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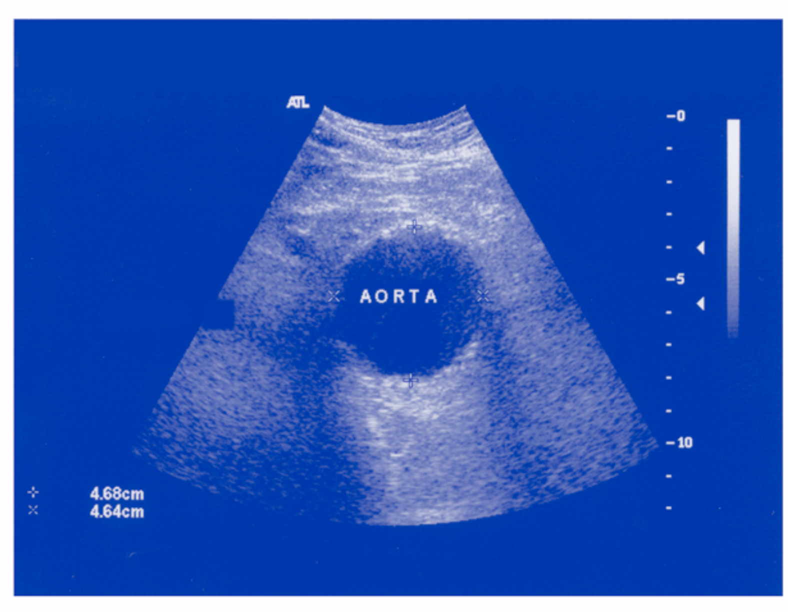

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Ultrasound for Surgeons

Heidi L. Frankel, M.D., F.A.C.S.
Associate Professor of Surgery
Section of Trauma and Surgical Critical Care
Yale University
New Haven, Connecticut, U.S.A.

LANDES
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VADEMECUM
Ultrasound for Surgeons
LANDES BIOSCIENCE
Georgetown, Texas U.S.A.

Printed in the U.S.A.

Please address all inquiries to the Publisher:
Landes Bioscience, 810 S. Church Street, Georgetown, Texas, U.S.A. 78626
Phone: 512/ 863 7762; FAX: 512/ 863 0081

ISBN: 1-57059-597-6

Library of Congress Cataloging-in-Publication Data

Frankel, Heidi L.
Ultrasound for surgeons / Heidi L. Frankel.
p. ; cm. -- (Vademecum)
Includes index.
ISBN 1-57059-597-6
1. Ultrasonics in surgery. 2. Operative ultrasonography. I. Title.
II. Series.
[DNLM: 1. Ultrasonography--methods--Handbooks. 2. Surgical
Procedures, Operative--methods--Handbooks. WN 208 F828u 2004]
RD33.7.F73 2004
617'.07543--dc22
2003025277

Dedication

Dedicated to my husband, John,
and spouses like him, who allow us to practice our craft.

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Editor

Heidi L. Frankel
Associate Professor of Surgery
Section of Trauma and Surgical Critical Care
Yale University
New Haven, Connecticut, U.S.A.
Chapter 1

Contributors

Richard Bellah
Surgical Resident
Children's Hospital of Philadelphia
Philadelphia, Pennsylvania, U.S.A.
Chapter 6

Jeffrey Carpenter
Associate Professor of Surgery
University of Pennsylvania School of Medicine
Director, Vascular Laboratory
Hospital of the University of Pennsylvania
Philadelphia, Pennsylvania, U.S.A.
Chapters 7, 14

Richard Charnley
Consultant Hepatobiliary and Pancreatic Surgeon
Hepato-Pancreato-Biliary Surgery Unit
Freeman Hospital
Newcastle upon Tyne, U.K.
Chapter 11

Shyr-Chyr Chen
Vice-Chairman and Associate Professor
Department of Emergency Medicine
National Taiwan University College of Medicine
Taipai, Taiwan
Chapter 5

George Counelis
Attending Neurosurgeon
Diablo Neurosurgical Medical Group, Inc.
Walnut Creek, California, U.S.A.
Chapter 9

Frank Davis
Assistant Chief Trauma, Surgical Critical Care
Memorial Health University Medical Center
Associate Professor of Surgery
Mercer School of Medicine
Savannah, Georgia, U.S.A.
Chapter 3

Sheryl Gabram
Director, Breast Care Center
Cardinal Bernardin Cancer Center
Vice Chairman of Education and Program Director
Associate Professor of Surgery
Loyola University Medical Center
Maywood, Illinois, U.S.A.
Chapter 13

Paul V. Gallagher
Consultant Surgeon
Northumbria Health Care NHS Trust
North Shields, Tyne and Wear, U.K.
Chapter 11

Raj R. Gandhi
Medical Director for Trauma Services
Hillcrest Baptist Medical Center
Waco, Texas, U.S.A.
Chapter 12

Vicente H. Gracias
Assistant Professor of Surgery
University of Pennsylvania Medical Center
Philadelphia, Pennsylvania, U.S.A.
Chapter 1

Ronald I. Gross
Assistant Professor of Traumatology and Emergency Medicine
University of Connecticut School of Medicine
Associate Director of Trauma
Hartford Hospital
Hartford, Connecticut, U.S.A.
Chapters 1, 2

Rajan Gupta
Assistant Professor of Surgery
Division of Traumatology and Surgical Critical Care
University of Pennsylvania School of Medicine
Philadelphia, Pennsylvania, U.S.A.
Chapter 7

Morad Hameed
Assistant Professor of Surgery
University of British Columbia
Trauma Services, Vancouver General Hospital
Vancouver, British Columbia, Canada
Chapter 10

Nicos Labropoulos
Assistant Professor of Surgery
Director, Vascular Laboratory
Department of Surgery
Loyola University Medical Center
Maywood, Illinois, U.S.A.
Chapter 13

Mark McKenney
Professor of Surgery
Department of Surgery
University of Miami
Miami, Florida, U.S.A.
Chapter 10

David Neschis
Assistant Professor of Surgery
Division of Vascular Surgery
University of Maryland Medical Center
Baltimore, Maryland, U.S.A.
Chapter 14

M. Gage Ochsner
Professor of Surgery
Mercer University School of Medicine
Savannah, Georgia, U.S.A.
Chapter 3

Oluyinka Olutoye
Surgical Resident
Children's Hospital of Philadelphia
Philadelphia, Pennsylvania, U.S.A.
Chapter 6

David B. Pilcher
Professor of Surgery
Division of Vascular Surgery
University of Vermont
College of Medicine
Burlington, Vermont, U.S.A.
Chapter 4

Tarek Razek
Assistant Professor of Surgery
McGill University Health Center
Montreal General Hospital
Montreal, Quebec, Canada
Chapter 8

Grace S. Rozycki
Department of Surgery
Emory University School of Medicine
Atlanta, Georgia, U.S.A.
Foreword

Michael Russell
Assistant Professor Anesthesia and Surgical Critical Care
University of Pennsylvania
Director, Anesthesia and Cardiopulmonary Services
The Outer Banks Hospital
Nags Head, North Carolina, U.S.A.
Chapter 8

Lee E. Smith
Professor of Surgery
Georgetown University
Director, Section of Colon and Rectal Surgery
Washington Hospital Center
Washington, D.C., U.S.A.
Chapter 15

Perry Stafford
Pediatric Surgeon
Jersey City Medical Center
Jersey City, New Jersey, U.S.A.
Chapter 6

Grant Sinson
Associate Professor of Neurosurgery
Medical College of Wisconsin
Milwaukee, Wisconsin, U.S.A.
Chapter 9

David Wherry
Professor of Surgery
Uniformed Services University of the Health Sciences
Bethesda, Maryland, U.S.A.
Chapter 11

John Winston
Assistant Professor of Surgery
Ohio State University
Columbus, Ohio, U.S.A.
Chapter 15

Foreword

In recent years, technology has revolutionized the practice of surgery. As part of this change, surgeon-performed ultrasound has become one of the most integral parts of the surgeon's clinical practice. It is not surprising to observe this current surge of interest in ultrasound by general surgeons because surgeons are highly motivated to provide the best possible care for their patients, including the use of the latest technologic advances in diagnosis and treatment. Furthermore, ultrasound equipment is compact, affordable and user-friendly so that extensive training is not required to master focused ultrasound techniques. Cost containment initiatives by patients, clinicians and third-party payers have encouraged the use of modalities, such as ultrasound, that save time and money. Considering the unique qualities of ultrasound...noninvasive, portable, rapid and easily repeatable..., ultrasound is especially suitable to the surgeon's practice. The FAST has replaced central venous pressure measurements for the detection of hemopericardium and diagnostic peritoneal lavage for the detection of hemoperitoneum. Bedside ultrasound detects a pleural effusion so well in critically ill patients that fewer lateral decubutis X-rays are ordered. Ultrasound directed biopsy of breast lesions is a common office procedure. Laparoscopic ultrasound allows for tumor staging without formal celiotomy while ultrasound is an adjunct to many hepatic and pancreatic procedures. Endoscopic and endorectal ultrasound have added a new dimension to the assessment and treatment of many gastrointestinal lesions. Color-flow duplex imaging and endoluminal ultrasound have significantly expanded the diagnostic and therapeutic aspects of vascular imaging.

Dr. Frankel and her colleagues have written a concise, organized and yet very thorough handbook on the use of ultrasound for surgeons. This outstanding book is the perfect companion for surgeons because it combines precision and practicality. The ultrasound images alone are educational because they are accurately done, appropriately labeled, and of superb resolution. As surgeons continue to incorporate ultrasound imaging into their practice, this scientific and clinically-based book will provide an excellent resource for practicing surgeons as well as for those in training.

The surgeon's use of ultrasound in North America is already reaching the fifteen-year mark. Ultrasound as used by surgeons has staying power and clearly advances in technology as well as books such as this one are integral to our progress.

Grace S. Rozycki, M.D., F.A.C.S.
Emory University School of Medicine
Atlanta, Georgia, U.S.A.

Acknowledgements

The field of “surgical ultrasound” has exploded in the last decade in the United States. This phenomenon has largely been the result of the efforts of several dedicated individuals who have tackled the logistic, political and educational challenges of making ultrasound a key part of surgical practice.

I have been fortunate to have received my introduction to and training in the discipline from one such individual—Dr. Grace Rozycki. Perhaps no one person is more associated with surgical ultrasound than Dr. Rozycki. She is the inspiration behind this manual and the innovator of many of the educational and clinical philosophies of ultrasound in surgical practice. For many years, Grace has provided the true “focus” for FAST and the other forms of surgical ultrasound. For this I am grateful.

The authors would also acknowledge the memory of Catherine Ann Gross, late wife of Dr. Ronald Gross, who lost a valiant struggle to breast cancer. Many of the contributors participated in ultrasound courses where Cathy cajoled and facilitated our best efforts. We will miss her greatly.

Finally, I would also acknowledge the tireless work of Jonathan Plessner and Eileen Carey, BS in manuscript preparation.

Education Credentialing and Getting Started: With Attention to Physics and Instrumentation

Vicente H. Gracias, Heidi Frankel and Ronald I. Gross

Historical Perspective

The inspiration for medical ultrasonography dates to the development of SONAR (Sound Navigation and Ranging) first used in a French ocean liner in 1928. Another important research milestone was the discovery of the piezoelectric effect by Pierre Curie in 1880. The phenomenon of expansion and contraction of piezoelectric crystals which interconvert mechanical and electric energy underlies the action of the modern ultrasound transducer.

Although research on medical ultrasonography dates back to the 1930s, the prototype of the first handheld contact scanner was not developed until the early 1960s. The first clinical uses of ultrasonography were in obstetrics and gynecology rapidly followed by cardiology and vascular applications. Abdominal applications of ultrasonography such as for trauma were largely pioneered in Europe and Asia and did not become a part of the U.S. general surgeon's armamentarium until the last decade.

Education in Surgeon-Performed Ultrasound: Training/Credentialing and Practice Domains

In Germany and Japan, training in surgeon-performed ultrasound is an integral part of the surgical residency training programs, and residents must demonstrate proficiency in ultrasound to qualify for the board exam in surgery. Although most American surgical residents have not been involved in specific ultrasound training programs at the residency level, many have become more familiar with ultrasound as its use expanded in North America. The American Board of Surgery has not, to date, put forth a definitive ultrasound training program for surgical residencies; this curriculum is being developed. Consequently, American surgeons had to learn ultrasound through courses sponsored by various individuals and organizations or through private mentoring. Surgeon-performed ultrasonography is not limited to trauma. Ultrasound has now become an integral part of surgical practice in most surgical subspecialties, including, but not limited to, general surgery, trauma and surgical critical care, colorectal surgery, vascular surgery, and neurosurgery.

For many years, a major obstacle to training the surgeon in use of ultrasound was the perception that the technology, and the ability to properly use it, rested strictly within the practice domain of the radiologist. Along similar lines, surgeons felt that only they could perform procedures such as abscess drainage, breast mass localiza-

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tion and excision, intra-abdominal tissue biopsies, caval interruption, and central venous access, to name a few. These "practice domains" no longer exist; it is now apparent that no specialty owns the rights to specific technologies or procedures, as they once did. As Rozycki and Shackford stated, "clinical considerations must supersede economic and political concerns in all decisions."

Although there is still no unified consensus regarding the way in which American surgeons could best meet these goals, there has been significant progress. In 1996, at its Annual Spring Meeting, the American College of Surgeons (ACS) introduced the first College sponsored ultrasound course, directed and taught by surgeons for surgeons. The Ultrasound for the General Surgeon postgraduate course has been taught at every Spring Meeting and Clinical Congress since, and includes both didactic and hands-on training in key areas of surgical ultrasonography. In order to receive verification of the successful completion of the course, participants are required to successfully perform and interpret sonographic examinations at each clinical station (as determined by the station instructor), and must receive a passing score on the post-course exam. Following a similar format, the first ultrasound specialty module, Ultrasound in the Acute Setting, was given at the Spring Meeting in 1999.

Further developments followed the success of the first postgraduate course. The College held the first Ultrasound Instructor Course at the 84th Clinical Congress, given to train dedicated surgeon-ultrasonographers as instructors for the basic course. The ACS Committee on Emerging Surgical Technology and Education (CESTE) issued a statement on the voluntary verification program for surgeon-sonographers. The program is based on the premise that "surgeons performing ultrasound examinations and ultrasound-guided procedures must be familiar with the principles of ultrasound physics, and the indications, advantages, limitations, performance, and interpretation of the ultrasound examination." The statement addressed surgeon eligibility and verification in basic ultrasonography, verification for surgeons performing specific sonographic examinations and procedures, recommendations for maintaining said qualifications, and ultrasound facility guidelines. Finally, the Ultrasound for the General Surgeon course will have a standard content and format, so that successful completion of this course will enable the surgeon to be eligible for the verification program, as recommended by CESTE (Appendix I).

Credentialing in Ultrasound

Lessons regarding credentialing can be gleaned from examination of other disciplines, other nations and other aspects of surgery. Cardiologists require the performance of 120 studies and three didactic hours for documentation of echocardiography competency.[1] Obstetricians are required to perform 200 focused obstetric ultrasounds in training for certification.[2] Radiologists require 1000 ultrasound examinations during surgical training.[3] Internationally, the German Board of Surgery has the best-known guidelines for ultrasonography competency for general surgeons—300 studies are required during surgical training.[4] Finally, credentialing philosophies regarding new surgical technologies can be garnered from experience with laparoscopic procedures. Common bile duct injuries during laparoscopic cholecystectomies are much less common if practitioners undergo proctoring for their first ten cases.[5]

German surgeons developed ultrasonography for trauma and bedside utilization in the 1980s. Excellent results with acceptable sensitivity and specificity were being reported in German surgical journals well before the American surgical community adopted FAST as a useful adjunct to the evaluation of the acutely injured patient.[6] It seems appropriate then that since 1988 the German Board of Surgery has mandated that only surgical residents skilled in ultrasonography are qualified to sit for their national board examination.[7] Stringent criteria for the teaching and training of surgical residents have once again been led by German impetus for quality assurance and again the American surgical community is agreeing with the need to formalize training in U/S.

To appropriately begin the process of certifying practitioners in the use of ultrasound, credentialing boards must first define competence as it relates to ultrasound usage in the trauma environment. Competency mandates that the clinician can be familiar with the indications for a procedure, be solidly proficient in the interpretation of the results of that procedure and, to minimize examiner error, the ultrasonographer must be cognizant of the limitations of ultrasound.

The most common method employed in evaluating proficiency is with sensitivity, specificity and accuracy. Experience with FAST by both surgeons and Emergency Department physicians has helped delineate the sensitivity, specificity and accuracy of ultrasound in the setting of trauma and acutely injured patients. The reported sensitivities for FAST are accepted to be between 90-100%, specificity range 95-100% and accuracy has been reported to be as high as 96-100%. These basic parameters can be set as required goals which must be met in order to achieve credentialing in FAST by trainees.

Although the goals for proficiency have been defined, there remains the question as to the best approach for training and testing student ultrasonographers so as to guarantee accepted proficiency for FAST. Attempts have been made to define the learning curve for FAST and to provide guidelines for credentialing processes. Amy Sisley and colleagues have published their experience with an objective structured clinical examination (OSCE) for the assessment of proficiency in the use of FAST.[8] In this study, competency of factual knowledge and US interpretation skills were addressed. Participants were asked to complete OSCE in ultrasound knowledge and videotaping was used to assess image interpretation skill before and after participation in an ultrasound training course. OSCE was shown to be valid vehicle to measure the competency of participants with ultrasound.

