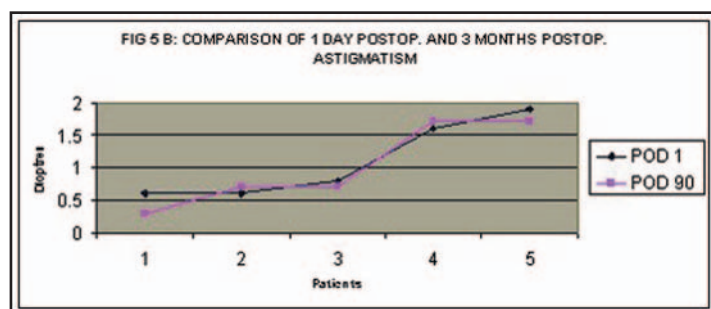
Discussion

Cataract surgery has witnessed great advancements in surgical technique, foldable IOLs, and phaco technology. This has made easier and safer cataract extraction utilizing smaller incisions possible. With the advent of the latest IOL technology that enables implantation through ultrasmall incisions, it is clear that this will soon replace routine phacoemulsification through the standard 3.2-mm incisions. The ThinOptX IOL design is based on the Fresnel principle. Flexibility and good memory are important characteristics of the lens. It is manufactured from hydrophilic acrylic materials and is available in a range from -25 to +30 with the lens thickness ranging from 30 μm up to 350 μm. I modified the lens further by reducing the optic size to 5.0 mm so it will fit through a smaller incision.

In this study, no intraoperative complications were encountered during CCC, phacoemulsification, cortical aspiration, or IOL lens insertion in any of the cases. The mean phacoemulsification time was 0.66 minutes. Previous series by the same authors showed more than 300 eyes where cataract surgery was successfully performed using the sub-1.0 mm incision.[3] Our experience and that of several other surgeons suggests that with existing phacoemulsification technology, it is possible to perform phacoemulsification through ultra-small incisions without significant complications.[2-6] In a recent study from Japan, Tsuneoka and associates[6] used a sleeveless phaco tip to perform bimanual phaco in 637 cataractous eyes. All cataracts were safely removed by these authors through an incision of 1.4 mm or smaller that was widened for IOL insertion, without a case of thermal burn and with few intraoperative complications. Furthermore, ongoing research for the development of laser probes,[7,8] cold phaco, and microphaco confirms the interest of leading ophthalmologists and manufacturers in the direction of ultrasmall incisional cataract surgery.[9]
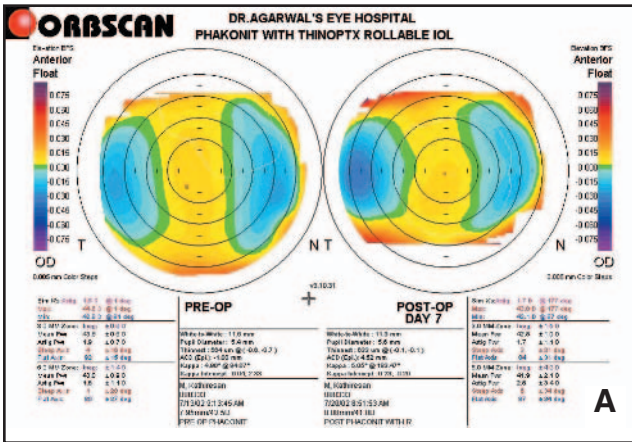
Figure 24-5A and B. Topographical comparison during different surgical periods.
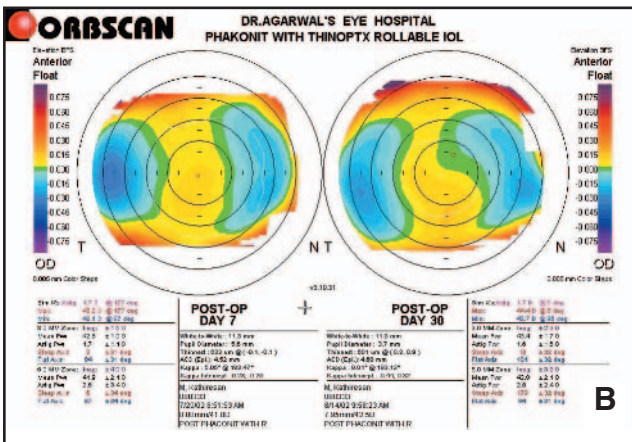
The postoperative course was uneventful in all the cases. The IOL was well-centered in the capsular bag. There were no significant corneal burns in any of the cases. Final visual outcome was satisfactory with four of the eyes having a BCVA of 20/30 or better. One eye that had dry ARMD showed an improvement in BCVA from 20/200 to 20/60. Thus, the lens was found to have satisfactory optical performance within the eye. In our study, the mean astigmatism on topographical analysis was 0.98 ± 0.62 D (range 0.5 to 1.8 D) preoperatively, 1.1 ± 0.61 D (range 0.6 to 1.9 D) on postoperative day 1 and 1.02 ± 0.64 D (range 0.3 to 1.7 D) by 3 months postoperatively. Figures 24-4A and 24-4B show a comparison of the- pre and postoperative astigmatism and clearly indicate that bimanual phaco with an ultrathin 5.0 mm rollable IOL is virtually astigmatically neutral. Figures 24-5A and 24-5B depict the topography comparison in different surgical periods and clearly show the virtual astigmatic neutrality of the procedure and stability throughout the postoperative course.