What remains is to define the best content for training programs. This content must ultimately provide accepted proficiency with FAST, as previously described and guarantee consistent and reproducible results. A report in the *Annals of the Royal College of Surgeons of England* reports registrars receiving two half days of instruction by radiology staff prior to applying ultrasound to assessment of acute surgical emergencies.[9] Some surgeons in the United States, led by suggestions provided by Rozycki and Shackford, have set forth training and credentialing guidelines for FAST program implementation. These include participation in a 4 hour didactic and a 4 hour practical course and the requirement for proctoring and/or gold-standard confirmation for the first 10-100 FAST examinations. Shackford has suggested calculating error rates based on the prevalence of the target disease (hemoperitoneum) to define the number or proctored exams that are required prior to independent usage of FAST. His study reported that the initial error rate of 17% fell to an acceptable 5% after 10 examinations.[10] Others feel that these numbers should be larger if true positive examinations are not included.[11] Few studies specifically and systematically address the learning curve for FAST. In one study by Thomas and associates it was observed that the learning curve for FAST did in fact plateau.[12] In this study of 300 consecutive ultrasound examinations, the learning curve plateaued at 100 exams. However, this study reports the institutional experience with FAST and with eight practitioners involved, we are not given a sense of the individual learning curve. Additionally, 102 patients (34%) did not have a confirmatory examination, questioning the validity of the sensitivity and specificity reported. In a study performed at the University of Pennsylvania by Gracias and Frankel, the learning curve for FAST was studied in a controlled prospective fashion and was found to plateau between 30 and 100 exams.[13]

Participating in ultrasound courses and having an apprenticeship approach to on-the-job training for FAST can minimize the operator dependent limitations of ultrasound. Early exposure to this technology is important so that trainees will view this technology as part of their surgical training and not as division specific technology. Curriculum should be selected based upon personal experience, participation in accepted major ultrasound workshops and texts with courses and information used to train other nonradiology residents and ultrasound technicians. The newest edition of the ATLS® manual includes didactic material on FAST. Limited resources make ATLS® a difficult venue for global instruction in FAST technique. The future may warrant the dedication of resources to ATLS® so that a section of training can be devoted to training in FAST. Currently ATLS® instruction does not provide in-depth application but aids in introducing the novice trauma care provider to the concepts and applications of US physics and FAST.[14]

While the ACS CESTE has stated that training in ultrasound should be standardized, the amount of training required to achieve proficiency in the use of FAST has not been established. In 1999, the FAST Consensus Conference Committee came to a majority opinion that the minimum amount of training to learn the FAST is four hours of didactic instruction, and four hours of practical instruction, with a minimum of 200 supervised examinations. The minority opinion was concerned that 200 studies would be impractical and that as few as 50 could be sufficient, as has been suggested by Boulanger and Falcone. It was also suggested that a minimum number of positive studies should be required to demonstrate the sonographer's ability to detect pathologic findings. To date, there has been no resolution of this debate, and it appears that, at the present time, training requirements are best set at an institutional level. In addition to taking a formal ultrasound course, the surgeon-sonographer can greatly expand his/her training opportunities by working one-on-one with (1) a credentialed surgeon or (2) a radiologist, whenever possible.

Credentialing criteria in the United States for the FAST examination remain unclear and await standardization. As it now stands, credentialing of the surgeon-sonographer is institution-specific. However, there are some concepts that do seem to be universal. Credentialing for surgeon-performed ultrasound must be granted by, and under the auspices of, the Department of Surgery. The FAST procedure must be carefully defined, it should be clearly distinguished from a formal abdominal ultrasound, the criteria for its use in the acute setting must be established in an institution-specific algorithm, and continuous and on-going quality assessment/ improvement program must be a part of the process. Cushing and Chiu outlined five principles of credentialing that appear to incorporate these concepts: (1) procedure specificity; (2) provider specificity; (3) institution specificity; (4) criteria for competence; and (5) performance measurements. An example of a credentialing document written by this author, (RIG) and utilized at two trauma centers in Connecticut is presented as Appendix II.

To better appreciate the limitations of ultrasound and to best utilize its potential, trainees should be required to study the physics of ultrasound, as well. With firm understanding of ultrasound physics and its application, trainees are better equipped to perform US and are more likely to successfully trouble shoot in order to enhance image acquisition. After extensive review it appears appropriate for credentialing programs to include:

- Tutorials in ultrasound physics and practical usage which include normal FAST examinations.
- At least 30 proctored clinical FAST exams after completion of the tutorial, prior to certification.

The process for testing and the standards for performance should be referenced. Technologists should be evaluated on a quarterly basis, and the results of that evaluation documented. Minimum performance evaluation should include:

1. Assure adherence to universal infection control precautions
2. Distance calibration—quarterly
3. Clinical images—Photographic images or films of normal and abnormal examinations should be available for review. In those facilities performing procedures, pre-and-post procedure films or photographs should be clearly labeled.
4. Equipment quality control—Each facility should have documented policies and procedures for monitoring and evaluating the effective management and proper performance of imaging equipment. Quality control programs should be designed to maximize the quality of the diagnostic information. Equipment performance should be monitored regularly in conformity with standards for ultrasound imaging and phantom testing for resolution. Such monitoring may be accomplished a part of a routine preventive maintenance program.
5. Quality improvement—Quality improvement procedures should be systematically monitored for appropriateness of examination, for technical accuracy, and for the accuracy of interpretation. The total number of examinations and procedures should be documented on a quarterly basis. Incidence of complications and adverse events incurred during ultrasound-guided interventional procedures should be recorded and regularly reviewed to identify opportunities to improve patient care.

Formal Ultrasound Accreditation

The American Institute of Ultrasound in Medicine (AIUM) is an organization of ultrasound sonographers, technicians, manufacturers and physicians with a voluntary Ultrasound Practice Accreditation Program. Areas of accreditation include obstetrics, gynecology, abdominal, breast and vascular. Several surgeon sonographers have opted to pursue formal ultrasound accreditation by the AIUM. In the future, this accreditation may be linked to reimbursement.

The American Registry of Diagnostic Medical Sonographers (ARDMS) administers examinations and awards credentials in general, cardiac and vascular ultrasound. Eligible surgeons must have a state license, formal training, 12 months of full-time clinical experience and 40 hours of relevant Category I CME credits within a three year cycle. Vascular laboratory directors often pursue this area of credentialing.

Ultrasound Privileges and Program Implementation

Once a surgeon is appropriately trained and credentialed whether as part of residency education or during postgraduate study, it may be difficult to implement a successful ultrasound program. The individual may face issues of politics and difficulties in reimbursement.

In December 1999, the AMA addressed the issue of "turf wars" in ultrasound practice thru resolution 802 ("1").

1. AMA affirms that ultrasound imaging is within the scope of practice of appropriately trained physicians;
2. AMA policy on ultrasound acknowledges that broad and diverse use and application of ultrasound imaging technologies exist in medical practice;
3. AMA policy on ultrasound imaging affirms that privileging of the physician to perform ultrasound imaging procedures in a hospital setting should be a function of hospital medical staffs and should be specifically delineated on the Department's Delineation of Privileges form; and
4. AMA policy on ultrasound imaging states that each hospital medical staff should review and approve criteria for granting ultrasound privileges based upon background and training for the use of ultrasound technology and strongly recommends that these criteria are in accordance with recommended training and education standards developed by each physician's respective specialty. (Res. 802, I-99)

Nonetheless, respective hospital medical staffs may provide obstacles to successful surgeon programs in ultrasound fields.

Finally, the successful surgeon sonographer must address the issue of technology acquisition. Ultrasound machines differ in size, portability, transducer availability and cost. Prior to purchase, the surgeon must consider his intended uses for the equipment and whether sharing with other departments is possible.

Rental agreements with an option to purchase and service contracts should be considered.

A Physics Primer

1. Ultrasound refers to sound above the frequency audible to the human ear or 20,000 cycles per second or Hertz (Hz)
2. Medical ultrasound typically uses frequencies of 2-10 MHz.
3. The speed of sound through tissue averages 1540 m/sec. It is lowest in fat (≈1450) and highest in bone (2700-4420 m/sec).
4. Impedance refers to the facility with which sound travels through a substance and is a product of propagation speed and tissue density.
5. Air increases impedance differences, ultrasound gel decreases it.
6. Ultrasound waves are attenuated as a result of absorption, reflection, refraction and scattering.
7. Frequency is directly related to resolution and inversely related to penetration. Thus, a 3.5 MHz transducer is suited for a trauma ultrasound whereas a 7.5 MHz probe would be used for soft tissue evaluation.
8. Time and depth gain compensation pods allow variable adjustment for sound attenuation as a result of time or distance traveled.
9. Resolution refers to the ability to distinguish two discrete structures, lateral resolution is proportional to the width of the structure, axial resolution is proportional to the depth.
10. Ultrasound transducers are curvilinear, linear and sector.

Appendix I. CESTE Guidelines Surgeon Eligibility and Verification in Basic Ultrasonography[15]

The surgeon should provide evidence of training by meeting the following criteria:

1. Satisfactory completion of an accredited residency program in a surgical specialty, for example, through documentation of current certification by an ABMS Board or its equivalent.
2. When residency and/or fellowship did include documented training in the principles of ultrasound physics, the indications, advantages, and limitations of ultrasound, and personal experience with performance and interpretation of the ultrasound examination and ultrasound-guided interventional procedures, including knowledge of the indication for these procedures, complications that might be incurred, and techniques for successful completion of these procedures, the surgeon will be eligible for verification of qualifications in the basic use of ultrasound on review of their documentation.
3. When residency or fellowship training did not include education and personal experience in the use of ultrasound, completion (Level 2) of a basic approved educational program in ultrasound physics and instrumentation, including didactic and practical components, is required for verification of qualifications in the basic use of ultrasound.

The basic level of ultrasound expertise includes the ability to acquire and interpret images of normal ultrasound anatomy.

1. Verification of surgeons who independently perform specific ultrasound examinations and procedures.

   Examples of specific ultrasound applications are: FAST examination in trauma; breast examination and biopsy; evaluation of the thyroid and parathyroid, transrectal examination of the prostate and rectal tumors; endoscopic examination of the upper gastrointestinal (GI) tract and hepatobiliary system; intraoperative and laraoscopic examination of intra-abdominal and thoracic organ systems; vascular, obstetric, gynecologic, ophthalmologic, and transcranial examinations. The surgeon using specific applications of ultrasound in an independent mode must have basic and specific expertise.
2. Specific application requirements:
   a. Verification of qualifications in the basic use of ultrasound.
   b. Fundamental knowledge of and current competence in the management of the relevant clinical condition together with additional clinical expertise and training in diagnostic ultrasound. The ability to distinguish abnormal findings, and to perform ultrasound-guided procedures in the relevant clinical condition is also necessary.

   These qualifications can be demonstrated by:

   Completion (Level 2) of an approved educational program in the specific application of ultrasound pertaining to the specific clinical area of interest (trauma, and so forth). OR Documented experience and satisfactory outcomes in the use of specific application of ultrasound in the specific clinical area of interest and meeting the specified learning objectives of the specific module (for example, successful completion of the written examination).

[Criteria (a) and (b) may be fulfilled in a residency or fellowship that specifically includes sufficient education and experience under the supervision of a qualified physician.]

3. Recommendations for maintenance of qualifications
   To maintain proficiency in ultrasound applications, surgeons are encouraged to perform and interpret ultrasound examinations and have regular ultrasound-related Category I CME. These surgeons must document that a continuous quality improvement process is established and that proper records are maintained.
4. Ultrasound facility guidelines
   Medical staff/medical director—A licensed physician is specified and responsible for determination and documentation of the quality and appropriateness of testing. This individual should oversee the development of a written policy for the granting of privileges for the medical staff. Such a policy should specify the scope of the privileges, specialty background, and education and experience in ultrasonography.
5. Scope of practice—The scope of practice (listing of all type of examinations and procedures) should be explicitly stated and documented.
6. Electrical safety—Testing of electrical safety of the ultrasound equipment must be performed on a regular basis and the results documented.
7. Equipment—For the proposed examinations and/or procedures the equipment and transducer selection should be the most appropriate to obtain optimal images of high resolution.
8. Quality Control—The ultrasound equipment should be calibrated at installation and at least annually thereafter. The following tests are recommended for inclusion in the quality control program on, at least, an annual basis:
   a. Maximum depth of visualization and hard copy recording with a tissue mimicking phantom.
   b. Distance accuracy. (1) vertical distance, (2) horizontal distance accuracy.
   c. Uniformity
   d. Anechoic void perception
   e. Ring down and dead space determination
   f. Lateral resolution
   g. Axial resolution
   h. Data logs on system performance and example of results

Appendix II. Credentialing Requirements for Granting of Privileges to Surgeons to Perform the Focused Abdominal Sonogram in Reply To: Trauma (FAST)[16]

General Principles

It has been established that surgeons properly trained in the use of ultrasonography can perform ultrasonographic studies as accurately as formally trained radiologists. Surgeons who care for trauma patients should be credentialed in the use of the Focused Abdominal Sonogram in Trauma (FAST) once documentation of formal training has been provided. The FAST examination is not a general abdominal ultrasound study used for the diagnosis of specific organ injury. It is a focused study to be used in the acute setting to determine whether or not there is blood within the pericardial sac, or within the abdominal cavity as a result of trauma, and should consist of four views: (1) sub-xiphoid; (2) right upper quadrant; (3) left upper quadrant; and (4) suprapubic.

Only surgeons credentialed by the Department of Surgery in the care of the trauma patient will be allowed to perform the FAST examination. Credentialing for FAST can only be granted by, and under the auspices of, the Department of Surgery.

Training

Didactic

The Section of Trauma and Surgical Critical Care of the Department of Surgery requires that all surgeons obtain a minimum of 8 hours of Category I CME accredited didactic training in (focused abdominal) ultrasonography before being allowed to perform the FAST clinically. This training must be obtained at a course sponsored or endorsed by the American College of Surgeons and/or a recognized regional/national (trauma) society, such as the American Association for the Surgery of Trauma, the Western Trauma Society, the Eastern Association for the Surgery of Trauma, or a state Committee on Trauma.

Practicum and Proctoring

Each surgeon who completes the didactic course requirements will provide the following in order to become credentialed in ultrasonography in trauma:

- Satisfactory completion of 50 normal abdominal sonographic studies using the FAST protocol as established by Rozycki et al.
- Provide hardcopy films and/or videotapes of above FAST examinations for review and evaluation by a qualified surgical ultrasonographer or radiologist.

The above studies can be done on any surgical patient, for no charge, with their prior approval; written consent is not needed.

Once credentialed, the surgeon is required to document successful completion of the FAST on 15 trauma patients during a six month proctored period ("supervision") to maintain these credentials; documentation will be as specified above. During the proctored period, all patients on whom the FAST was performed will undergo clinical correlation with an abdominal/pelvic CT scan or DPL whenever the clinical situation permits.

Maintenance of Qualifications

Evidence of continued use and proficiency in ultrasound must be demonstrated. This can be done through the CME process, and by providing documentation (video, film) of use. Diagnostic errors must be reviewed at the department level using the departmental QA/QI process.

Suggested Reading

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FAST (Focused Assessment by Sonography in Trauma)

Ronald I. Gross

Introduction

Although a careful physical examination is the mainstay of the evaluation of the trauma patient, even the most experienced physician can have trouble accurately evaluating the patient with possible truncal injury. The presence of distracting injuries, cervical spine injury, and/or alterations in mental status due to head injury or substance abuse, often make the physical examination less than reliable. The introduction of diagnostic peritoneal lavage (DPL) by Root[1] in 1965 proved to be an invaluable tool in trauma care, providing physicians with a rapid technique to aid in the diagnosis of intra-abdominal injury. The open DPL, as described by Pachter and Hofstetter,[2] quickly became the most common technique used in the initial assessment of abdominal trauma because of its extremely low false positive and negative rates and low complication rates. However, DPL is invasive, and its extreme sensitivity was known to result in a fair number of nontherapeutic laparotomies.[3] Because of this fact, the invasive nature of DPL, its inability to assess the thoracic cavity, the definite risk of complications (Pachter et al,[2] and van Dongen et al[4]), and limitations of use in some patients, surgeons began to look to ultrasonography as an adjunct, and perhaps an alternative, to DPL.[5]

The impact of computerized axial tomography (CT) in trauma care was equally as great as, and followed closely on the heels of, that of DPL. The CT scan improved our ability to assess both the thoracic and abdominal cavities for the presence of blood. In addition, it enabled the clinician to assess the extent of solid organ injury, thus aiding in the evaluation for potential nonoperative management of selected patients. However, CT scanning is time consuming and usually requires the use of oral and intravenous contrast for best results. The fact that only the hemodynamically stable patient could be transported to the CT scanner placed further severe limitations on its use in the acute setting. Once again, trauma surgeons were forced to explore other technologies, namely ultrasound, in the evaluation of the trauma patient. After studying 200 acutely injured patients, and reviewing the literature, McKenney et al[6] concluded that ultrasonography can be used in place of DPL or CT for the detection of intraperitoneal fluid. In a subsequent study, that same group[7] concluded that ultrasonography can be effectively used as the primary screening technique for blunt abdominal trauma. In fact, except when performed for teaching purposes, the use of DPL as the initial screening procedure has been eliminated in favor of ultrasonography in most major trauma centers today,[6,8-11,13] and the number of CT examinations performed has been cut dramatically.[7]

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The focused assessment by sonography for trauma, or FAST, was recently described by Fallon as "one of the most valuable tools of trauma care of this decade", and, "a routine component of the initial assessment in all of the major trauma care centers in this country and abroad".[12] The use of ultrasonography in the evaluation of the acutely injured patient, as a standard of care by trauma centers across the United States, has been extensively documented.[13-16] Because the use of ultrasonography has become so prevalent, and so routine, in the initial assessment of the trauma patient, an international panel of surgeon ultrasonographers recently convened, and their recommendations on important issues regarding the use of ultrasonography in trauma care were published in the *Journal of Trauma*.[17]

Ultrasound technology has improved dramatically over the last ten years. The current technology has provided the clinician with extremely high quality, high resolution, real-time images from portable machines that are remarkably user-friendly. As a result, ultrasonography is immediately available at the patient's bedside, in the hands of the physician caring for the patient. It is reliable, repeatable, and, therefore, cost-effective. Ultrasound has been shown to have the same accuracy for the detection of hemoperitoneum as DPL, and has been associated with a negative laparotomy rate of 5%, similar or better that rate associated with either CT scanning or DPL. It has, therefore, become an integral part of trauma care today.

History

Although the use of surgeon-performed ultrasound has rapidly gained acceptance in the United States over the last seven years, surgeons in Europe and Japan have predated our routine use of this technology by over 20 years. Much of the early literature dealing with the use of ultrasound to assess the trauma patient came from Europe

The sensitivity of ultrasound was first documented by Goldberg et al in 1970,[18] who demonstrated the ability to reliably detect as little as 100 cc of free intraperitoneal fluid. The first case documenting the use of ultrasonography as a diagnostic tool in trauma was published by Kristensen and colleagues one year later.[19] Over the next several years, reports of the sonographic detection of hepatic, pancreatic, renal and retroperitoneal injuries followed.

In 1976, in what may be the first published prospective study using ultrasonography in the acute setting, Asher et al[20] reviewed their results using ultrasonography to screen 70 blunt trauma patients where splenic disruption was suspected, and peritoneal lavage was only weakly positive. They demonstrated an 80% sensitivity rate for the detection of splenic injury and described the ultrasonographic criteria they used to determine its presence. In 1983, Ammann and colleagues[21] reported the detection of a diaphragmatic rupture and demonstration of small bowel peristalsis and mucosal folds using real-time ultrasonography; this became the first report in the surgical literature where urgent surgical intervention was prompted by a sonographic study.

The pediatric trauma literature may have provided some impetus for surgeons to look at routine ultrasound use in the adult trauma patient. In 1985, Kuhn discounted the role of ultrasound in the initial evaluation of the injured child.[22] He stated that, in his experience, ultrasound is used primarily to follow the healing of known intra-abdominal hematomas, and not for initial evaluation of the pediatric trauma patient. Over the next 12 months, studies from the United States,[23] Canada,[24] Scotland,[25] and Great Britain[26] refuted that conclusion. These authors concluded that ultrasonography was a reliable tool to assess pediatric trauma patients for the presence of intra-abdominal injury. Furthermore, they promoted the use of ultrasonography to assist in the decision-making process for conservative management, as well as to follow patients post-injury. Presently, ultrasonography is used in the initial assessment of the injured child in much the same way that it is used in the adult population. In a 1998 study, Patrick et al[27] published their two year study in which surgeon-performed ultrasound was done at the time of arrival of 230 pediatric patients (<18 years old) as part of an ultrasound-based clinical pathway. All stable patients with a positive abdominal ultrasound were evaluated by CT scan, and all hemodynamically unstable patients with a positive ultrasound went directly to surgery. The findings of the study led the authors to conclude that using ultrasound as a triage tool may dramatically reduce to overall cost of blunt pediatric trauma, while at the same time enabling the surgeon to quickly identify significant intra-abdominal fluid that requires further evaluation or laparotomy. It now appears that the pediatric and adult trauma patients have achieved equal status.

Chambers and Pilbrow,[28] in a 1988 publication, studied 32 patients ultrasonographically over a two year period (1985-1987) and detected the presence of intra-abdominal fluid (blood) with a high degree of reliability, with no false negatives in their study. In Europe, one of the strongest proponents of the routine use of ultrasonographic screening in the emergent setting has been Tiling, from Cologne, Germany. Tiling's initial work with ultrasonography began in 1976 when he started to use ultrasound to diagnose intra-abdominal pathology. His subsequent studies using ultrasonography to evaluate the trauma patient showed that an experienced surgical sonographer could diagnose hemoperitoneum with 96% sensitivity, 100% specificity, and 99% accuracy, numbers that were as reliable as those achieved using either CT or DPL.[29] Tiling was able to show surgeon-performed ultrasonography to be rapidly obtainable, cost-effective, and repeatable. And, because ultrasonography provided a noninvasive method to evaluate both the abdomen and the thorax, it actually exceeded the capabilities of DPL. His work was instrumental in advancing surgical ultrasonography in Europe. In fact, in 1988, the German Association of Surgery incorporated ultrasound training into their surgical residency programs. The ability to perform ultrasonography is considered so important that only residents who show mastery of the technology can sit for their surgical national board examinations.[30] In the United States, many of the initial conceptual and practical developments were founded on Tiling's data and techniques, and many of the American surgical sonographer "pioneers" traveled to Cologne to work and study with him.

In 1992, Tso, Rodriguez and colleagues,[31] from the MIEMSS Shock Trauma Center, became the first Americans to assess the use of surgeon-performed ultrasonography in the acute setting. Although they felt that sonography did not replace CT or DPL in the evaluation of the trauma patient, they did show the technique to be readily available, rapid, and accurate in the detection of intra-abdominal fluid (blood). Of note, their study results were obtained by trauma fellows with as little as one hour of didactic and one hour of hands-on training.

In 1993, Rozycki and colleagues[32] published a study that would set the stage for the routine use of surgeon-performed ultrasound in the acute setting. This landmark publication was the largest prospective study done by American surgeons to date. It included both blunt and penetrating trauma victims, it routinely evaluated for pericardial tamponade, and it provided the first defined curriculum for surgical resident training. The time to complete a full evaluation was seen to drop from an initial study average of 4.7 minutes to 2.5 minutes per patient, as the surgeons gained proficiency, with a specificity of 95.6%. In their next study, published in 1995, Rozycki et al[33] studied 371 blunt and penetrating trauma patients, using ultrasound as the primary adjuvant modality to detect hemoperitoneum and pericardial effusion. In addition to FAST's high sensitivity and specificity, the authors found that, in the blunt trauma population, 66% would have had DPL ($150 per study), and 34% would have had CT scans ($650 per study) if ultrasonography were not available.

The acronym FAST, standing for "focused abdominal sonogram for trauma", appeared in a 1996 article in the *Journal of Trauma*, written by Rozycki and Shackford.[34] This publication leveled the playing field between surgeon-ultrasonographers and radiologists, showing that surgeons could perform and interpret ultrasound studies of the abdomen as well as their radiology colleagues. Their discussion of liability and turf issues, training and credentialing guidelines, and performance improvement set the stage for many articles that followed and has been a cornerstone for the development of the trauma surgeon ultrasonographer in the United States.

Numerous authors, both in the United States and abroad, have confirmed Rozycki's work, and learning curves have been established.[6,15,35-37] The indications for the use of ultrasound in the acute setting have expanded, and its use is no longer restricted to the trauma resuscitation room. The FAST examination has been included in the recently updated curriculum of the ATLS® provider course,[38] and the American College of Surgeons has included ultrasound in the algorithm that outlines the abdominal evaluation of the injured patient.[39]

Technique: Performing the FAST Examination

There are many ultrasound machines currently available for use, at a cost of under $30,000, that include the 3.5 MHz tight curve transducer that is best suited for this study, as well as video and hard copy recording capabilities. Many institutions have purchased these machines for explicit use in the trauma resuscitation suite, where they are kept on a permanent basis. Although the choice of equipment is institution specific, the transducer frequency is not, and should be a fixed 3.5 MHz, or 2 to 5 MHz variable frequency transducer. Due to the anatomy of the areas to be studied, the footprint of the transducer that is easiest to use is a tight curve, or "bullet" shaped transducer.

The focused sonographic assessment of the trauma patient is simple, and, as the term 'focused' implies, it is geared towards one thing—determining the presence or absence of hemopericardium or hemoperitoneum. The FAST exam can be completed in about 2.5 minutes, and although it is usually performed during the "secondary survey" of the ATLS® protocol,[37] it can be performed immediately upon the patient's arrival to the trauma resuscitation suite, as part of the primary survey. The exam, by convention, studies the pericardium, and the most dependent portions of the abdomen, namely Morison's pouch, the splenorenal recess, and the pelvis. If nasogastric and foley catheters have been inserted prior to scanning, it is important to remember to clamp the foley catheter until completing the scan. This will keep the bladder distended, and provide a good acoustic window through which the pelvis can be easily visualized.

With the ultrasound machine positioned to the right of the patient, the room lights are dimmed, whenever possible, so as to best visualize the images as they are

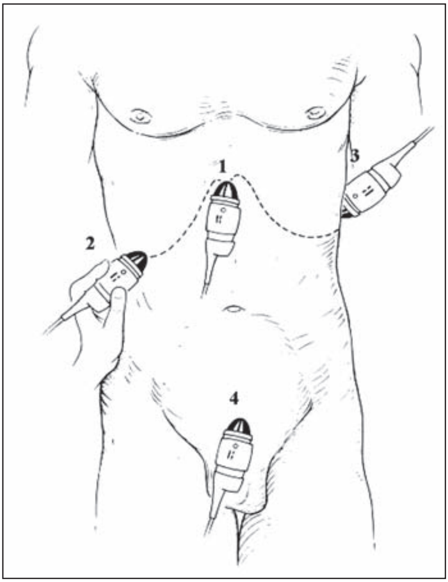

Figure 1.Transducer positions for performing the FAST examination: 1. sub-xiphoid; 2. Right upper quadrant; 3. Left upper quadrant; 4. Pelvis. (From: Rozycki GS et al. Ultrasound as used in thoracoabdominal trauma. Surg Clin NA 1998; 78:295, with permission).

acquired in real time. Warmed hypoallergenic ultrasound transmission gel is applied to the four areas to be studied (Fig. 1), and the first view obtained is the subxiphoid (pericardial) view, with the transducer positioned to obtain sagittal sections. This region is imaged first because it allows the ultrasonographer to use the blood within the heart as a standard for the gain setting, and, more importantly, it immediately examines for the presence or absence of a potentially life-threatening hemopericardium. It should be remembered that accurate visualization of the pericardium requires a beating heart. Furthermore, this view can also be used to confirm the absence of cardiac activity, and corroborate the clinical impression of electrical-mechanical dissociation (EMD). Illustration of a normal and abnormal subxiphoid image is shown in Figure 2.

The transducer is then placed in the right midaxillary line between the 11th and 12th ribs, to obtain sagittal imaging of the right upper quadrant (RUQ), looking for blood in Morison's pouch. Only when the liver, right kidney, and diaphragm have been seen together in the same image can this view be considered acceptable, and clinically significant. It often helps to change the angle of the transducer, or move the transducer up and down, so that the ribs do not obscure imaging. If the patient is alert and can cooperate with the examiner, having the patient inhale or exhale deeply can often make image acquisition easier and more reliable. Examples of this view are seen in Figure 3.

Sagittal views of the left upper quadrant (LUQ) are now obtained. The transducer must be placed in the posterior axillary line, in the region of the ninth or tenth intercostal space, so as to image the spleen, left kidney, and diaphragm. Once again, all three structures must be seen on the same image to adequately view the splenorenal recess and the perisplenic space for the presence or absence of blood (Fig. 4). As with the previous (RUQ) view, minimal movement up or down, as well as slight changes

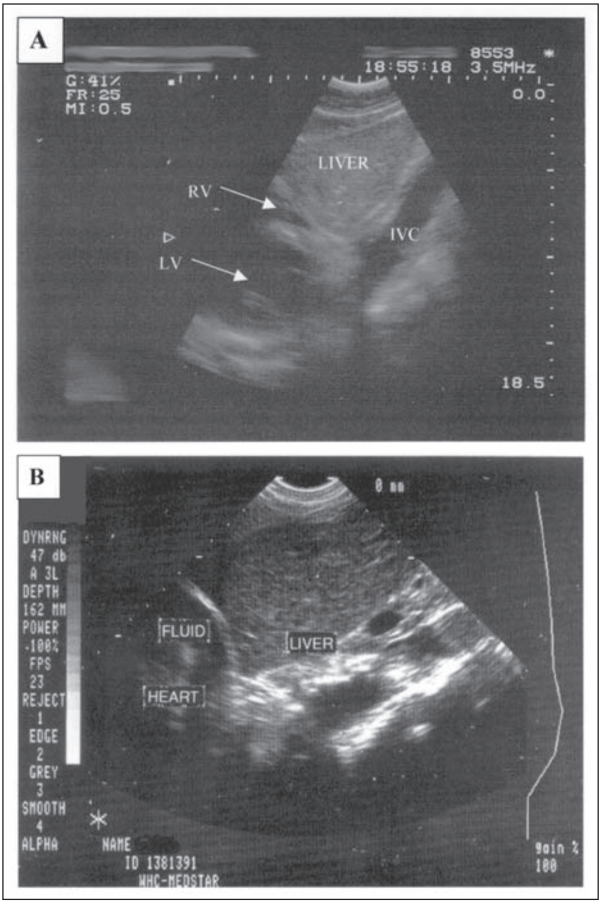

Figure 2. Sagittal view of (A) normal subxiphoid image showing heart and pericardium as hyperechoic white line abutting liver, and (B) "positive" image showing fluid (blood) as a hypoechoic band between the pericardium and the heart. RV = right ventricle, LV = left ventricle, IVC = inferior vena cava. (From Rozycki, with permission.)

in the angle of the transducer, will greatly enhance visualization by elimination of rib shadowing. Here too, cooperation by the patient can assist the examiner in image acquisition. It is important to remember the normal anatomical location of the spleen and its relation to the left kidney. A common mistake made by the novice sonographer is to place the transducer too far anterior and caudal; this makes acquisition of accurate images impossible and delays completion of the exam.

The transducer is now placed approximately four fingerbreaths above the pubic symphysis, in a transverse orientation (patient's right is to the left of the screen). Slight downward pressure is exerted on the transducer while it is swept inferiorly so that a coronal view of the pelvis is obtained. If the bladder is full, the deep pelvis, as well as

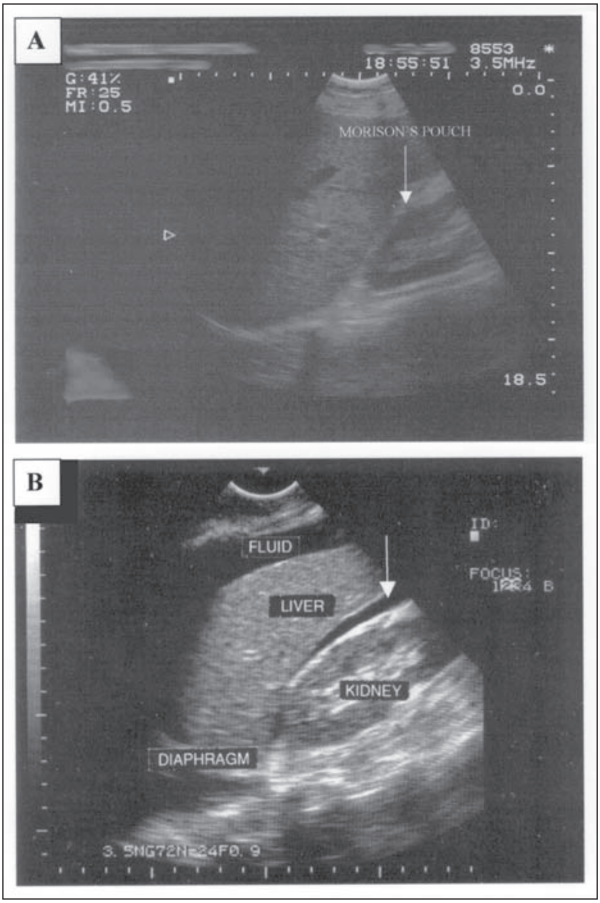

Figure 3. Sagittal views of right upper quadrant (Morison's pouch) showing (A) normal image, and (B) hemoperitoneum, with fluid (blood) in Morison's pouch (arrow) and anterior to the liver. (Adapted from Rozycki, with permission.)

the regions to the right and left of the bladder, can be well visualized. Although static images can nicely reveal the presence of blood in the pelvis (Fig. 5), the real time visualization of a positive study is very dramatic, where peristaltic loops of bowel can be seen to be "floating" in a black medium that represents a hemoperitoneum.

It had been assumed that the RUQ should be the first abdominal image obtained because of the probability that this view will be positive fairly early in the course of the development of hemoperitoneum[40,41] and because of the relative ease with which this view can be performed. McKenney et al reported their results of a study that imaged nine abdominal areas.[42] They observed that blood was most often identified in the right subhepatic/subphrenic, perisplenic, and pelvic areas, with the subhepatic space (Morison's pouch) being the most common location of blood.

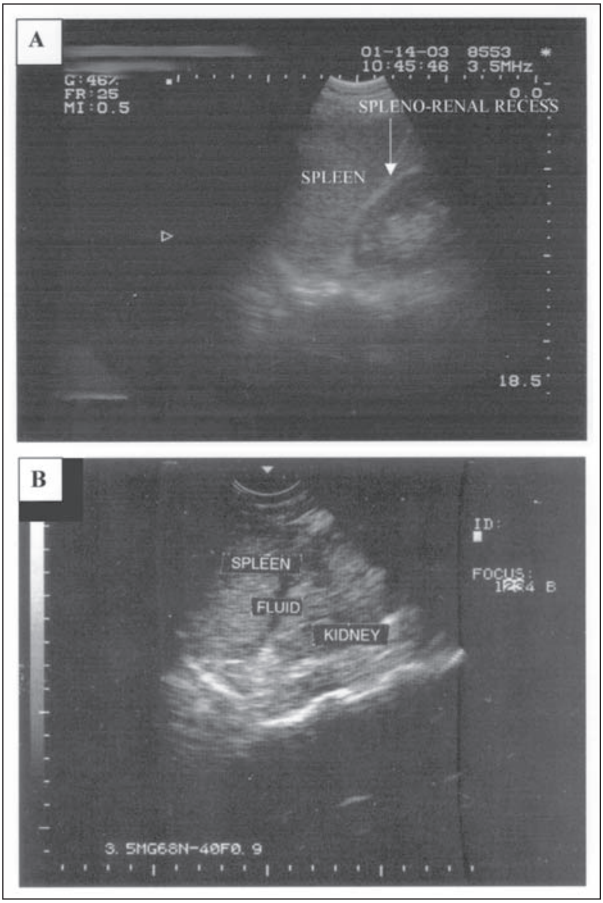

Figure 4. Sagittal views of the left upper quadrant showing (A) normal image, and (B) image positive for fluid (blood) in the spleno-renal recess. (From Rozycki, with permission.)

They did not, however, subject their findings to a statistical comparison between the three areas. Their findings, and thus the study sequence, were validated in a multicenter study that used the FAST to examine 10,300 patients with varied intra-abdominal injuries from blunt and penetrating mechanisms.[43] Of the 275 positive FAST examinations (220 blunt and 55 penetrating), the RUQ was the most common site where hemoperitoneum accumulated, regardless of organ of injury or the number of organs injured. In fact, the RUQ was positive more often than the LUQ in the presence of an isolated splenic injury (Table 1).