There is an active ongoing attempt to develop newer IOLs that can go through smaller and smaller incisions. Bimanual phaco ThinOptX modified ultrathin rollable IOL is the first prototype IOL which can go through sub-1.4 mm incisions. Research is also being done to manufacture this IOL using hydrophobic acrylic biomaterials combined with square-edged optics to minimize posterior capsule opacification.

SUMMARY

Bimanual phaco with an ultrathin 5.0-mm optic rollable IOL implantation is a safe and effective technique of cataract extraction, the greatest advantage of this technique being virtual astigmatic neutrality.

KEY POINTS

✔ With the availability of the ThinOptX rollable IOL that can be inserted through sub-1.4 mm incision, the full potential of bimanual phaco can be realized.

✔ With the advent of the latest IOL technology that enables implantation through ultrasmall incisions, it is clear that this will soon replace routine phacoemulsification through the standard 3.2-mm incisions

✔ The ThinOptX IOL design is based on the Fresnel principle.

✔ A comparison of the pre- and postoperative astigmatism indicate clearly that bimanual phaco with an ultrathin 5.0-mm rollable IOL is virtually astigmatically neutral.

✔ The stability of refraction occurs within 4 days in bimanual phaco compared to 2 to 3 weeks in phaco.

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Bimanual Phaco Surgery With an AcrySof IOL Through a 2.2-mm Opening

Hiroshi Tsuneoka, MD

Introduction

Current bimanual phaco surgery (Phakonit, MICS, microphaco, etc) makes it possible to safely remove the lens through an incision of 0.9 to 1.4 mm,[1-2] and several companies are developing soft foldable lenses which are thinner than the current commercially available foldable intraocular lenses (IOLs). In Europe, we can see the marketing of IOLs which can be inserted through an incision of 2.0 mm or less. However, in the United States and Japan, there have been no commercially available IOLs that can be inserted through such a small incision, so we have been forced to enlarge the incision to 2.8 to 4.1 mm in order to insert the IOL.[3]

Recently, however, I successfully modified a commercially available IOL injector so that the cartridge can insert a soft acrylic lens having an optic diameter of 5.5 mm (AcrySof, Alcon, Fort Worth, Texas) through a 2.2-mm incision.[4] This development increases the importance of being able to perform lens extraction through an ultrasmall incision of less than 1.5 mm.

My Technique of Bimanual Phaco Surgery

Two-Stab Corneal Incision

A 19- or 20-gauge keratome is used to make a temporal clear corneal incision into the anterior chamber for a 20-gauge phaco tip (Figure 25-1). A superior nasal side-port is created using a 20-gauge keratome for a 20-gauge irrigating chopper. These incisions are approximately 0.9 mm in length.

The surgeon sits at the patient's head, and uses the phaco tip with his right hand and the irrigating chopper with his left hand for the right eye, but uses the phaco tip with his left hand and the irrigating chopper with his right hand for the left eye.

Figure 25-1. A 19-gauge keratome is used to make a temporal clear corneal incision into the anterior chamber for a 20-gauge phaco tip.
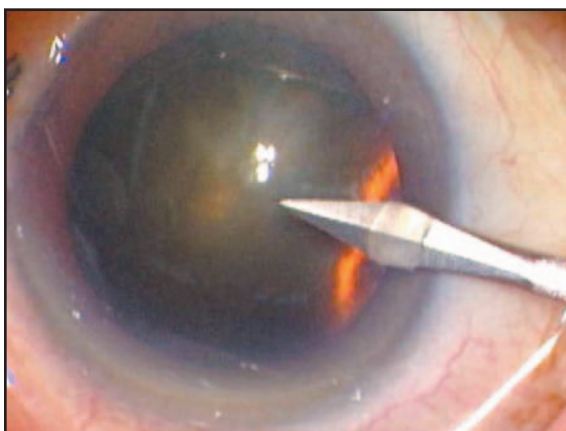
Figure 25-2. A Tsuneoka irrigating chopper (MST) is inserted through the superior nasal side port. A sleeveless 20-gauge phaco tip is inserted through the temporal clear corneal incision, and bimanual nucleofractis is carried out using the hook of the irrigating chopper.
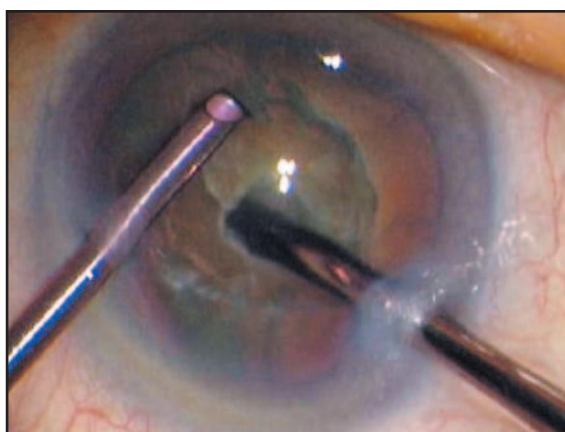
Anterior Capsulorrhexis and Hydrodissection

A 26-gauge needle or a microincision capsulorrhexis forceps is used to perform continuous curvilinear capsulorrhexis (CCC) with a diameter of approximately 5.0 mm, after which hydrodissection is started. *In order to prevent an abrupt rise in anterior chamber pressure, it is important to press the base of the hydrodissection needle firmly down against the lower side of the incision so that excess fluid can leak out of the incision during the procedure.*

Phacoemulsification and Aspiration of a Nucleus

A Tsuneoka irrigating chopper (MST, Redmond, Wash) is inserted through the superior nasal side port (Figure 25-2), and a sleeveless 20-gauge phaco tip is inserted through the temporal clear corneal incision.

Bimanual nucleofractis technique is used to emulsify and aspirate the nucleus with the hook at the tip of the infusion chopper. The divide and conquer, quick chop (karate chop), or crater and vertical chop methods are chosen depending on nucleus hardness.
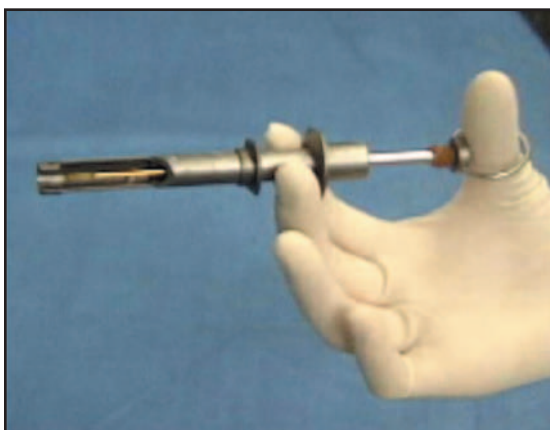
Figure 25-3. Modified Royal injector. The plunger can be operated with one hand when using the injector Royal.

To keep the anterior chamber depth stable, it is very important to balance the settings for phaco tip aspiration (flow rate and maximum aspiration pressure) with the rate of side port infusion. In order to obtain satisfactory infusion flow, irrigating choppers of Duet's system (MST, Redmond, Wash) are recommended. The parameters of the phacoemulsification unit (flow rate and maximum aspiration pressure) should be set to provide the appropriate aspiration level in order to maintain the balance between infusion and aspiration.

To improve the safety of this surgery, it is important to set the ultrasound power as low as is feasible. Pulse mode oscillation is recommended to reduce the extent of endothelial injury from nucleus "kick" and thermal injury at the incision site.

When emulsifying hard nuclei, considerable heat can be generated by the phaco tip, making it necessary to provide sufficient leakage of infusion solution through the incision in order to cool the tip and prevent thermal burn. In such cases, a 19-gauge keratome should be used to create the incision for the 20-gauge phaco tip.

Aspiration of the Residual Cortex

The residual cortical fragments can be aspirated through a micro incision using a 23-gauge side port aspiration cannula. When it is difficult to aspirate cortical fragments below the incision, the positions of the irrigating chopper and the aspiration cannula can be reversed so that these fragments can be safely aspirated.

TECHNIQUES FOR INSERTING ACRYSOF SA30AT THROUGH A 2.2-MM OPENING

Modified Injector System

I have succeeded in inserting Alcon acrylic foldable lenses having an optic diameter of 5.5 mm (the AcrySof SA30AT) through a 2.2 mm incision by using a cartridge (Monarch IIC) and an injector (Royal) manufactured by ASICO (Westmont, Ill) and modified in my laboratory (Figure 25-3).

When using the Royal injector, I can operate the plunger with one hand, which leaves my other hand free to stabilize the eyeball. When inserting an IOL, it is neces-

Figure 25-4. The plunger length should be adjusted by placing a rubber ring at the back end of the plunger to avoid posterior capsule rupture.

Figure 25-5. How to insert the AcrySof SA30AT through a 2.2-mm opening. The injector is positioned so that the front tip of the cartridge tip is pressed against the incision but does not project into the anterior chamber.
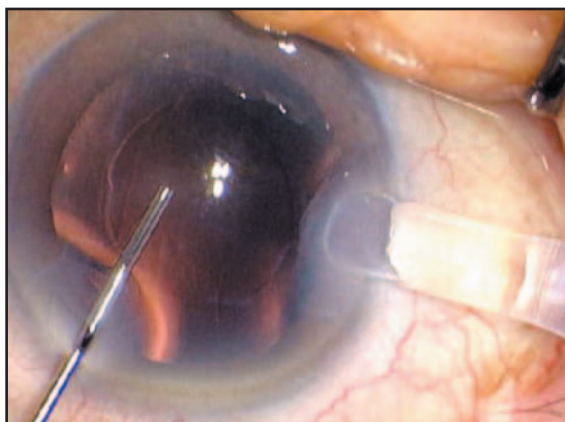
sary to press firmly on the plunger during insertion. However, too much pressure can cause the lens to be inserted too deeply within the eye, which can result in posterior capsular rupture. Because the plunger is a little too long on ASICO's commercially available Royal injector, I have adjusted the plunger length by placing a rubber ring at the back end of the plunger (Figure 25-4). This allows me to press firmly on the plunger during insertion without placing the IOL too deeply in the eye, and avoids posterior capsular rupture. Also, since the stopper is made of rubber, after most of the IOL is inserted within the eye I can press slowly on the plunger again to adjust the position of the IOL.

How to Insert the Acrysof SA30AT Through a 2.2-mm Opening

After the micro incision of 1.2 to 1.4 mm is enlarged using a 2.2-mm keratome, I load a single-piece AcrySof SA30AT (5.5.mm optic) into a Monarch IIC cartridge, which is set in the modified Royal injector.