Although the “standard” FAST exam is a four-view examination, some advocate the routine use of sagittal and transverse views of the right and left upper quadrants, as well as coronal and sagittal views into the pelvis. This is mentioned here only for

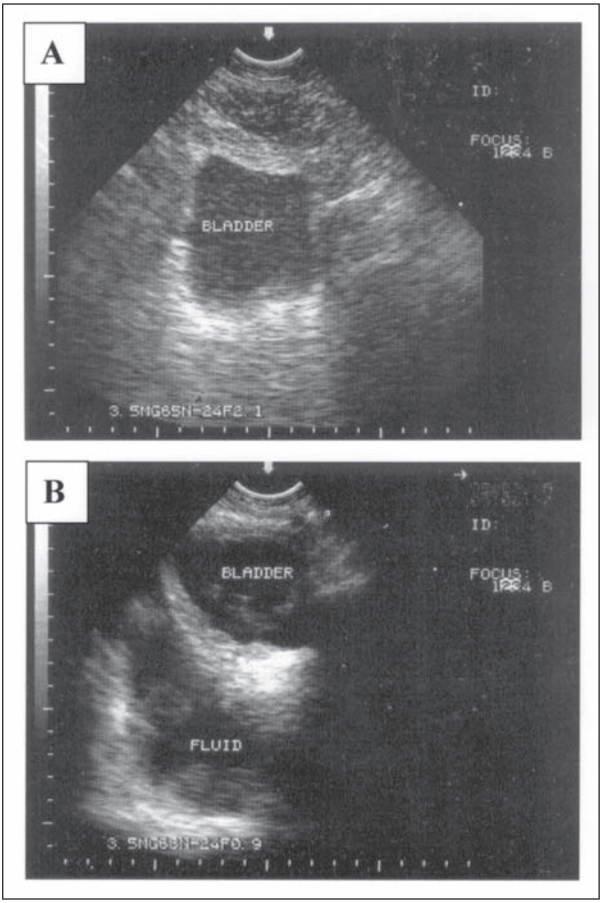

Figure 5. A) Coronal view into pelvis, showing bladder with normal through transmission. B) Pelvis with bladder surrounded by hypoechogenic fluid (blood). (From Rozycki, with permission.)

the purpose of completeness; the additional views are not necessary to satisfactorily perform the exam if good images are obtained using the guidelines suggested above.

Advantages and Drawbacks of the FAST Examination

Ultrasonography is extremely valuable because it provides the clinician with real time imaging that reflects the clinical situation in a very dynamic way. The exam is performed by the surgeon responsible for the patient's care and, therefore, most knowledgeable of the patient's injuries and physiologic status. Interpretation of the study by the trained surgical sonographer can be accomplished with the same accuracy as that of a radiologist (Table 2).[33] The study is extremely sensitive; it has been shown that as little as 100 ml of fluid can be detected in the abdominal cavity using

Table 1. Analysis of 275 patients with positive FAST examinations

Intra-abdominal Injuries	Number of Patients[1]	Right Upper Quadrant (RUQ)	Left Upper Quadrant (LUQ)	Pelvis	P. Value
Multiple	114	97 (85.5%)	63 (55.3%)	49 (43%)	0.001[2]
Single					
Spleen	69	49 (71%)	23 (33%)	21 (30.4%)	0.001[2]
Liver	53	41 (77.4%)	18 (34%)	20 (37.7%)	0.001[2]
Hollow viscera only	26	16 (61.5%)	7 (26.9%)	19 (73.1%)	0.578
Retroperitoneal only	13	10 (76.9%)	4 (30.7%)	2 (15.4%)	0.013[3]

[1] 275 patients with 439 positive areas. [2] RUQ vs. LUQ or pelvis. [3] RUQ vs pelvis. (Modified from Rozycki GS, Ochsner GM et al. Early detection of hemoperitoneum by ultrasound examination of the right upper quadrant: A multicenter study. J Trauma 1998; 45:878. Used with permission.)

Table 2. Performance of FAST: Comparison between surgeons and radiologists

	Surgeons	Radiologists
Patients	4,941	997
Sensitivity	93.4%	90.8%
Specificity	98.7%	99.2%
Accuracy	97.5%	97.8%

Data from Rozycki GS, Shackford SR. Ultrasound, what every surgeon should know. J Trauma 1996; 40:1, with permission.

ultrasound.[44,45] It is, therefore, almost as sensitive as DPL or CT scans but is not invasive. Unlike CT scans, it can be done rapidly, usually in about 2.5 minutes. The study is repeatable, and, because the machine is portable, it can be repeated at any point in the patient's care, be it in the trauma resuscitation suite, the operating room, or the intensive care unit. All of the above make the FAST exam very cost effective.

As with every technology, FAST does have drawbacks which render its use less effective. Because of the inherent characteristics of ultrasound, obesity, or the presence of subcutaneous emphysema, make the exam difficult to perform or interpret. Wounds that interfere with transducer placement, or suprapubic pain due to pelvic fractures, can preclude satisfactory completion of the study. As with CT scans, hollow viscus injuries can easily be missed with the FAST, and, to date, evaluation of the retroperitoneum cannot be reliably accomplished using the FAST. A comparative summary of the advantages and disadvantages of the FAST exam, CT scanning, and DPL is illustrated in Table 3.

Part of the routine performance of any clinical ultrasonographic study must be the recording of the images obtained. The value of static (permanent) prints of satisfactory imaging cannot be sufficiently stressed. Hard copy of all radiographic

Table 3. Advantages and disadvantages of diagnostic modalities used in the evaluation of the blunt abdominal trauma

	DPL	CT	FAST
Time (minutes)	10-12	30-60	2.5
Transport from trauma resuscitation suite	No	Yes	No
Easily repeatable	May repeat once	No	Yes
Sensitivity	87-99%	74-97%	60-100%
Specificity	97-98%	98-99%	97-100%
Accuracy	95-99%	92-99%	97-98%
Hospital Costs	\$105-\$137	\$432-\$650	\$59
Complications	Perforation of vessels, intestine, or bladder	Aspiration of oral contrast, allergic reaction to IV contrast	None
Contraindications or limitations	Prior abdominal surgeries, pregnancy, bleeding disorders	Uncooperative patient, allergy to contrast agents, hemodynamic instability	None
Diagnostic limitations	Retroperitoneal injury, diaphragmatic rupture	Mesenteric or hollow viscus injury	Mesenteric or hollow viscus injury

Data compiled, with permission, from (1) Fernandez L, McKenney MG, McKenney KL et al. Ultrasound in blunt abdominal trauma. J Trauma 1998; 45:841, and (2) Rozycki GS, Ochsner MG et al. Prospective evaluation of surgeons' use of ultrasound in the evaluation of trauma patients. J Trauma 1993; 34:516.

studies, including the FAST, are an essential part of the patient's medical record and serve to document the initial sonographic impressions. In addition, these prints, in conjunction with video recordings of the examination, are invaluable tools for credentialing, quality assessment, and quality improvement programs, which should be an integral part of every surgical sonographic program. Although such recording equipment may increase the initial equipment cost slightly, the long-term benefits obtained far outweigh the perceived initial financial burden.

Application: Uses of FAST in the Acute Setting

Based on the many published reports in the North American literature over the last eight years, many trauma centers have incorporated the FAST examination as a routine part of the evaluation of the blunt trauma patient. In fact, this technology has come to be viewed by many as an extension of the physical examination that is not influenced by the patient's mental status or by the pain of distracting injuries. The American College of Surgeons Committee on Trauma included ultrasound in the evaluation of abdominal trauma[48] and has included the FAST examination in the syllabus of the latest edition of the ATLS® provider course. Numerous publications have cited the usefulness of the FAST examination in the pediatric population,[22-28,46-48] for the same reasons as cited in the adult literature, but also

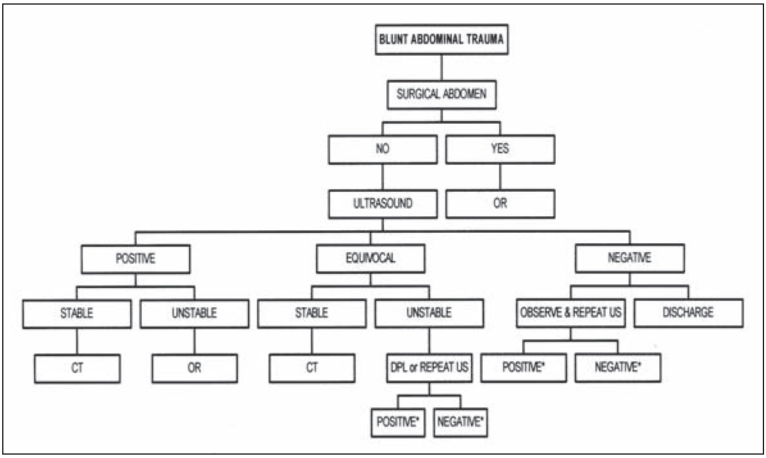

Figure 6. Possible algorithm for the use of FAST for the evaluation of a blunt trauma patient. OR = operating room; DPL = diagnostic peritoneal lavage. *Reenter algorithm.

because it is far less intimidating than CT scanning to the injured child. New algorithms have been developed that determine the progression of the work-up based on the results of the ultrasound exam. While the algorithms are usually institution specific, they all share the fundamental principal that the unstable patient with a surgical abdomen belongs in the operating room.

The FAST examination is used as the initial screening test, usually as part of the secondary survey and was initially reserved for patients with blunt truncal injury. The selective use of DPL or CT is based on the results of the FAST, as well as the patient's clinical presentation (Fig. 6). The use of ultrasound is facilitated by the fact that the machine is extremely portable and can be wheeled up to the bedside in the trauma resuscitation suite. The study can be completed in less than three minutes, and can be repeated at any time. It can, therefore, be repeated in the event of sudden, unexplained hypotension or to reassess the extent of an already detected hemoperitoneum in the stable patient.

The use of ultrasound in the evaluation of patients with penetrating thoracoabdominal trauma was also recognized, and algorithms for the use of FAST such patients were developed (Fig. 7). The reliability of the subxiphoid view in the evaluation of penetrating chest trauma was examined in an analysis of 247 consecutive patients with penetrating chest wounds[49] following a similar, but institution-specific, algorithm. The pericardium was successfully visualized in 246 of 247 patients with a mean time of 0.8 minutes. There were 10 true-positive results, 236 true-negatives, and no false-positives or false-negatives. Although all of the true-positives sustained potentially lethal injuries, 7 were normotensive at the time of the ultrasound examination. In the true-positive cases, the mean time from ultrasound to operation was 12.1 minutes, and all ten patients survived. The authors concluded that the pericardial view of the surgeon-performed FAST (1) was rapid and accurate for the diagnosis of hemopericardium and subclinical pericardial tamponade, and that (2) delays in operative intervention were minimized.

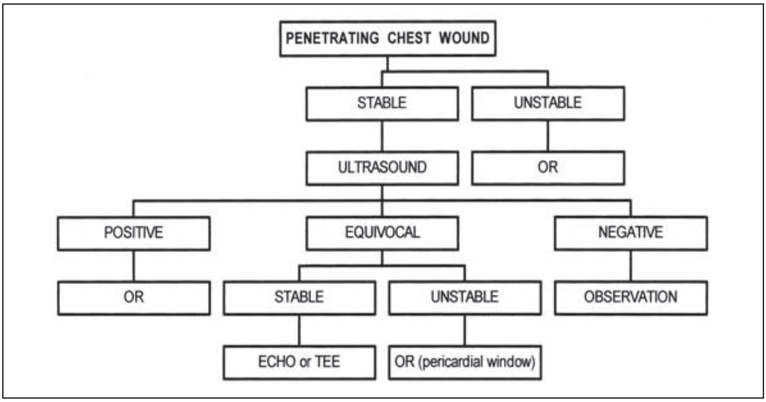

Figure 7. Algorithm for the use of ultrasound in the patient with penetrating chest injury and potential hemopericardium.

Until now, the detection of a traumatic hemothorax was done either on the basis of clinical signs and symptoms or with chest radiography. The insertion of a tube thoracostomy is often performed based only on clinical findings; it is painful, invasive, potentially dangerous to both patient and surgeon, and not always therapeutic. Supine chest radiographs, done through a backboard, are often difficult to read and are not always immediately available for interpretation. Noting that the lung bases were visualized on many FAST exams, Sisley et al[50] added right and left thoracic views to the "traditional" FAST exam (Fig. 8), and compared this augmented FAST exam to chest radiography for the detection of traumatic thoracic effusions (hemothoraces).

The right thoracic space is visualized by slowly moving the transducer cephalad from the RUQ view until the right supradiaphragmatic space is seen. A similar technique is followed in the LUQ to visualize the left supradiaphragmatic space.

Among 360 patients examined with both chest radiographs and thoracic ultrasonography, 40 traumatic pleural effusions were discovered, 39 by ultrasound and 37 by portable supine chest X-ray. There were no statistical differences for specificity, sensitivity, or positive/negative predictive values in either group. Three patients with false negative chest radiographs had effusions diagnosed by other radiographic exams (chest CT or upright chest X-ray), and ultrasound was positive in all three. The major issue was the performance time factor, with chest radiography requiring about 14 minutes and ultrasound needing only 1.3 minutes to complete.

The equivocal exam poses a diagnostic, and at times, therapeutic dilemma, to the surgeon. As Rozycki demonstrated, the frequency of an equivocal exam in penetrating chest trauma is low. Boulanger and colleagues studied this problem, as it related to blunt abdominal trauma, in 1998.[51] In their study, only 6.7% (28) of 417 blunt abdominal trauma patients imaged with FAST were considered to have equivocal or "indeterminate" examinations. Of these, 21% were obese, 50% had massive subcutaneous emphysema, and 21% had pelvic fractures. These results supported the previously mentioned limitations associated with the use of the FAST and confirmed the need to use other diagnostic modalities in selected patients. Only 8 studies were

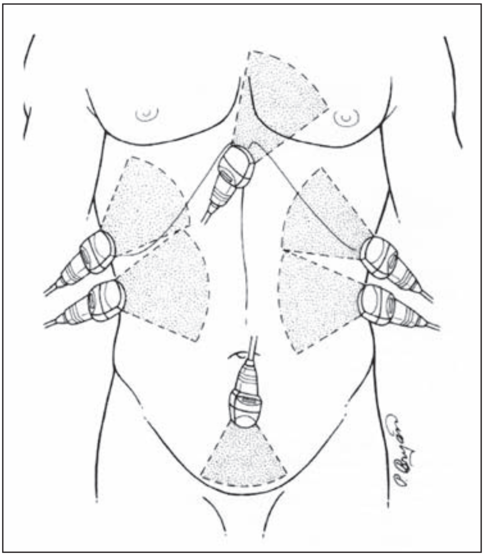

Figure 8. Four-view FAST with additional right and left thoracic views (arrows). (Modified from Sisley AC, Rozycki GS et al. Rapid detection of traumatic effusion using surgeon-performed ultrasonography. J Trauma 1998; 44:291, with permission.)

felt to be indeterminate due to factors attributable to the sonographer; in four of those exams the sonographer was suspicious of, but could not confirm the presence of, blood in the abdominal cavity. In all, seven of these 28 went to the operating room (Fig. 10).

It must be remembered that the FAST relies on the detection of fluid (blood) within the abdominal or thoracic cavities to identify those patients with injury. There are those patients who, on arrival, will not have blood within either cavity on FAST and yet will still have serious intra-cavitary injury; these are the patients at risk for missed injuries. This was highlighted in a multicenter study that looked at a subset of 772 blunt trauma patients that underwent FAST as well as CT scanning as part of their initial evaluation. Of the 52 patients found to have abdominal injuries, 29% (15) had no detectable hemoperitoneum on the admission FAST but were found to have significant solid organ injury on CT scan. Eleven of these patients were managed nonoperatively for injuries to the liver (5) and spleen (6). Four other patients, all with splenic injuries, underwent laparotomy. Three required surgery for control of hemorrhage, and only one was nontherapeutic. The authors concluded that, while FAST is a valuable tool for the early assessment of the abdominal cavity in blunt trauma, it should not be used to the exclusion of other technologies currently available. The conclusions of these authors, in fact, concur and support those of the many supporters of the surgeon-performed ultrasound.

Future Applications of Ultrasound in the Acute Setting

The portability of ultrasound equipment, coupled with the rapidity with which images can be obtained, make the FAST exam an ideal triage tool for the trauma resuscitation suite and in the prehospital setting. The use of the FAST (and the thoracic extension of the FAST) as a battlefield triage tool is currently under investigated by the United States Army, and development of an ultralight ultrasound

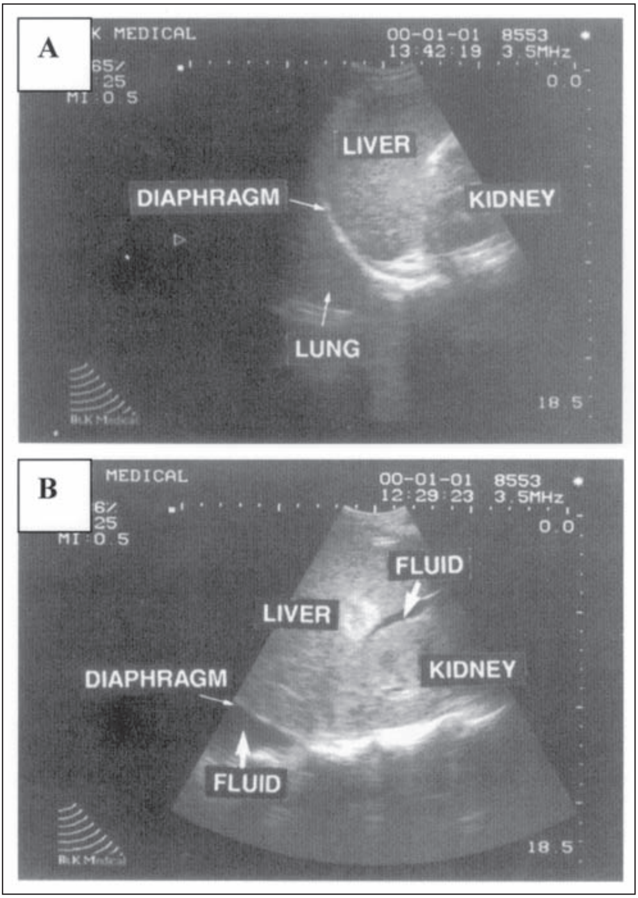

Figure 9. A) Normal right thoracic view. B) Positive right thoracic view, with traumatic hemothorax and hemoperitoneum. (From Sisley AC, Rozycki GS et al. Rapid detection of traumatic effusion using surgeon-performed ultrasonography. J Trauma 1998; 44:291, with permission.)

machine is ongoing. This technology, when coupled with the ability to transmit real time images via satellite (telemedicine), could revolutionize the concept of prehospital triage. The concept of prehospital FAST by civilian ground and aeromedical personnel is also being investigated[56] and is likely to change the way in which we triage the injured patient in the civilian setting. The ultrasound information made available from the scene might eventually influence the mode of transport, the destination hospital, and the more timely mobilization of the resources needed to best treat the injured patient. It is in this area that the FAST will probably show the most significant advances in the next five years.