The injector is positioned so that the front tip of the cartridge tip is pressed against the incision but does not project into the anterior chamber (Figure 25-5). As the tip of the lens moves through the incision, I insert an appropriate tool, such as a Sinskey hook, through the side-port and apply pressure to ensure that the patient's eye is turned
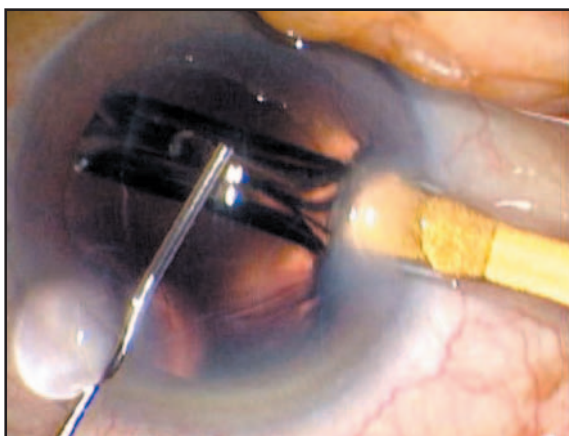
Figure 25-6. As the tip of the lens moves through the incision, an appropriate tool, such as a Sinskey hook, is inserted through the side port to apply pressure to ensure that the patient's eye is turned toward the incision. The plunger is pressed without decreasing the pressure of the cartridge on the incision, until the entire optic and the trailing loop are within the anterior chamber. The hook is used to rotate the lens and to insert the trailing loop into the capsular bag.
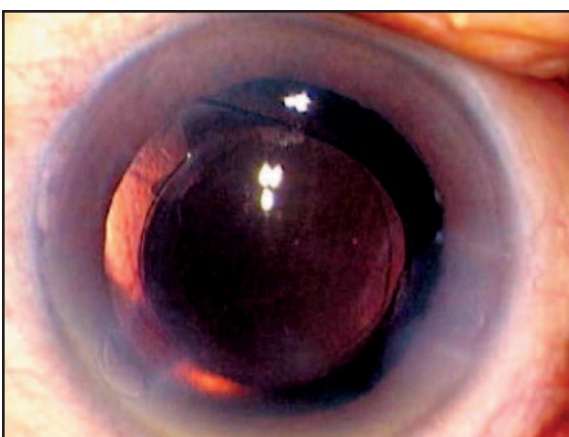
Figure 25-7. IOL in the bag.

toward the incision. After positioning the cartridge tip so that it elevates the inner edge of the corneal incision and presses down on the outer edge, I slowly press the injector plunger forward, without decreasing the pressure of the cartridge on the incision, until the entire optic and the trailing loop are within the anterior chamber (Figure 25-6). I then use the hook to rotate the lens and to insert the trailing loop into the capsular bag (Figure 25-7).

Final Incision Size After the IOL Insertion

Immediately after implanting the IOL, I verify the final incision size with a Tsuneoka microincision caliper (ASICO).

Central positioning of the inserted IOL was satisfactory, and I noted no instances of damage to either the optic or the haptic of the IOL. Following aspiration of the viscoelastic substance, all incisions self sealed. No suturing was required in any of these patients.

Because the central thickness of the AcrySof SA30AT varies depending on lens diopter, it is not possible to insert IOLs of all diopter levels through a 2.2-mm incision. I experienced no problem when using IOLs less than 20 diopter (D), but it may be safer to use an incision of 2.3 to 2.4 mm for 20 D or above.

SUMMARY

Until recently, even if we could remove the original lens through an incision of less than 1.5 mm it was still necessary to enlarge the incision to 2.8 to 4.1 mm in order to insert the IOL. It is thus quite significant that we are now able to implant the AcrySof SA30AT, which is highly reliable and one of the most widely used foldable IOLs in the world, through an incision of 2.2 mm. Currently a number of companies are working to develop soft foldable lenses that are even thinner than the foldable IOLs now commercially available, and insertion systems are also being improved. I thus expect that we will soon have IOLs which can be inserted through a 1.5-mm incision in Japan and the United States. At that point it will become quite important to be able to remove the original lens through an incision of 1.5 mm or less, and bimanual phaco surgery using a sleeveless phaco tip will appear even more promising as a technique for lens removal.

KEY POINTS

✔ A commercially available IOL injector has been modified so that the cartridge can insert a soft acrylic lens having an optic diameter of 5.5 mm (AcrySof SA30AT) through a 2.2-mm incision.

✔ In order to prevent an abrupt rise in anterior chamber pressure while doing hydrodissection in bimanual phaco, it is important to press the base of the hydrodissection needle firmly down against the lower side of the incision so that excess fluid can leak out of the incision during the procedure.

✔ To keep the anterior chamber depth stable, it is very important to balance the settings for phaco tip aspiration (flow rate and maximum aspiration pressure) with the rate of side port infusion.

✔ One can insert an Alcon acrylic foldable lenses having an optic diameter of 5.5 mm (the AcrySof SA30AT) through a 2.2-mm incision by using a cartridge (Monarch IIC) and a Royal injector manufactured by ASICO.

✔ The injector is positioned so that the front tip of the cartridge tip is pressed against the incision but does not project into the anterior chamber.

✔ As the central thickness of the AcrySof SA30AT varies depending on the lens diopter, it is not possible to insert IOLs of all diopter levels through a 2.2-mm incision. It is safer to use an incision of 2.3 to 2.4 mm for 20 D or above IOLs.

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Ultrasmall Incision IOLs: Experimental Studies and Clinical Applications

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Introduction

The evolution of cataract surgery and the intraocular lens (IOL) since Sir Harold Ridley's invention of the implant in 1949 has been one of the stellar achievements in current ophthalmology.[1] The advent of small-incision cataract surgery made possible by phacoemulsification and foldable IOLs represents a major milestone in this evolutionary process. Phacoemulsification has become the preferred method of cataract surgery owing to numerous advantages such as a small self-sealing incision, less surgically induced astigmatism, and a closed-chamber with controlled capsular surgery.[2] Our experience and that of several other surgeons suggests that with evolving phaco technology, it is possible to perform bimanual microphacoemulsification through ultrasmall incisions (less than 1.2 mm) without significant complications.[3-12] As IOL technology that enables insertion through very small surgical wounds becomes available, it is clear that ultrasmall incision cataract surgery will become more commonplace.

Acri.Smart Lens

The first ultrasmall incision IOL available for implantation through sub-2.0 mm incisions was the Acri.Smart lens (model H44-IC-1, manufactured by Acri.Tec GmbH [Berlin, Germany]).[9] The Acri.Smart lens is a hydrophilic acrylic lens with 25% water content and a hydrophobic coating. The overall design is that of a plate haptic lens with square edges. The lens has an optical diameter of 6 mm and a total length of 12.3 mm. Therefore, a folded +19-diopter (D) lens with a width of about 1.2 to 1.3 mm can be inserted through an ultrasmall incision. Acri.Smart lenses (model 48S with a 5.5-mm optic, and model 46S with a 6.0-mm optic) have been developed for implantation with a specially designed injector through a sub-2.0-mm incision. Their overall design is that of plate haptic lenses with square edges, which are loaded into the injector already in a hydrated state, thus the unfolding is faster than with the dehydrated version. A recently published report indicates that Acri.Smart can be inserted through a sub-2.0-mm incision and unfolds slowly in the capsular bag, being completely unfold-

Figure 26-1. Photograph illustrating the design and performance of the Acri.Tec Acri.Smart lens in a laboratory setting. Miyake-Apple view showing a well-centered Acri.Smart lens (model H44-IC-1) in the capsular bag of a human eye obtained postmortem.

ed within a half-hour.[9] Model 36A, with a special aspherical design, has also been developed to compensate for the positive spherical aberration of the cornea, in a mechanism probably similar to that of the Tecnis lens.[12]

Experimental studies using the closed-system and the Miyake-Apple posterior video techniques suggest that it is possible to insert the Acri.Smart lens through a sub 2.0-mm incision in postmortem human eyes. Figure 26-1 illustrates well-controlled unfolding of the Acri.Smart lens design. The capsulorrhexis opening and the capsular bag geometry were well-maintained without any evidence of ovaling or distortion.

THINOPTX ULTRACHOICE IOL

Another lens available for insertion through a sub-2.0-mm incision is the UltraChoice (ThinOptX, Abingdon, Va) lens.[8] The ThinOptX IOL is manufactured from hydrophilic acrylic material with 18% water content. The refractive index of the material is 1.47. The dioptric power of this lens ranges from +15 to +25 D, as of April 2003. The optical thickness is 300 to 400 μm, with a biconvex optical configuration having a meniscus shape. The overall diameter of the lens is 11.2 mm, and the optical diameter is 5.5 mm. The ultrathin properties of the lens are attributable to its Fresnel optic design. Other unique properties of the ThinOptX IOL include its flexibility and ability to retain original memory. The manufacturer has received CE Mark approval for the UltraChoice monofocal cataract lens in September, 2002 in Europe and US Food and Drug Administration (FDA) trials are in progress in the United States.

Experimental studies using the closed-system and Miyake-Apple posterior video technique suggest that it is possible to insert the rolled/folded lens through a sub-2.0-mm incision in postmortem eyes. The Miyake-Apple posterior video technique demonstrated well-controlled unrolling/unfolding of the ThinOptX UltraChoice lens design in the capsular bag after injection of body temperature balanced salt solution (BSS). The capsulorrhexis opening and the capsular bag geometry were well-maintained. The lens was well-centered in the bag and removal of residual viscoelastic was not difficult.

Clinical experience with the ThinOptX IOL was recently reported by Dogru and associates.[13] These authors prospectively assessed the clinical and visual outcomes of phacoemulsification and implantation of a rollable ThinOptX IOL and compared the results with those of implantation of a foldable hydrophobic acrylic IOL (AcrySof MA60BM) in 16 consecutive eyes of 8 patients with corticonuclear cataract. The patients' refractive status and uncorrected and best-corrected distance visual acuities,

Figure 26-2. Photograph illustrating design characteristics and experimental performance of the one-piece SmartIOL. At room temperature, the SmartIOL biomaterial is formed into a solid rod of approximately 30.0 mm length and 2.0 mm width. There is a transformation of the rod into a biconvex lens, after immersion in BSS at body temperature.

and contrast sensitivity were assessed preoperatively and 1 week and 1, 3, and 6 months after surgery. Results of this study suggested that the ThinOptX IOL provided best corrected near and distance visual acuities comparable to those provided by the AcrySof IOLs. The significantly higher contrast acuities attained after implantation of the ThinOptX lens may be attributable to its ultrathin properties.