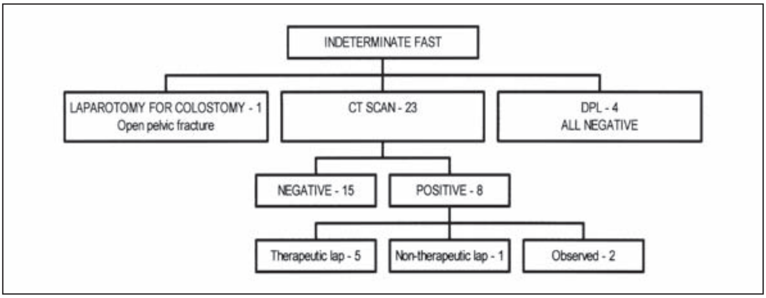

Figure10. Clinical course of patients with indeterminate abdominal sonograms. (Modified from Boulanger BR Brenneman FD et al. The indeterminate abdominal sonogram in multisystem blunt trauma. J Trauma 1998; 45:52, with permission.)

Summary

The use of the Focused Assessment by Sonography in Trauma, or FAST, has been accepted as part of the standard of care in trauma centers across the United States over the last decade. The FAST is a noninvasive study that has proved to be as accurate, specific, and sensitive as CT scanning or DPL in the diagnosis of intra-abdominal or intrathoracic injury and is quickly becoming the new "gold standard" for the initial screening of the trauma patient. Ultrasound imaging of the trauma patient has markedly decreased the use of CT scanning and DPL in the trauma setting but should not be seen as their replacement. The FAST should, instead, be used by surgeons a "second stethoscope", and should be incorporated into algorithms that include all appropriate diagnostic modalities in an organized and methodical fashion. While the use of FAST is rapidly expanding, the standards that surgeons are trained to will need to be firmly established, as will the standards that are used to credential surgeon-sonographers. The American College of Surgeons, in partnership with the American Board of Surgery, will need to establish such standards, and incorporate them into accredited surgical residency programs in the United States.

Appendix I. Lectures for Postgraduate Course No. 23: Ultrasound for the General Surgeon

Ultrasound physics and instrumentation Common pitfalls of ultrasound
Breast ultrasound for surgeons* Vascular ultrasound*
General abdominal ultrasound* Hepatobiliary ultrasound*
Colorectal ultrasound (Benign)* Colorectal ultrasound
(Malignant) Laparoscopic ultrasound (IOUS)*
Credentialing, liability, and "turf wars" Ultrasound in the acute setting:
Trauma and Critical Care*

*includes hands-on component on day two of course

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Chapter 3

Chest Trauma

Frank Davis and M. Gage Ochsner

Introduction

Of the 150,000 traumatic deaths in the Unites States each year, thoracic injuries have been responsible for one fourth of these. Timely diagnosis of these injuries is essential to reduce the number of preventable deaths.[1]

Ultrasound has been widely used in Europe for more than 25 years for the diagnosis of thoracic trauma. More recently over the last 10-12 years, American surgeons have adopted ultrasound for use in the acute setting.[2]

Ultrasound is rapidly becoming the accepted standard for initial evaluation of the trauma patient in many U.S. trauma centers. Of the four views usually performed during the focused assessment with sonography for trauma (FAST), the subxiphoid view of the heart has been reported to be the most accurate in detecting a pathologic condition.[1]

Ultrasound has proven useful in thoracic trauma, especially for cardiac injuries. Its role continues to expand to include injuries to the hemithorax and aorta.

Cardiac Injuries

Penetrating injuries to the heart have a high mortality, with more than 75% dying before reaching the hospital. In those patients reaching the hospital, stab wounds had a considerably higher survival rate (65%) than gunshot wounds (16%).[2] It has been further demonstrated that those patients requiring an emergency department thoracotomy had a higher mortality than those performed in the operating room.[3]

Thoracic ultrasound has probably proven of greatest benefit to patients with penetrating injuries to the anterior chest or transthoracic region, so called injuries within "the box" (Fig. 1). The box is defined as that region of the anterior chest bounded superiorly by the clavicles, laterally by the mid-clavicular lines and inferiorly by the costal margin at the mid-clavicular line.[4] One must also include any penetrating transthoracic injuries that could potentially pass through this zone, i.e., a GSW to the back that passes through the anterior mediastinun. These patients are at substantial risk for cardiac, tracheal, esophageal as well as great vessel injuries which all need to be appropriately evaluated. However, it is the cardiac injuries that can often remain elusive on initial evaluation. These patients often present in extremis but a small subset will present with normal or near normal vital signs. The best chance of patient survival is a rapid diagnosis followed by early definitive treatment. Subxiphoid pericardial window has been considered the gold standard for the diagnosis of these injuries. More recent studies would suggest that this can be best achieved by the surgeon-performed ultrasound in the trauma bay as soon as possible after patient arrival.[5]

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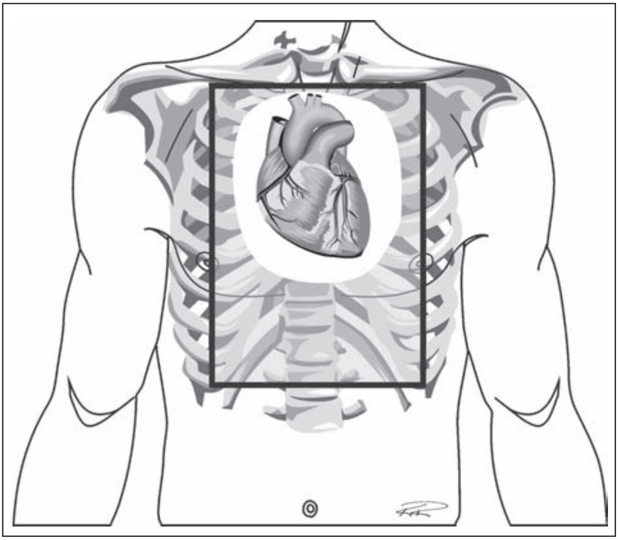

Figure1. Cardiac "box". See text for description.

In the past, the diagnosis of a cardiac injury in stable patients was often problematic. Physical exam to include the development of pulsus paradoxicus or Beck's triad is often unreliable. Jugular vein distention is present in <16% of patients with cardiac injury.[4,6] Central venous pressure measurements can often be falsely elevated (pain, straining, shivering) or depressed (hemorrhage).[7] Chest X-rays are normal in >80% of patients with cardiac tamponade. Patients with cardic tamponade can be saved by a procedure such as pericardiocentenesis but is a poor diagnostic test. It can be falsely positive in >50% of patients due to puncturing one of the cardiac chambers and carries the risk of producing a cardiac injury in the normal heart. Because of the lack of findings on physical exam, these injuries in the past have, in the past, usually required a mandatory subxiphoid pericardial window.[8,9] A subxiphoid pericardial window is very accurate for the diagnosis of cardiac injury but is both invasive and carries the risks of a general anesthetic. Furthermore, a negative exploration rate has been reported as high as 75 to 80%. More recently, a transthoracic or transesophageal echocardiography has been advocated in hemodynamically patients. This, however, has usually required calling in an echocardiography technician, cardiology fellow and/or cardiologist.[5,10] Transthoracic or transesophageal echocardiography have both reported as very sensitive for cardiac injuries, but their performance can lead to substantial time delays in diagnosis.[11,12] In unstable patients, a blind subxiphoid pericardial window or median sternotomy was usually required. This could potentially be problematic in patients with multicavitary penetrating trauma with competing etiologies for hemodynamic instability.

With the advent of surgeon-performed ultrasound, it has been reported that the initial time to perform a FAST exam is less than 2.5 minutes total, with less than .8 minutes for the cardiac portion of the exam.[5] Furthermore, in one recent multicenter study, the interval from positive diagnosis to the operating room was reported to

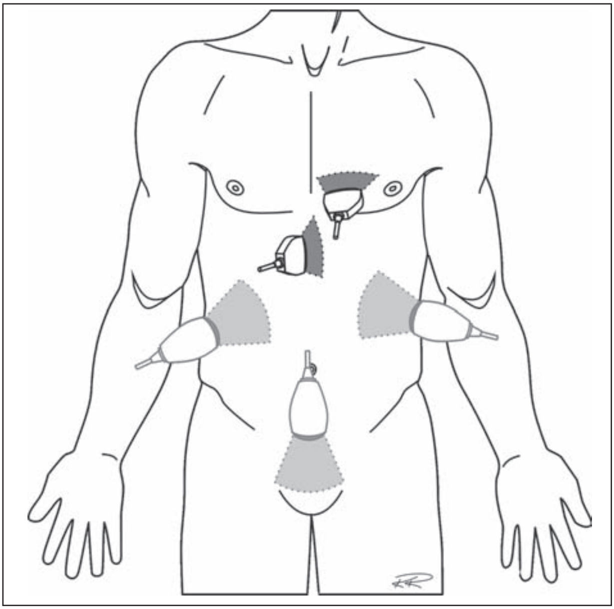

Figure 2. Probe positioning for pericardial views. Light gray transducer beams illustrate the traditional abdominal views of the FAST exam. The dark gray transducers represent the subxiphoid sagittal view as well as the transverse parasternal view.

have averaged approximately 12 minutes.[13] Studies by surgeon-performed ultrasound have recently demonstrated 100% sensitivity, 97.7% specificity and 97% accuracy in identifying cardiac injuries.

Technique

Exams are usually performed with the patient in the supine position during the secondary survey as recommended by the Advanced Trauma Life Support (ATLS)® course. Most commonly, a 3.5 MHz transducer is utilized since this is what is generally available for most FAST exams.

The initial views usually include a subxiphoid sagittal or long-axis view and an alternative transverse parasternal view of the pericardium (Fig. 2). The subxiphoid view uses the liver as an acoustic window to achieve a four chamber view.[9] The parasternal view is usually performed through the sixth, seventh or eight intercostal space adjacent to the left (sometimes right) parasternal border. The subxiphoid view can sometimes be limited by a narrow subxiphoid space or abdominal obesity.[5] Even though the subxiphoid view is taught by many courses, some have suggested that the parasternal view be the initial exam since it sometimes allows a more rapid view of the pericardium.[11,12]

Even though ultrasound can provide a considerable amount of information about the heart, the primary purpose in the acute setting is identifying the presence or absence of pericardinal fluid. In a positive exam, one will see black or anechoic stripe or space (collection of fluid) between the heart and the pericardium[5] (Fig. 3). Clotted

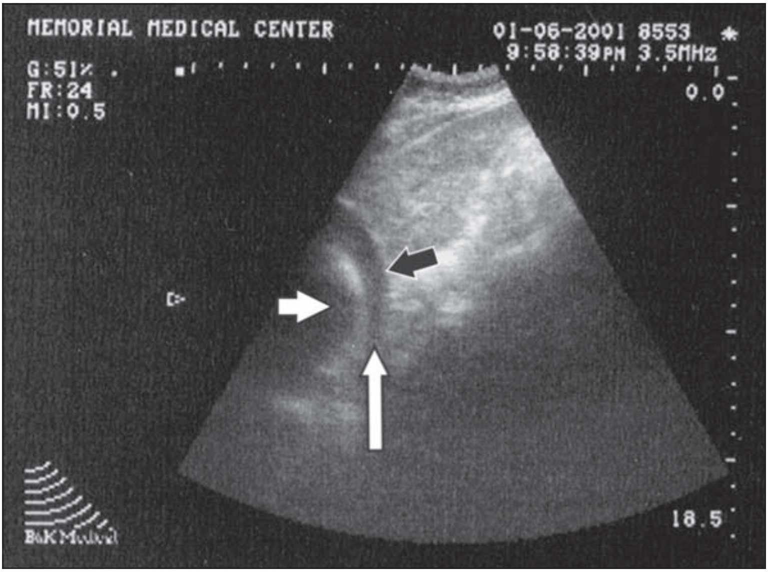

Figure 3. Subxiphoid view of a pericardial effusion. The short white arrow demonstrates the heart and the short black arrow demonstrates the pericardium. The long white arrow demonstrates the pericardial effusion.

blood in the pericardium can sometimes be elusive, appearing as a gray heterogenetic stripe which can be confused as normal myocardium. Sometimes one may see a thin black "pencil line" of fluid between the two layers, which represents the normal 20 to 60 cc of normal pericardial fluid.

A positive exam would mandate immediate surgical intervention (Fig. 4). An equivocal or poor quality study would warrant either a subxiphoid pericardial window or a formal transthoracic or transesophageal echocardiogram (TEE) as indicated by clinical suspicion and hemodynamic stability.[13]

It must be remembered that ultrasound cannot distinguish between blood and physiologic fluid. Therefore, in a stable patient, a subxiphoid pericardial window should be considered prior to a median sternotomy in a patient with a positive ultrasound for pericardial fluid.

Limitations

Ultrasonography of the pericardium can be severely limited by patients with pneumothorax and subcutaneous or mediastinal emphysema. TEE may be an option in these patients if time allows. Otherwise, one needs to consider a subxiphoid pericardial window.

There have been concerns raised about the accuracy of surgeon-performed ultrasound in patients with significant hemothoraces. The concern is that a large hemothorax can produce a false negative exam by obscuring a small hemopericardium. Also, as reported by Meyer[14] as well as experienced by the authors on a number of occasions, a hemopericardium may decompress into the thoracic cavity and thereby

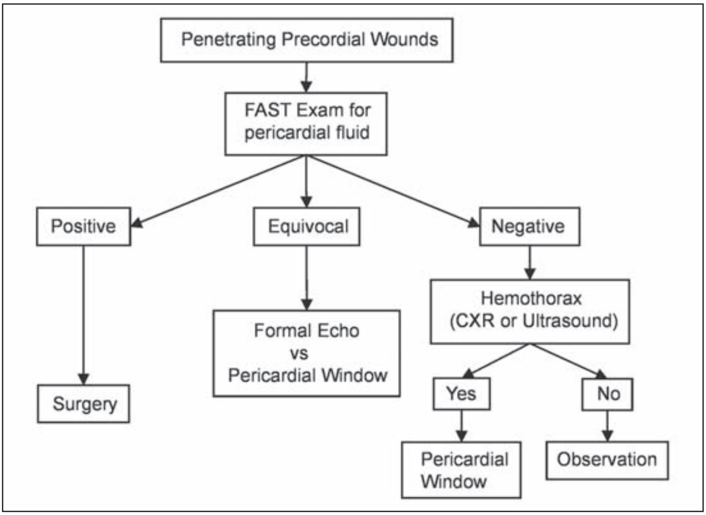

Figure 4. Algorithm for penetrating precordial and transthoracic wounds. Se text for description.

produce a false negative exam. Furthermore, there is the concern that a large hemothorax surrounding the pericardium might produce a false positive exam. This would suggest the need for a subxiphoid pericardial window in patients with significant hemothoraces as depicted in Figure 4.

In addition to hemothoraces, it has been reported that the presence of an epicardial fat pad can be confused as a pericardial effusion.[15] Therefore, one should consider confirming an effusion using one of the alternative views.

The role of repeat exams of the pericardium is yet to be defined.[13] However, if the physiologic parameters or physical exam fail to improve or deteriorate, it may be prudent to repeat the ultrasound, obtain a formal echocardiogram or proceed with a subxiphoid pericardial window.

Surgeon-performed ultrasound is clearly the initial diagnostic test of choice in patients sustaining precordial or transthoracic penetrating trauma. Its advantages include that it is rapid, accurate, noninvasive (painless), portable, repeatable and cost effective. It can also facilitate earlier operative intervention, which in one study demonstrated a decrease in mortality.[16]

In any patient with an equivocal exam, one must consider either a subxiphoid pericardial window or a formal echocardiogram if time permits. Also, in patients with a hemothorax, one may want to also consider a subxiphoid pericardial window because of the potential for a false negative exam with ultrasound.

Blunt Cardiac Injuries

Blunt cardiac rupture is responsible for approximately 2,500 deaths per year from MVC's.[17] The majority of these patients die prior to reaching the hospital. With modern improvements in prehospital care, a small group of these patients will survive 30 minutes or longer. Of those reaching the emergency department, right atrial rupture is the most common finding.[18] One third will have multiple chamber involvement, which is almost always fatal. The mechanism of death is usually tamponade if the pericardium is intact or exsanguination in those patients with a ruptured pericardium.

In one series of 59 patients with blunt cardiac injury, 50% sustained cardiac arrest during transport and another 24% arrested in the ED.[19] Since death can occur very rapidly in this group of patients, rapid diagnosis and treatment is essential. Ultrasound appears to be the modality with the greatest potential to make an early diagnosis of pericardial fluid and thus suggest a diagnosis of blunt cardiac rupture. Since the majority of these can be repaired without cardiopulmonary bypass, these injuries can potentially be repaired by most general and trauma surgeons. Since 77% of these patients have multisystem injuries, the diagnosis can often be elusive with multiple competing etiologies for hypotension, further emphasizing the value of the role of surgeon-performed ultrasound. This has been further substantiated by several recent reports, which have demonstrated the value of timely diagnosis with ultrasound being immediately available in the ED.[17,20]

The exam for blunt trauma is performed in the same manner as above for penetrating precordial injuries (routine FAST exam). It is important to emphasize the inclusion of the subxiphoid (or parasternal) views of the heart during the routine FAST exam for all patients sustaining blunt trauma. This not only allows adjustment of the time-gain compensation controls but also helps maintain proficiency in evaluating the normal heart. Furthermore, event though blunt cardiac injuries are rare, it is important to screen all patients at risk since a timely diagnosis is critical to patient survival.

Traumatic Effusions (Hemothoraces)

By using a slight modification of the FAST exam, traumatic pleural effusions can be easily diagnosed. Studies have demonstrated that surgeon-performed ultrasound can accurately detect fluid collections in the hemithorax with 97 to 100% sensitivity and 98 to 100% specificity.[22] This is easily performed by the addition of right and left supradiaphragmatic views to the standard FAST exam.[2] The two additional sagittal views are sequenced using the same transducer after the standard view of the right upper quadrant and left upper quadrant, respectively. This adds minimal time to the FAST exam, approx. 1.3 minutes on average. Focused thoracic examinations can detect effusions as small as 20-60 ml.

After visualizing the right upper quadrant in a sagittal plane, the transducer is simply moved cephalad in the midaxillary line until the supradiaphragmatic view is obtained[22] (Fig. 5). Normal lung gives a gray appearance due to the scattering from the air filled lungs (Fig. 6). Fluid in the supradiaphragmatic space appears as anechoic or a black line just cephalad to the hyperechoic (white) line of the diaphragm[23] (Fig. 7). The same process is then repeated on the left side. After visualizing the kidney and spleen, the transducer is moved slightly cephalad in the posterior axillary line until the left supradiaphragmatic space is identified.

A significant advantage of the focused thoracic exam for hemothoraces is that it is faster than standard chest radiography. This may be advantageous in the unstable patient with secondary survey. It can facilitate treatment of a hemothorax with a tube thoracostomy prior to the initial chest radiograph, thus saving the cost and time of a second chest radiograph.[22,23] Another potential advantage is during a mass causality environment when radiographic technicians and/or film development resources are scarce.

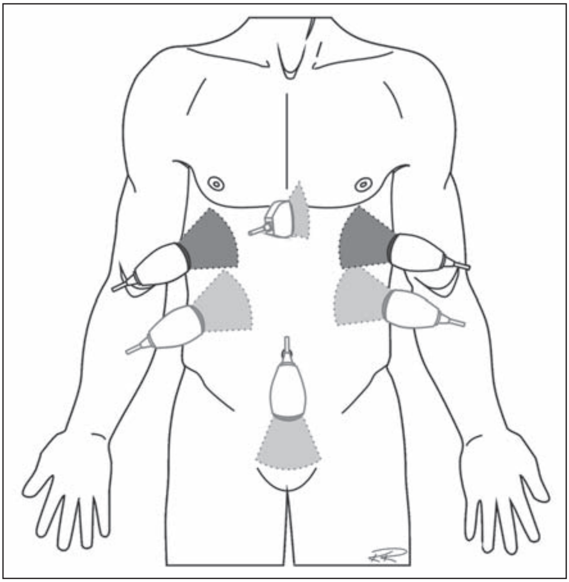

Figure 5. Probe positioning for supradiaphragmatic views of the chest to detect pleural effusions. Light gray transducer beam demonstrates the traditional FAST exam, while the dark gray transducer beam demonstrates the supradiaphragmatic views.

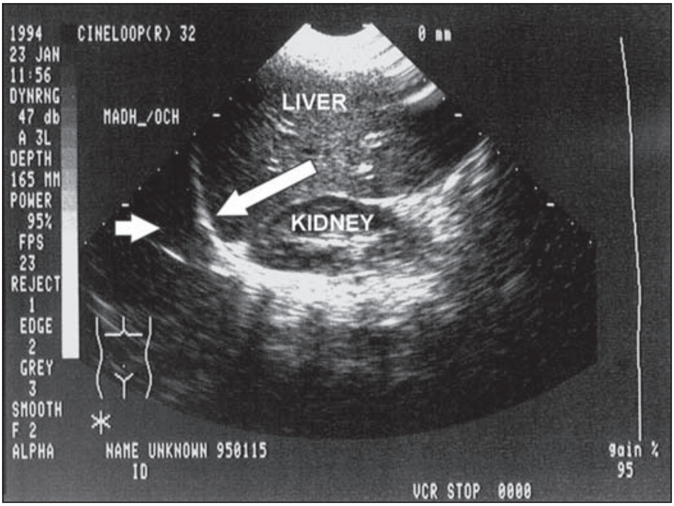

Figure 6. Ultrasonic view of the right supradiaphragmatic space. The short arrow depicts the inferior aspect of the lung while the long arrow demonstrates the hyperechoic diaphragm.

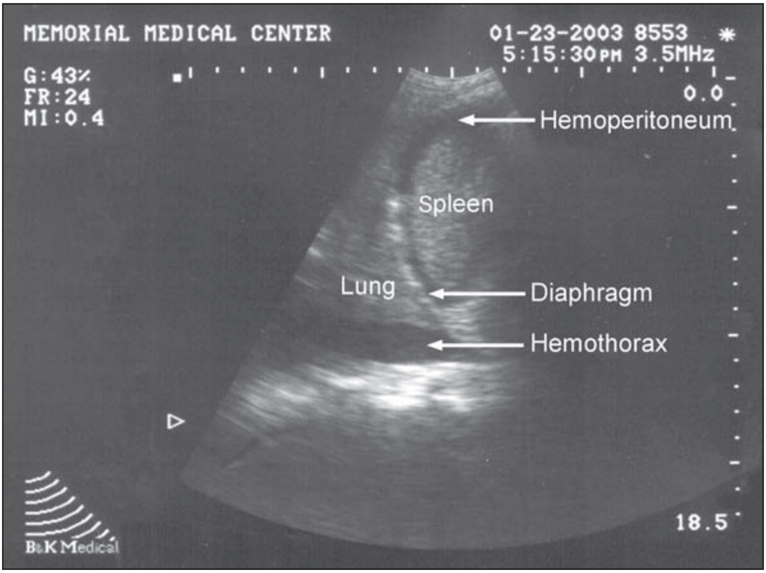

Figure 7. Demonstration of fluid in the left chest (supradiaphragmatic space). Also, note there is fluid below the diaphragm, between the diaphragm and spleen.

These two additional views can easily be added to the FAST exam in those patients with the potential of thoracic trauma with minimum increase in time and may allow more efficient utilization of resources. Its greatest advantage may prove to be in the hemodynamically unstable patient with multisystem injuries.

Limitations: no data exists to quantitate the effusions and most would agree that very small effusions can be observed without tube thoracostomy.

Ultrasound Diagnosis of Pneumothorax

In most trauma centers today, the standard chest radiography is the usual diagnostic modality used to establish or confirm the diagnosis of pneumothorax. CT scans have also proven reliable to detect small occult pneumothoraces. More recently there are more reports appearing in the literature of thoracic ultrasound being used to detect pneumothoraces.[24-27]

This may be particularly applicable when chest radiographs are not immediately available, such as remote locations, mass casualty scenarios or military conflicts. Although data are severely limited, FAST may also prove useful to help identify occult anterior pneumothoraces missed on suspine chest radiographs. Future applications could include its use on space stations where ultrasound machines are much smaller and lighter than conventional chest radiographic equipment.

Ultrasound examination of the lung is suboptimal due to the scattering effect produced by the air-filled lung on ultrasound waves. However, the presence of certain specific artifacts effectively rules out a large pneumothorax.

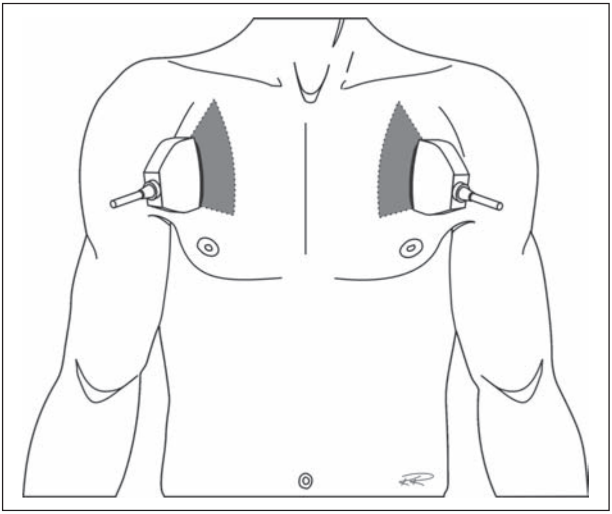

Figure 8. Sagittal probe positioning for the diagnosis of pneumothorax. See text for description.

Technique

Ultrasonographic examination for pneumothoraces is performed with the patient in the supine position. Pneumothoraces are best visualized over the anterior chest wall, in approximately the third or fourth interspace using the standard 3.5 MHz probe (Fig. 8). With a normally expanded lung, the hyperechoic pleural line is easy visualized. The normal to and fro sliding of the visceral pleura against the stationary parietal pleura is easily visualized and is synchronized with respirations. This is referred to as the "slide" and is usually absent in the presence of a pneumothorax.[24,26,27] Also, directly below this hyperechoic pleural line, only artifacts are normally visualized, most commonly the so-called comet-tail artifact. This is a reverberation artifact that has been described as a vertical, narrow-based, echogenic band extending from the pleura into the deeper portions of the imagine (laser ray-like)[25] (Fig. 9). This is generated by the large difference in impedance between the pleura (highly reflective) and its surrounding air filled lungs. This arises from the pleural line and fans out to the edge of the screen. Comet-tail artifacts can be single or multiple. In the presence of a pneumothorax, the ultrasound beam fails to cross the "pocket of air", therefore these reverberation artifacts are lost.

In contrast to most ultrasonic diagnosis, the diagnosis of pneumothorax relies on the "absence" of both the normal lung slide as well as the normal of comet-tail artifacts. In one study, combining the absence of normal lung sliding and comet-tail artifacts, Liechtenstein was able to demonstrate a sensitivity of 100% and a specificity of 96%.[26]

No data have correlated size of pneumothorax to the presence or absence of lung sliding and comet-tail artifacts.[28] Also, absent lung sliding has been reported in patients with ARDS.

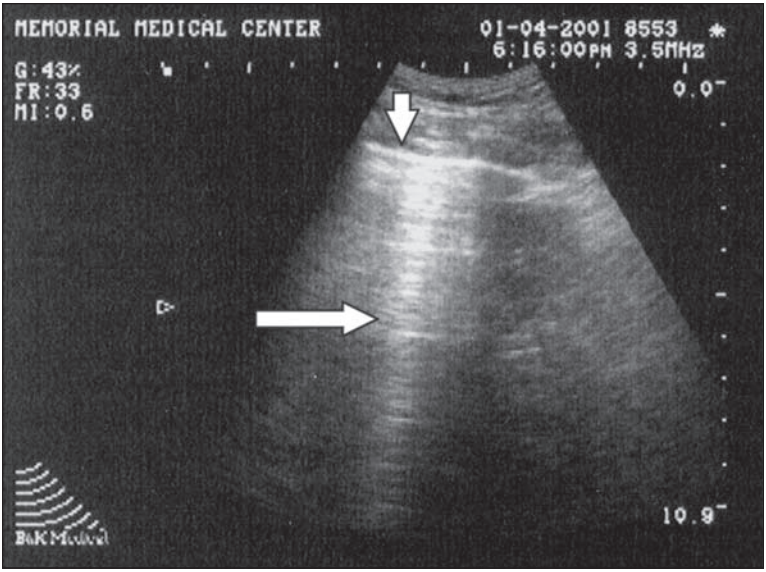

Figure 9. Comet-tail artifacts that are seen in patients without pneumothorax. The long arrow represents the Comet-tail artifacts, while the short arrow demonstrates the pleura.

TEE

Once felt to be the exclusive domain of the cardiologist, the role of transesophageal echocardiography (TEE) has expanded to be used by both anesthesiologists and surgeons.[29] As the technology has improved with smaller transducer size and multiplane imaging, TEE's use continues to expand to include the emergency department, the operating room as well as the ICU. TEE's intraoperative role continues to expand, particularly during certain types of cardiac surgery and for the diagnosis of thoracic injuries.

Most TEE probes are 5 MHz as opposed to 2.5-3.5 MHz for transthoracic echocardiology (TTE).[29] This is dictated by the laws of physics. Since the TEE probe is closer to the structures being examined, less penetration is required and the higher frequency allows better resolution. Doppler flow analysis is usually added to TEE to determine blood flow velocity and direction. With the addition of color-flow Doppler imaging, flow towards the transducer is usually displayed as red and flow away from the transducer is displayed as blue.

The advantages of TTE over TEE include ease of use, more readily available and superior images of the ventricular apex.[31] However, in trauma patients, TEE offers several advantages over TTE. TEE provides excellent visualization of the heart and a majority of the thoracic aorta in almost all patients. The short distance from bone allows a higher frequency probe, which provides superior anatomic details. This allows better visualization of the aorta, cardiac valves and wall motion abnormalities.

Four Primary Indications for TEE in the Acute Setting[1,29,31]

1. Imaging the thoracic aorta to rule out blunt aortic injury
    a. Indeterminate arteriogram
    b. Patient too unstable to be transported to the CT scanner or angiography suite
    c. Patient already in the operating room undergoing treatment for another life threatening injury
2. Visualization of pericardial blood in patients with penetrating chest trauma where transthoracic ultrasound was equivocal or limited (subcutaneous or mediastinal air)
3. Evaluate cardiac dysfunction in patients with multisystem trauma (blunt cardiac injury)
4. Evaluate intracardiac shunts in patients following repair of penetrating cardiac injuries

Other uses for TEE in the ICU for trauma patients:

1. Allows liberal follow-up on patients with blunt aortic injury treated nonoperatively.
2. In the critically ill ICU patient with high intrathoracic pressures, provides a better indicator of true preload than conventional pulmonary artery catheters.
3. More sensitive than EKG or pulmonary artery pressures at detecting myocardial ischemia

Contraindications

Esophageal pathology, unstable cervical spine and potential airway issues (if patient not intubated)

Limitations

- Blind spot (However, with the newer multiplane transducers, this blind segment can often be minimized or eliminated, see below)
- Technical success rate varies from 85-98.5% in multiple series
- Inability to document injuries to the brachiocephalic arteries[32]
- In patients with severe atheromatous disease, may be difficult to distinguish traumatic lesions from atheromatous lesions
- Poor visualization of true left ventricular apex
- View can be compromised with significant pneumomediastinum
- Extremely operator-dependent and interpreter-dependent (significant learning curve)

Training

Training includes attendance at a comprehensive TEE course.[29] Other options include an apprenticeship under the mentorship of an experienced surgeon, anesthesiologist or cardiologist. Training, credentialing and competency are areas that are yet to be clearly defined.

TEE in Blunt Aortic Injuries

It has been reported that 85% of patients with blunt thoracic aortic injuries die at the scene with 40% of the scene survivors dying within the first 24 hours after injury if not treated.[33] Most aortic injuries occur at the aortic isthmus (90%), just distal to the subclavian artery takeoff. The ascending aorta is injured in approximately 5-9% of

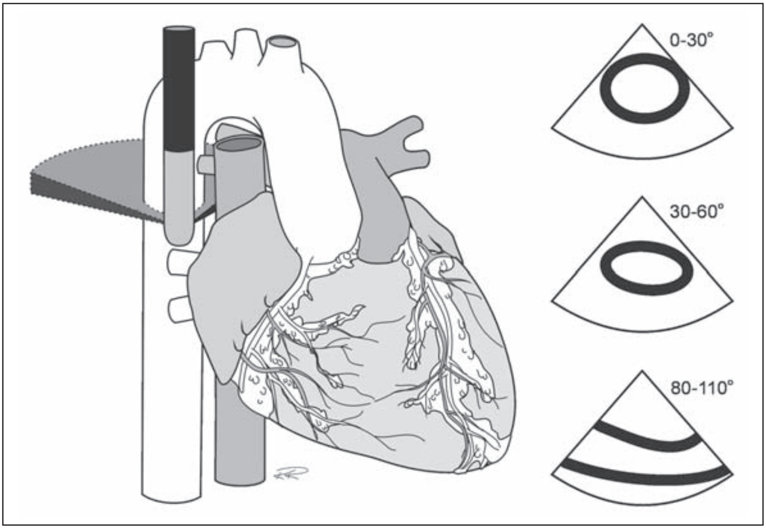

Figure 10. TEE probe positioned behind the descending aorta. (Modified from: Surg Clin North Am, 78(2):311-33, Johnson SB, Sisley AC, The surgeon's use of transesophageal echocardiography, ©1998 with permission from Elsevier Science.)

patients with 1%-3% of the injuries occurring in the descending aorta. Also, in 4-10% of cases, there may be concomitant injuries to the great vessels. The adventitia is intact in 60% of the cases, which usually results in pseudoaneurysm formation rather than free rupture. Because of the potential of rupture of the pseudoaneurysm, it is imperative that these injuries undergo expeditious diagnosis and treatment. The gold standard has been aortography but this diagnostic modality remains imperfect. It requires moving the patient to the angiographic suite where monitoring and resuscitation are often suboptimal. There are reported false positive studies due to factors such as prominent ductus diverticulum, atheromatous plaques and contrast streaming artifacts. There are also occasional false negative studies due to nontransmural intimal flaps.

The thoracic aorta is in close proximity to the esophagus, which allows excellent evaluation of the majority of the thoracic aorta[29] (Fig. 10). However, the left mainstem bronchus and trachea are located between the esophagus and the aorta which results in an ultrasonic “blind spot.” This “blind spot” refers to a poor view of a 3-5 cm segment of upper ascending aorta from approximately 3 cm above aortic valve distally to include part or all of the aortic arch when using a single plane transducer. This blind spot is greatly reduced or eliminated with multiplane transducers and increased experience.[31]

Technique

The best view of the aortic segment at risk is usually achieved with the probe positioned approximately 24 cm from the incisors (Figs. 11, 12). The characteristic aortic intimal flap or intramural hematoma can be seen on the transverse and longitudal images with TEE. TEE allows visualization of different images in multiple planes for confirmation and allows better definition of the extent of the injury.

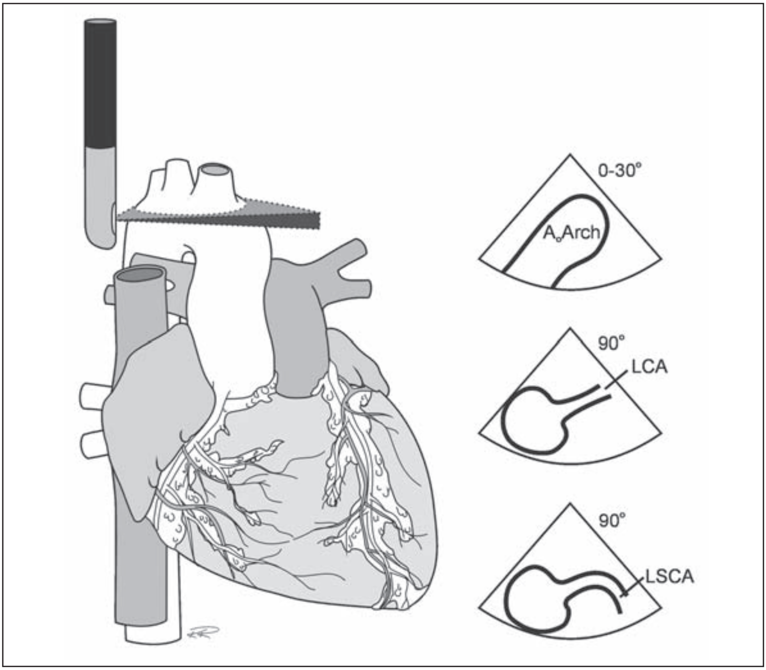

Figure 11. TEE probe positioned behind the aortic arch. AArch = aortic, LCA = left carotid artery, LSCA + left subclavian artery. (Modified from: Surg Clin North Am, 78(2):311-33, Johnson SB, Sisley AC, The surgeon's use of transesophageal echocardiography, ©1998 with permission from Elsevier Science.)