MEDENNIUM SMARTIOL

The third ultrasmall incision IOL in the experimental, preclinical phase is the SmartIOL (Medennium Inc, Irvine, Calif). This is made of a thermoplastic hydrophobic acrylic gel polymer that can be formed to any size and shape with any dioptric power imprinted on it. The refractive index of the hydrophobic acrylic biomaterial is 1.47, and the glass transition temperature is 20 to 30° C. At room temperature or colder, the material is formed into a rod of approximately 30.0 mm length and 2.0 mm width for implantation through a small incision (Figure 26-2). Upon reaching body temperature the IOL reconfigures into its original size, and fills the entire capsular bag. This process takes about 30 seconds and results in a lens about 9.5 mm wide and 2.0 to 4.0 mm thick (averaging about 3.5 mm at the center), depending on the dioptric power. According to the Helmholtz theory, presbyopia is caused by loss of flexibility in the ageing lens. Because it entirely fills the capsular bag, the SmartIOL may theoretically restore accommodation. Due to its high refractive index, small changes in the shape will result in significant changes in the lens power. The hydrophobic acrylic biomaterial is expected to adhere to the lens capsule, which may possibly reduce capsular bag opacification. Furthermore, a lens that has the dimensions of a natural lens will not cause problems with decentration or edge glare and could reduce spherical aberration induced by many IOLs. A new design (three-piece SmartIOL with polyvinylidene fluoride [PVDF] haptics) is under investigation, which will probably eliminate potential problems related to the different diameters of the capsular bags in different eyes.

Experimental studies using the closed-system and the Miyake-Apple posterior video technique demonstrated that experimental designs of one-piece and three-piece

Figure 26-3. Photograph obtained from the Miyake-Apple posterior video technique showing the unfolding of the three-piece SmartIOL within the capsular bag of a postmortem human eye after injecting body temperature BSS.

SmartIOLs centered well within the capsular bag without any evidence of capsular bag distortion (Figure 26-3).

Summary and Conclusions

Globally, contemporary cataract surgeons have witnessed great advancements in cataract surgery, foldable IOLs and phaco technology. Ultrasmall incision lenses (Acri.Smart, ThinOptX UltraChoice, and SmartIOL) are being developed by the manufacturers that will take advantage of microincision cataract surgery. Many other companies are working on innovative microincision IOL designs. Experimental studies using the Miyake-Apple posterior video technique confirmed the well-maintained configuration of the capsular bag after implantation of these lens designs. It was possible to insert Acri.Smart and UltraChoice IOLs through sub-2.0 mm incisions as indicated by recent clinical and laboratory studies. A short-term clinical study of the ThinOptX UltraChoice IOL suggests that this design provides good visual outcome, and better contrast sensitivity than a common foldable IOL due to its ultrathin properties.

Acknowledgment

KEY POINTS

✔ The Acri.Smart lens is a hydrophilic acrylic lens with 25% water content and a hydrophobic coating. The overall design is that of a plate haptic lens with square edges. Model 36A, with a special aspherical design has also been developed to compensate for the positive spherical aberration of the cornea, in a mechanism probably similar to that of the Tecnis lens.

✔ The ThinOptX IOL is manufactured from off-the-shelf hydrophilic acrylic material with 18% water content.

✔ The ultrathin properties of the ThinOptX IOL are attributable to its Fresnel optic design. Other unique properties of the ThinOptX IOL include its flexibility and ability to retain original memory.

✔ The SmartIOL is made of a thermoplastic hydrophobic acrylic gel polymer that can be formed to any size and shape with any dioptric power imprinted on it.

✔ At room temperature, the SmartIOL is formed into a rod of approximately 30 mm length and 2.0 mm width for implantation through a small incision. Upon reaching body temperature the IOL reconfigures into its original size, and fills the entire capsular bag.

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SEALED CAPSULE IRRIGATION DEVICE

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HISTORY

One of the real concerns in cataract surgery is posterior capsule opacification. It has not been possible to effectively isolate and specifically target lens epithelial cells following phacoemulsification. Dr. Anthony Maloof from Australia developed and designed a disposable instrument (Figure 27-1) called the Perfect Capsule (Milvella Pty. Ltd, Sydney, Australia) which helps selective targeting of the lens epithelial cells with a new technique called the sealed capsule irrigation (SCI) device. This device has been used in human eyes by many surgeons since then. On July 11, 2003, the first live surgery in a conference showing the SCI after bimanual phaco cataract surgery under no anesthesia[1-3] was telecast during the Indian Intraocular Implant and Refractive Surgery Conference at Chennai, India by the author. With more and more ultrasmall incision IOLs coming into the market, the goal will be to create them with a sharp edge optic to prevent posterior capsular opacification. The sealed capsule irrigation device will be a handy tool then in bimanual phaco once the device is perfected to pass through 1.0 mm incision.

PRINCIPLE

Using an injection-molded (Figure 27-2) silicone device, sealed capsule irrigation[4-5] isolates the internal lens capsule—including residual lens epithelial cells—from the rest of the eye. The basic idea is to seal the rhexis (Figure 27-3) and then irrigate the capsular bag with an irrigating solution (Figure 27-4) which would prevent posterior capsular opacification. The main point here is that the sealing of the capsule should be perfect so that the surgeon can irrigate the capsular bag without it leaking into the anterior chamber. Then finally the device is removed from the eye (Figure 27-5).

Figure 27-1. Perfect capsule.
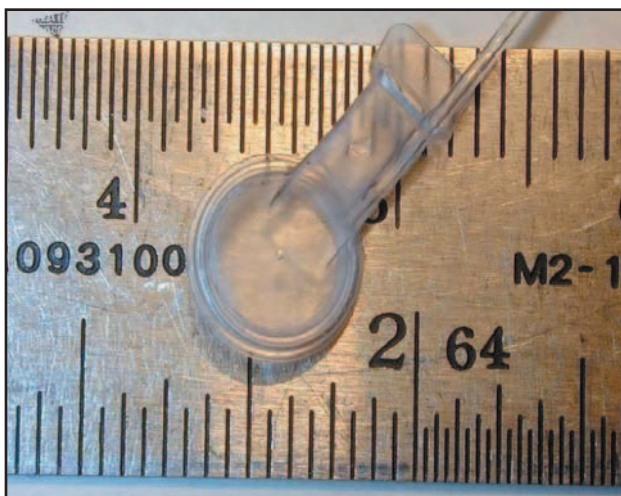
Figure 27-2. Perfect capsule passed into the eye.
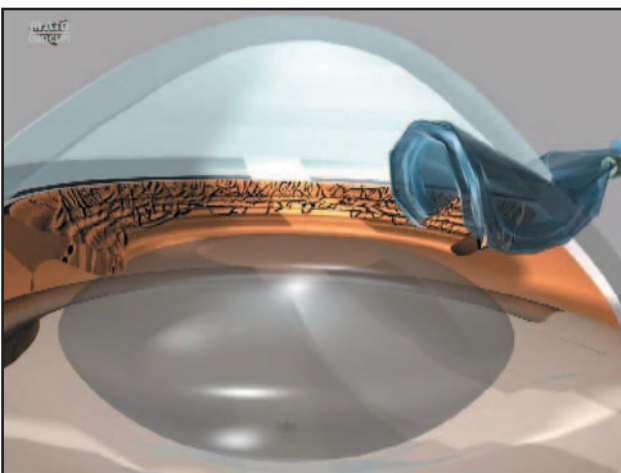
Figure 27-3. Perfect capsule is placed onto the capsular bag and vacuum activated by a syringe.
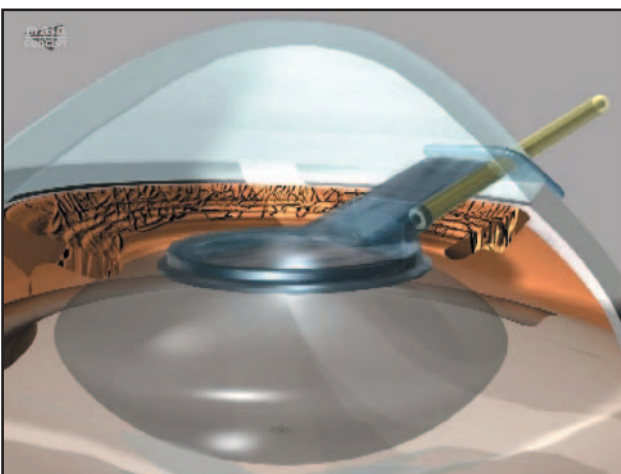
Figure 27-4. Irrigation of the capsular bag is done.
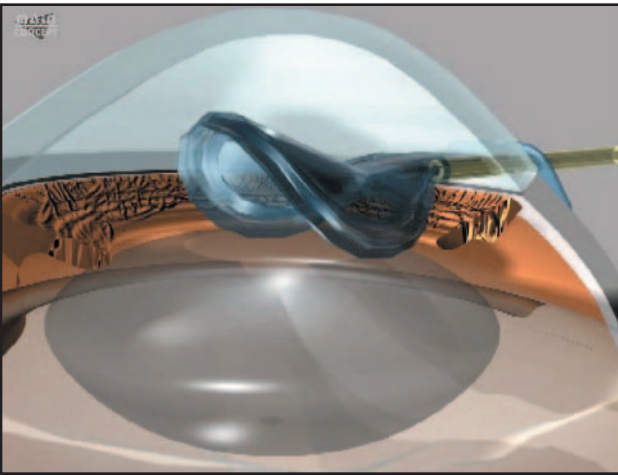
Figure 27-5. Perfect capsule is removed from the eye.

PERFECT CAPSULE

The sealed capsule irrigation device (see Figure 27-1) known as perfect capsule (Milvella, Australia) is made of medical grade silicone. It has an overall diameter of 7.0 mm and an inner diameter of 5.0 mm. It has been designed to temporarily seal a rhexis of less than 5.0 mm. The device utilizes a vacuum ring (similar to that used to fixate the globe during LASIK), which attaches onto the outer surface of the anterior lens capsule and seals around the rhexis. There is a separate channel through which one can pass an irrigating solution into the capsular bag and through that same area there is a channel for the outflow of fluid.