Some of the earlier studies had reported somewhat disappointing results with sensitivity for blunt aortic injuries. However, when combining the results of the recent literature, TEE was found to have an overall sensitivity of 89% (range 62.5% to 100%), specificity of 99% (range 91.3% to 100%) and accuracy of 97.7% (range of 86.2% to 100%) in diagnosing blunt thoracic aortic injuries. These findings are very similar to that obtained with aortography where a 89% to 99% sensitivity and 98% to 100% specificity have been reported.[34,35] As experience is gained, the numbers for TEE should be more closely approach that of aortography.

The advantages of TEE in diagnosis of blunt aortic injury:

- Portable, can be brought to the patient
- Performed during resuscitation or during OR procedures
- Can be performed by appropriately trained surgeons, eliminating another consultant
- TEE allows good visualization of the aortic wall
- Faster time to diagnosis (27-45 min. in some institutions)[32,36]

Pneumothorax, pneumopericardium and pneumomediastinum are often a problem for TTE but less of a factor for TEE. However, in patients with suspected

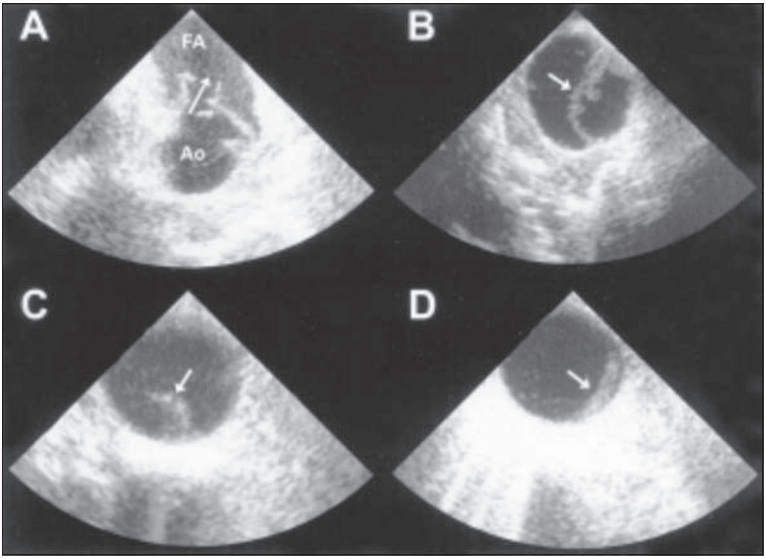

Figure 12. Transesophageal echographic aspect of main categories of traumatic injury. A) Traumatic aortic rupture with false aneurysm (FA) communicating (arrow) with the aortic lumen (Ao); B) traumatic aortic rupture with a large medial flap; C) intimal flap without hemomediastinum or modification in the aortic geometry; D) intramural hematoma (arrow) without hemomediastinum. (Reprinted from ref. 30: Goarin JP, Cluzel P, Gosgnach M et al. Evaluation of transesophgeal echocardiography for diagnosis of traumatic aortic injury. Anesthesiology 2000; 93:1373-7.)

brachiocephalic branch injuries, aortography is indicated since TEE is unreliable in visualizing these vessels.

It has been reported in several series that TEE is able to identify intimal injuries that are below the threshold of conventional angiography.[34] Then the question becomes, can these minimal injuries be treated with nonoperative management? Perhaps intravascular ultrasound may help answer these types of questions in the future.

TEE in Penetrating Precordial Injuries

TEE may be used to visualize pericardial blood in patients with penetrating chest trauma where transthoracic ultrasound was equivocal or limited due to subcutaneous or mediastinal air and body habitus. In addition, echocardiographic evidence of cardiac dysfunction has been diagnosed from the blast effect of close range thoracic gunshot wounds without pericardial penetration.

Additional indications for TEE following penetrating precordial injuries include follow-up after cardiorrhaphy to identify intracardiac shunts.[36] These include such injuries as traumatic septal defects, aortic-to-right ventricular outflow tract fistulas and severed papillary muscles. There are also several reports of TEE used to better define the exact location of intracardiac foreign bodies (bullets, nails from nail guns) that had failed localization with TTE or CT scans.

TEE in Blunt Cardiac Injury

Additional uses for TEE include the evaluation of blunt cardiac injury (myocardial contusion). Myocardial contusion often presents as refractory hypotension (cardiac dysfunction) and/or dysrhythmias. Both blunt cardiac injury and cardiac tamponade can present with a similar clinical picture of hypotension and increased central venous pressure.[29] A clinical example would be a patient in the emergency department or ICU with multisystem injuries and refractory hypotension without any signs of ongoing blood loss. TEE would be very helpful to sort things out since the treatment for tamponade vastly different from blunt cardiac injury.

TEE allows the following assessment of cardiac function:[29]

- Wall motion abnormalities
- Pericardial effusions (with or without evidence tamponade)
- Valvular injuries (aortic valve, rupture of mitral valve chordae tendinae / papillary muscle)
- Contractility
- Chamber disruption
- Valvular incompetence
- Coronary artery thrombosis
- Ventricular aneurysm

As previously discussed, pericardial effusions on TTE or TEE appear as an anechoic space between the cardiac wall and the pericardium. However, in hemodynamically stable patients, TEE or TTE can provide additional diagnosis of impending tamponade with the findings of: paradoxical septal wall motion, changes in transvavular flow, decreased right atrial size and decreased biventricular size.[21]

TEE in the ICU

TEE can also be very useful in the ICU. It can be performed in stable as well as some hemodynamically unstable patients. It can detect new wall motion abnormalities indicative of myocardial ischemia, in this instance, TEE is more sensitive than EKG monitoring. In addition, TEE can often provide a better estimation of left ventricular end-diastolic volume in critically ill patients compared to pulmonary artery catheters.[29] This allows for a more accurate determination of intravascular volume status.

IVUS Assessment of Traumatic Injury to the Thoracic Aorta

Conventional angiography as well as digital subtraction angiography have been considered the gold standard for confirming the diagnosis of traumatic injuries of the thoracic aorta. These injuries usually include pseudoaneurysms and intimal flaps. However, atherosclerotic disease as well as prominent ductus arteriosus diverticulum can produce false positive scans. With continued miniaturization of ultrasound probes, intravascular ultrasound (IVUS) has become technically practical. This is a catheter mounted ultrasound crystal that allows sonographic evaluation of both the intravascular lumen as well as the vessel wall.[37] IVUS provides cross-sectional images of the aortic wall with usually good visualization of all three layers. Findings on IVUS with blunt aortic injury include intimal flaps, intramural lesions (hematomas), blurring of the three-layered appearance of the wall, disruption of the wall with pseudoaneurysms and perivascular hematomas (Fig. 13). IVUS can be used alone or in combination with aortography to increase the sensitivity and specificity of the invasive procedures.

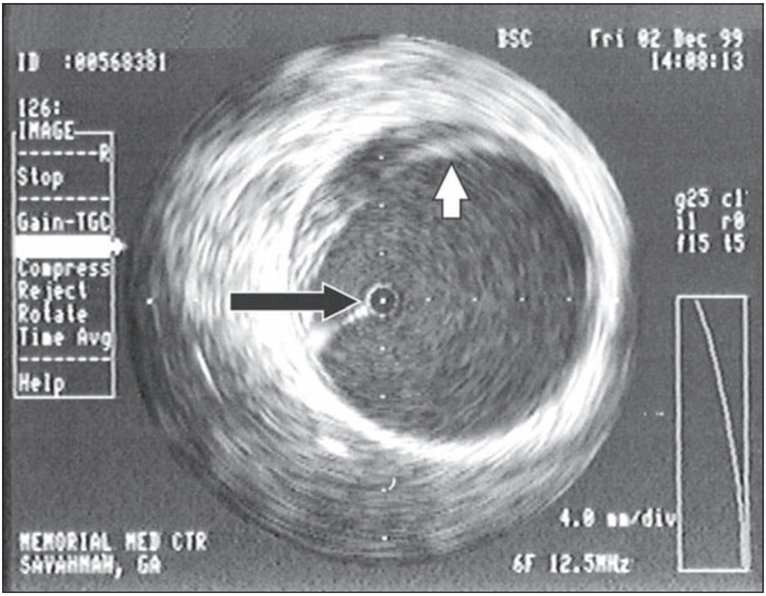

Figure13. Intravascular ultrasound demonstration of a blunt aortic injury. The small arrow represents the intravascular ultrasound probe. The large arrow represents an intimal flap with intramural hemorrhage.

From a technical viewpoint, IVUS catheters are mechanical transducers that are mounted inside of a protective catheter. They use either a rotating angled ceramic crystal or a rotating mirror that deflects the ultrasound beam from an adjacent crystal. A small, external motor with a speed of 700-1500 RPM is required for rotation of the crystal or mirror.[38] The frequency of the probe determines the field of view, which usually ranges from 12.5 MHz to 20 MHz. Access is commonly gained via the common femoral artery and requires fluoroscopic positioning with an "over-the-wire" system for selective catheterization of each vessel to be evaluated. Normal IVUS exam of the intact aorta shows a three-layered appearance with a hyperechoic inner layer (intima), a hypoechoic middle layer (media) and a hyperechoic outer later (adventitia).

One of the advantages of IVUS includes identification of intramural hematomas which are often not well visualized with aortography unless there is an associated intimal flap. IVUS has recently been considered a natural extension of aortography and usually does not add significant time or morbidity to the procedure. It may prove to provide superior data regarding the extent of the intimal dissection, the presence or absence of intramural hematoma as well as the distance of the rupture from the left subclavian artery. At the present time, it appears that the role of IVUS is complementary to aortography when there is an equivocal or indeterminate study.

It is clear that further prospective data will be required to better define the role of IVUS. With continued improvements in technology, it is very likely that IVUS will

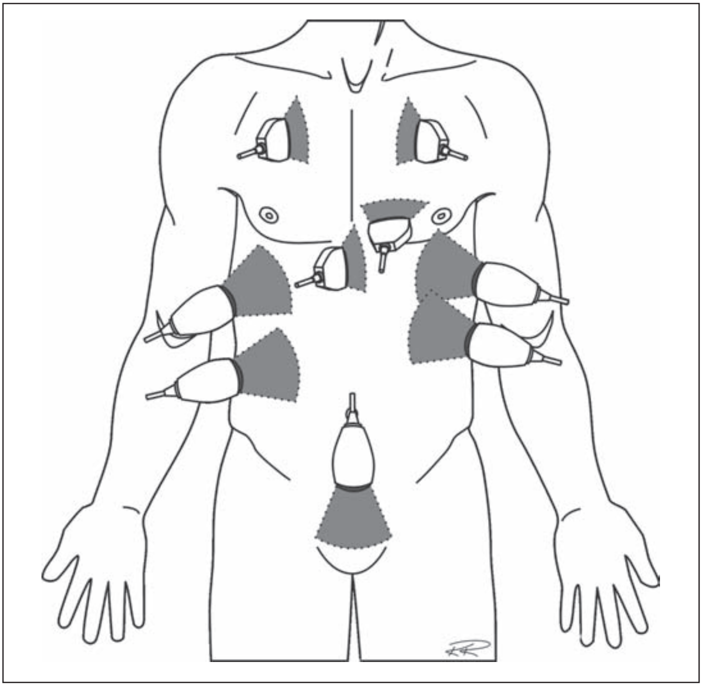

Figure 14. This diagram demonstrates a combined view of the FAST exam as well as all of the thoracic views.

have an expanded role in the diagnosis of the ruptured thoracic aorta. It may prove very useful to more accurately delineate which patients might benefit from nonoperative management or identify candidates for endovascular covered stent repair.

Summary

It is clear that ultrasound has had a significant impact on the management of thoracic trauma. The most important contribution appears to be surgeon-performed ultrasound, which is now the standard of care in many trauma centers for thoracic trauma. In patients with both blunt or penetrating injuries, this modality has decreased the time from patient presentation to the operating room and has decreased the number of negative pericardial windows. More recently, ultrasound appears useful in the diagnosis of both hemothoraces as well as pneumothoraces. Combining the FAST exam with all the transthoracic views would create an ultrasound examination as depicted in Figure 14. Even though this diagram may appear complicated, all the views can be rapidly acquired in a matter of minutes. The portability of TEE has provided an alternative diagnostic modality with proven sensitivity for the diagnosis of blunt aortic injury as well as blunt cardiac injury (myocardial contusion). Even though TEE requires a significant learning curve, it is likely that with improved technology and due diligence it will more frequently be found in the hands of surgeons and anesthesiologists.

TEE is currently not considered the first-line imaging modality at most trauma centers today for blunt aortic injuries. However, its use continues to expand as more anesthesiologists, trauma surgeons and intensivists become more facile with this technique. Its biggest advantage is portability. It can be performed in the OR while undergoing exploratory laparotomy for uncontrolled hemorrhage or at the bedside in the ICU. Additional advantages also include: rapidity, low cost, safety and repeatability. However, TEE is operator experience-dependent and observer-dependent which requires a substantial time commitment to become proficient.

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Abdominal Aortic Aneurysm Screening in the Emergent Setting

David B. Pilcher

Introduction

In the emergent setting, the advantage of ultrasound is the rapid detection of an abdominal aortic aneurysm and the measurement of its size. This can be done with minimal interference with resuscitative efforts.

Definition of Aneurysm

An aneurysm is defined as an aorta >3.0 cm, or 1 1/2 times the normal suprarenal aorta. Cronenwett suggested that 3-6 cm AAAs expand at 10% per year, whereas others have suggested 0.3-0.5 cm/ year as the standard rate.

In 1995, Ricci et al showed the normal aortic diameter in males as <2 cm (1.7 ± 0.2 cm). The aortic diameter in females is normally <1.7 cm. (1.5 ± 0.2 cm).

Relation of Aneurysm Size to Risk of Rupture

Although small aneurysms have been known to rupture, aneurysms <5 cm rupture rarely. A recent United Kingdom study of small aneurysms and a US Veterans study of larger aneurysms prospectively showed that rates of rupture one year after measurement clearly related to aneurysm size as follows:

AAA size	Rupture
<4 cm	0.3%
4-5 cm	1.5%
5-6 cm	6.5-9.4%
>7.0 cm	32.5%

It seems clear that someone in shock with no aortic aneurysm, or an aneurysm <5 cm in diameter, has a low likelihood that aneurysm rupture is the cause of shock.

Patient Preparation

In the emergent situation of severe abdominal/back pain where the question of clinical relevance is: "Is there an aneurysm >5 cm present?" no preparation is possible. Removal of gastric gas by nasogastric tube could help, but avoidance of stimulation is usually practiced in patients with possible ruptured aneurysm. Increasing blood pressure by stimulation could increase leakage from an aneurysm.

Ultrasound Equipment

To measure ultrasound diameter, B-mode alone is all that is required. Low frequency probes (2-4 MHz) are necessary for adequate penetration. Curved linear or phased array probes give a wider field at the depths necessary for aneurysm imaging (Fig. 1).

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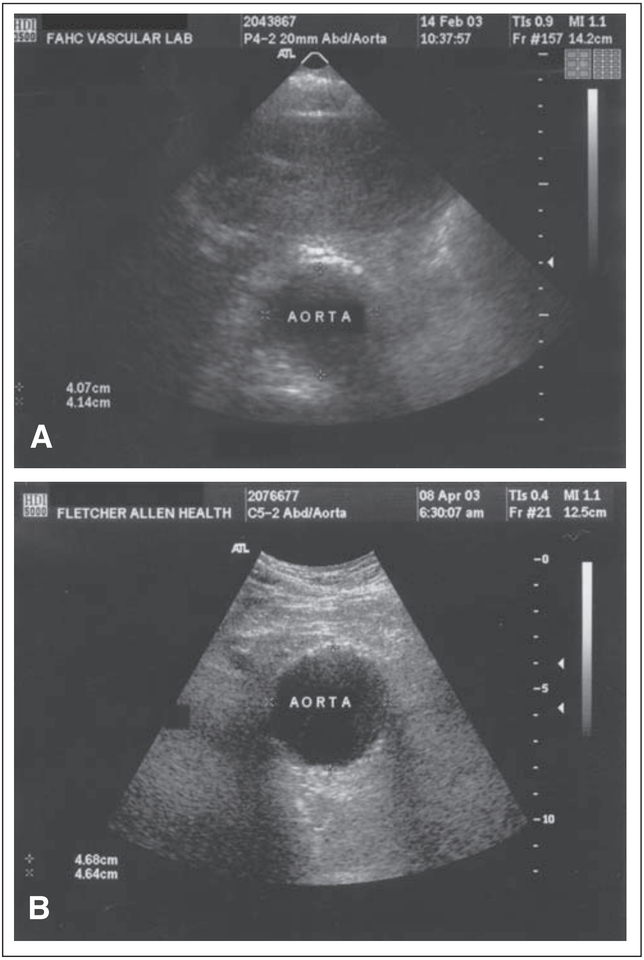

Figure 1. A) Phased array transverse image using 4-2 Mhz B-mode scan might not show the anterior wall of an aneurysm in a thin patient. Shown here is an obese patient with anterior wall 7 cm deep. B) Curved linear sequential array transducer (commonly called curved transducer) imaging at 5-2 5 MHz shows good penetration with depth set at 12 cm in this case. The anterior wall is only 3 cm from anterior abdominal wall.

Scanning Technique

Most ultrasound machines have "presets" for abdominal aorta, which optimize compression, reject, frame rate, and depth for general usage. With proper "presets" the TGC (Time Gain Compensation) slides may need adjustment to amplify attenuated signals from deeper structures. Once this TGC is balanced, adjustments should be made for optimal visualization.