SURGICAL TECHNIQUE

The tunnel construction is very important—it should be short and steep, pointing towards the rhexis. This allows a proper placement of the perfect capsule on the capsular bag, especially in high myopic eyes where the AC is deep. The next step is to perform a rhexis of less than 5.0 mm. After removing the nucleus and cortical aspiration,

Figure 27-6. The perfect capsule is folded and inserted through a 3.0-mm incision.
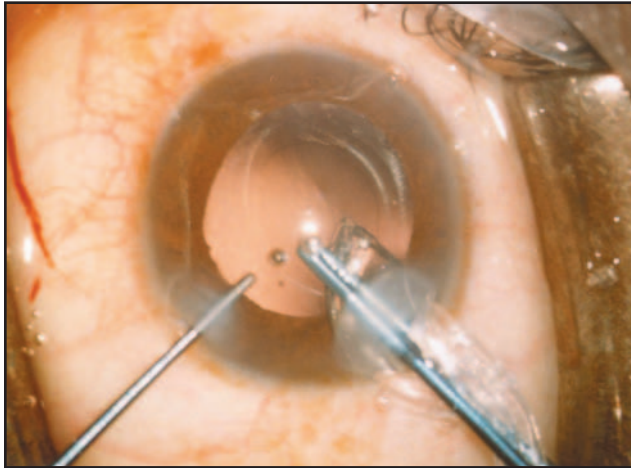
Figure 27-7. Once the perfect capsule is in place, irrigation of the capsular bag is done with distilled water and then finally the perfect capsule is removed.
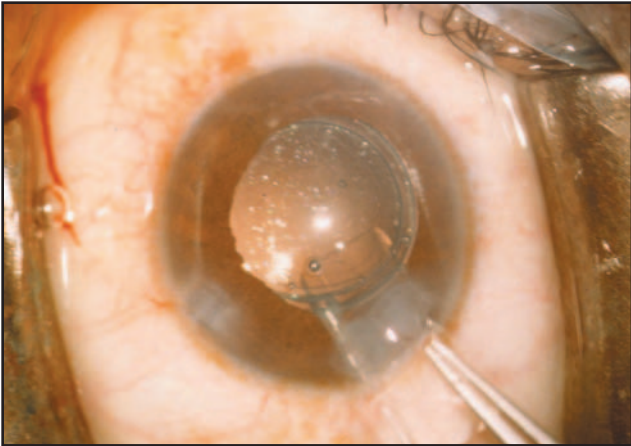
one should fill the chamber a little bit with viscoelastic. Then the perfect capsule is taken out of its sterile package. The perfect capsule is held with a forceps and as it is soft it can be folded and passed through a 3.2-mm incision (Figure 27-6). If one has done bimanual phaco, the 1.0-mm incision has to be increased. Once folded the forceps is passed into the anterior chamber with the perfect capsule. The perfect capsule then unfolds inside the anterior chamber. Using the left hand with a globe stabilization rod one should press gently on the perfect capsule so that it touches the anterior capsule. Once done then the assistant is told to pull the syringe connected to the perfect capsule and lock it. This syringe creates a suction so that the perfect capsule seals the rhexis margin (Figure 27-7). One should be careful that the iris does not get stuck in between the capsule and the perfect capsule.

Once the sealing has been done one can inject Trypan Blue (Blurhex, Dr. Agarwal's Pharma, Chennai, India) via a cannula through the opening in the perfect capsule meant for irrigation. The Blurhex will not leak into the anterior chamber. This indicates the sealing is perfect. Then the capsular bag is irrigated with distilled water. The distilled water will not come into contact with any other structures as it passes in and out of the capsular bag. We used the air pump in the irrigation to make the flow through the cannula better (see Chapter 7).

Once done, the next step is to remove the perfect capsule. For this, the assistant disengages the lock in the syringe so that the suction is broken. Then gradually viscoelastic is injected inside the eye. Then the perfect capsule is disengaged from the capsule with the globe stabilization rod. Once it is free in the anterior chamber the perfect capsule is pulled out of the eye. As it is soft, it comes out quite comfortably.

RESEARCH

Further research has to be done to use cytotoxic drugs which will prevent posterior capsule opacification. This is just the beginning and not the end. Today we are able to seal the capsular bag effectively and this can lead to many more uses in the future. We are now trying to work on the perfect capsule so that it can be passed through a sub-1.5-mm incision so that one can use it after bimanual phaco. The point here is that microlenses will not need a sharp optic to reduce the posterior capsular opacification.

SCI was started off with focusing on prevention of PCO, however today with all the feedback from surgeons who have seen and used it, SCI will be widened in its positioning. SCI is targeted to maintain a clear capsular bag and through this provide long term quality of vision. This is immediately relevant for:

1. Any lens-based refractive procedure (accommodating lenses, clear lens extraction/multifocal lenses, piggyback lenses).
2. Cataract surgery where in the future one can implant IOLs without sharp edges—and using lens materials which today are seen as inferior (eg, hydrophilic, silicone, etc)—to introduce optically improved materials with improved techniques like bimanual phaco.
3. Midterm relevance for retinal surgeons who benefit from clear capsules when doing a vitrectomy.

KEY POINTS

✔ With more and more ultrasmall incision IOLs coming into the market, the goal will be to create them with a sharp edge optic to prevent posterior capsular opacification. The sealed capsule irrigation device will be a handy tool then in bimanual phaco once the device is perfected to pass through 1.0 mm incision.

✔ The basic idea is to seal the rhexis and then irrigate the capsular bag with an irrigating solution which would prevent posterior capsular opacification.

✔ The sealed capsule irrigation device known as perfect capsule (Milvella, Australia) is made of medical grade silicone.

✔ One can use the air pump to irrigate the bag with distilled water.

✔ Further research has to be done to use cytotoxic drugs to prevent posterior capsule opacification.

✔ There is a midterm relevance for retinal surgeons who benefit from clear capsules when doing a vitrectomy.

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