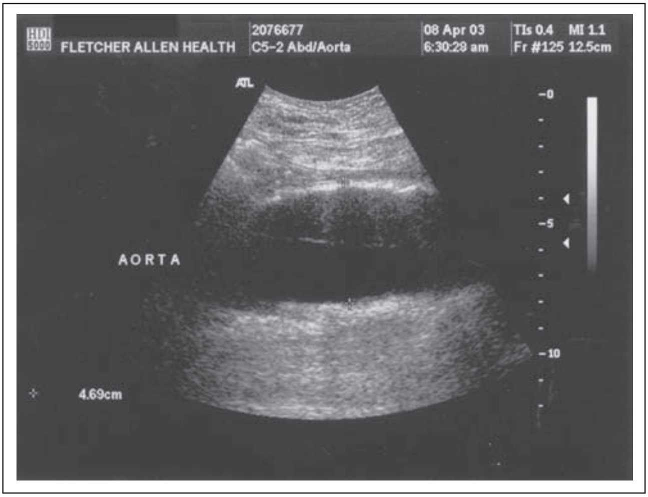

Figure 2. A longitudinal (or sagittal) view can show the maximal A-P diameter with the transducer oriented in the plane of the aorta, rather than to the patient or the examining table. This can be useful in a tortuous aorta or aneurysm. Measurements are to the outer aortic wall.

When using "preset" for general abdominal instead of aorta, for example, the depth may be set at 22 cm instead of 14 cm. This allows visualization of the kidneys, which are deeper than the aorta. The presets optimize settings for the usual situation and should be used as a starting point to be modified for specific situations. Obesity or massive hemoperitoneum may require a much greater depth than a thin emaciated patient.

One technique is to apply gel to the supine epigastrium and start at the midline with the probe transverse (be sure the marker is oriented to the right!). Move the probe inferiorly and look for the shadow of the vertebral column. Look just anteriorly and identify the aorta. Continue scanning inferiorly to below the umbilicus and look for the largest aortic diameter. Freeze the image and measure AP and transverse measurements in this transverse scan (Fig. 1). If gas is scattering the ultrasound waves and prohibiting image acquisition, a phased array probe may look through a narrower window and avoid gas. Gentle compression with the probe may push gas laterally and improve the image.

Once in the widest area of the aorta, rotate the probe 90 degrees (so the transducer marker is cephalad) (Fig. 2). The probe can then be rocked and angled back and forth to see the widest point with the probe in the axis of the aorta at the widest point. Freeze and measure the AP diameter. (Measuring length of the aneurysm has no clinical correlation and is only confusing). This is the sagittal AP diameter (also termed longitudinal AP diameter).

The sagittal AP diameter is most accurate in a tortuous aorta to measure perpendicular to the long axis of the aneurysm and is more reproducible.[4] Axial resolution is superior to lateral resolution in an ultrasound beam, making the transverse measurement on the transverse scan more difficult. Zwebel[5] has popularized the sagittal measurement of the transverse aneurysm diameter by a "coronal" scan, which shows the IVC behind the aorta in sagittal view with the probe in the left lateral abdomen.

Information by Ultrasound Other Than Aneurysm Presence and Size

Ultrasound can visualize mesenteric arteries and renal arteries with help from a color flow Doppler. The presence or absence of intraluminal thrombus can be identified with B-mode ultrasound. The presence of fluid in Morison's pouch or the pouch of Douglas is a part of the FAST exam (Focused Abdominal Ultrasound for Trauma). In the trauma situation the ultrasound finding of free fluid has clinical relevance.

NONE of this additional information has been of clinical value in emergent aneurysm ultrasound imaging.

Performing Aortic Aneurysm Ultrasound

If an ultrasound technologist were available, aneurysm assessment is one of the easier exams he or she would perform. Their completeness must be directed at finding only the information of clinical relevance. Vascular technologists routinely define the neck, mesenteric vessels, and evaluate the complete aortic anatomy. This can become time-consuming and interfere with resuscitative efforts.

A surgeon or emergency physician can easily learn the focused technique of determining aneurysm presence and measuring its size. This exam is easier to learn than the FAST exam that has been documented as highly accurate in the hands of physicians. Like the FAST exam, this is only a B-mode exam.

Patients may present to the emergency department when no sonographer or radiologist is immediately available. Many emergency rooms have an ultrasound machine present in the immediate area for FAST exams and this should be adequate for aortic exams in all cases.

Comparison to CT Scan and Plain X-Rays

Before ultrasound, plain lumbar spine films showed a rim of calcification and allowed only an estimate of aneurysm size. The divergence of the X-ray beam exaggerates aneurysm size. Although an aneurysm may be incidentally discovered on plain lumbar spine films. The aneurysm's diameter should be measured with ultrasound.

CT scan may exaggerate aneurysm diameter, as CT cuts are perpendicular to the table rather than to the axis of the aneurysm. CT scan can measure misleadingly large diameters in tortuous aneurysms.

Documentation of leakage outside of the aortic wall (the definition of aneurysm rupture) is most rapidly seen with CT scan. If there is a large aneurysm (>5 cm) and the patient has hypovolemic shock, CT scan may be contraindicated, as operative control of flow into the aneurysm may frequently be the urgent lifesaving maneuver needed.

Summary

In the emergent setting, physicians may rapidly perform ultrasound to determine aneurysm presence and size with clinical relevance, without interfering with other resuscitative efforts.

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CHAPTER 5

Appendicitis

Shyr-Chyr Chen

Introduction

Acute appendicitis is one of the most common abdominal emergencies requiring surgery and is a challenging diagnosis in emergency practice. A wise general surgeon never places appendicitis lower than second on the list of differential diagnoses for the patients with acute abdomen unless an appendectomy has been performed on these patients. Although this disease entity has been recognized for more than 100 years, as of yet there has been no definitive test to diagnose an acute appendicitis. The diagnosis of acute appendicitis is still based on the results of history, physical examinations, and laboratory findings. The accuracy of diagnosis of acute appendicitis has been reported to be between 71 and 85%. However, the clinical and laboratory findings can be nonspecific and variable, depending on the age and sex of the patient. Although the morbidity and mortality rates of appendicitis have been markedly reduced, the high negative laparotomy rate has not changed in the past 50 years. It has been reported that overall negative appendectomy rate is about 15 to 47% and females of childbearing age have the highest negative appendectomy rates. The major factors contributing to this high negative appendectomy rate have been the nonspecificity of clinical findings and the lack of readily reliable tests allowing direct visualization of the appendix.

To reduce the high negative appendectomy rates, additional sensitive and specific examinations are necessary to increase the accuracy of diagnosis of acute appendicitis.

Many modalities have been used to aid the diagnosis of acute appendicitis, including leukocyte count, barium enema, CRP, and computed tomography. However, these examinations are nonspecific and cannot be used as the definitive diagnostic test. Several reports showed that when sonography is used to aid in the diagnosis of different diseases there has been high sensitivity, specificity, and accuracy. This chapter will focus on how general surgeons used sonography to diagnose appendicitis.

Historical Review

Abdominal sonography was first performed in 1981 to demonstrate inflamed appendixes. Deutsch reported a 22 cm x 4 cm oblong-shaped mass in the right lower quadrant with peripheral anechoic structure and a more central hyperechoic area, containing within it an anechoic tube. The central dense echoes arise from the mucosa of the bowel lumen, and the anechoic halo from the bowel wall. Since then, many studies have found the promising value of abdominal sonography in the diagnosis of acute appendicitis. These studies show a sensitivity of 75 to 100%, a specificity of 73 to 98%, and an accuracy of 76 to 96%. Therefore, if a general surgeon is able to perform sonography, and the sonographic findings are integrated with the

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patient's history, physical examination, and laboratory findings, the accuracy of diagnosing appendicitis will be more promising, and negative appendectomy rates will decrease.

The graded compression technique described by Puylaert in 1986 was widely used to examine the appendix in recent decades. There is no doubt that sonography is operator dependent and requires skill and experience. Although most reports used 5.0 MHz or 7.5 MHz, high resolution linear array transducers, some reports used 3-5 MHz curved array transducers, which also had the same results. Thus the importance of technique and experience is equal to the resolution power of sonography. Although the role of sonography in the diagnosis of emergency appendicitis is undefined, a beneficial change in proposed management in approximately 20% of patients resulted in a lowered negative laparotomy rate without an increase in morbidity have been widely reported. However, Wade found that 24% of patients with normal sonographic examination were subsequently found to have appendicitis, emphasizing that sonography can not be relied upon completely.

To increase the diagnostic accuracy of sonography, color Doppler sonography has been used to help the diagnosis of an acute appendicitis since 1992. Blood vessels within the inflamed appendix and surrounding mesoappendix show an increase in size and number, which is a sensitive indicator for inflammation. When using color Doppler sonography to detect appendicitis, the following measurements can be obtained a sensitivity of 87%, a specificity of 97%, and an accuracy of 93%. Although sonography is promising in the diagnosis of acute appendicitis, there are some defects of sonographic examinations. First, sonography beams cannot penetrate gas and bone. Second, sonography is limited in obese patients. Advances in electronic technology will amend these drawbacks in the future.

Technique

Patient Preparation

The patient is put in a supine position with the abdomen exposed from xiphoid process to pubic symphysis (Fig. 1). All the adhesive tape or gauze on the abdominal wall should be removed to prevent the interference of the resolution power of the transducer.

Operative Technique

The various locations of the appendix can be classified into retrocecal, pelvic, preileal, postileal, promontoric, subcecal or right paracolic area. The area of examination of the appendix is localized in the right lower quadrant of the abdomen, especially around the cecal area. Before the examination, all patients were routinely asked to point out the site of maximal tenderness with one finger in the right lower quadrant of the abdomen. Scanning of this area was often helpful in the identification of inflammatory appendixes. Although most reports used a 5.0 MHz linear array transducer to diagnose an appendicitis, a 3.75 curved array transducer also had good results. In general, for obese patients choose a 5.0 MHz transducer and for thin patients choose 3.5 MHz transducer to screen for appendicitis.

Graded Compression Technique

The examiner exerts gentle compression with the transducer using both hands in the same way as when palpating the abdomen (Fig. 2). Following the respiratory

Figure 1. The area of sonographic examination from xiphoid process (upward arrow) to public symphysis (downward arrow).

Figure 2. Technique of graded compression method.

movements of the abdomen, this technique allows deep penetration with the transducer into the pelvis, which can alter the anatomic relation of the intra-abdominal organs. Compression was continued until all bowel loops or fluid could be displaced

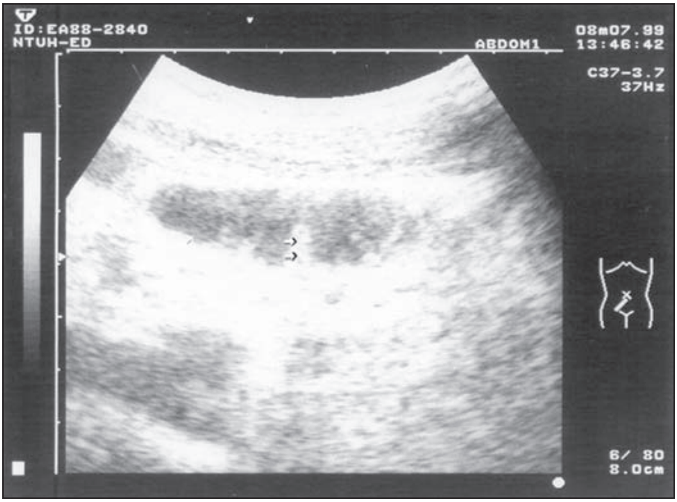

Figure 3. Compressible small bowel loop with keyboard sign (double arrow).

from the ascending colon and cecum. The inflamed appendix is most often visualized at the base of the cecal tip. An attempt was made to image the cecal tip in the transverse plane by scanning caudad to the approximate insertion of the terminal ileum. An appendix is a noncompressible tubular structure. Those compressible tubular structures are segments of small bowel loops (Fig. 3).

Modified Compression Method

The examination is initiated by scanning in the longitudinal scan in the right paracolic gutter and screening from the descending colon to cecum (Fig. 4). The examination is continued caudally or cephalically around the cecum. The psoas and iliacus muscles and the external iliac artery and vein should be identified as landmarks of the retroperitoneum (Figs. 5, 6). The focus is on the cecal wall and the surrounding structure to see any noncompressible blinded tubular structure with fluid accumulation or bowel aggregation. If any tubular structure is found near the cecum, the probe is compressed against the abdominal wall (Fig. 7) to examine whether it is a compressible or noncompressible structure. A noncompressible tubular structure is without peristalsis and food chylous flow in the lumen when compared with bowel loops.

Screening Scan

Three sonographic scans are used to examine the appendix. When screening along the descending colon to cecum, apply the longitudinal scan (Fig. 4) to examine the cecum and the surrounding structures. If a suspicious tubular structure is found during the longitudinal scan, you can apply transverse scans to confirm it. On transverse scans, a tubular structure on the longitudinal scans will change to a target structure. The center of the abnormal appendix is poor echogenic density, surrounded by an inner echogenic or hyperechogenic ring and outer hypoechogenic

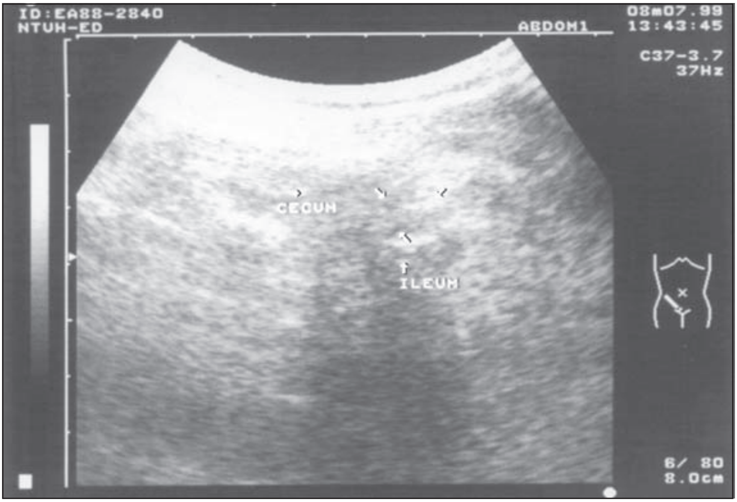

Figure 4. Longitudinal scan of the right lower abdomen shows cecum (transverse arrow), ileum (upward arrow) and appendix (oblique arrow).

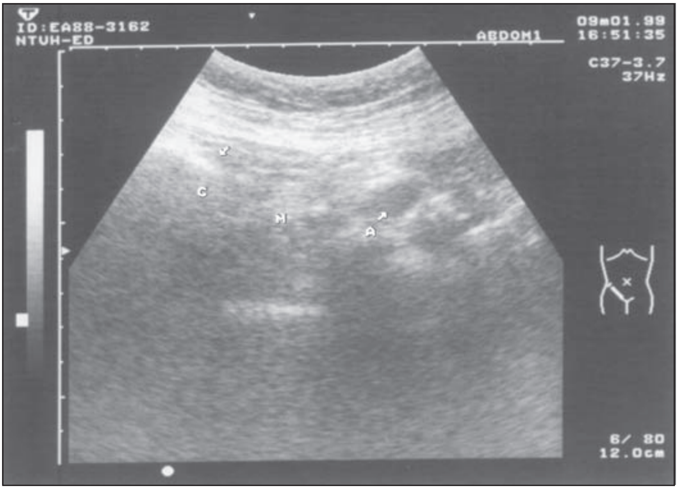

Figure 5. Longitudinal scan of the right lower abdomen shows cecum (C), retroperitoneal muscle (M), and external iliac artery (A).

layer (Fig. 8). The echogenic submucosal layer may not be visualized in a more advanced state of appendicitis. Usually, a longitudinal scan that reveals an enlarged noncompressible tubular structure and/or an interruption in the continuity of the

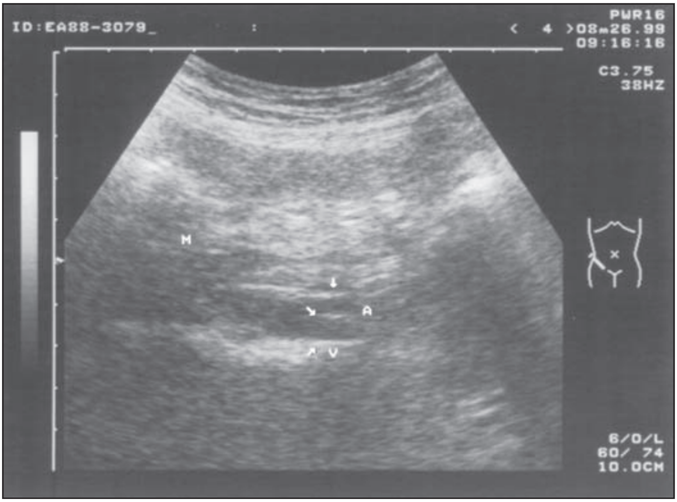

Figure 6. Longitudinal scan of the right lower abdomen shows retroperitoneal muscle (M), external iliac artery (A) and vein (V).

Figure 7. Technique of applying oblique scan over right lower abdomen.

echogenic submucosa around the cecum is an adequate sign to diagnose an acute appendicitis. If the sonographic diagnosis is uncertain, you can use a transverse scan to demonstrate a target structure and confirm the tubular structure found on the longitudinal scan. Generally, longitudinal scans and transverse scans are adequate to

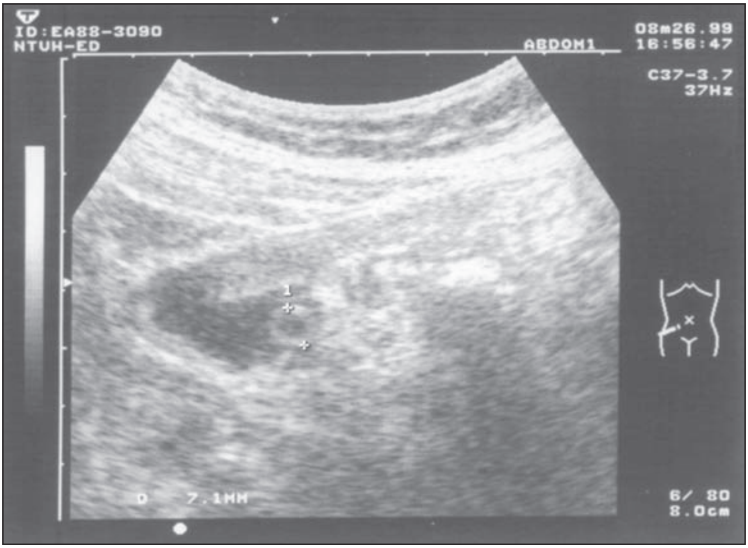

Figure 8. Transverse scan of the lower abdomen shows a target structure.

examine the appendix. If you want to trace the location and direction of a tubular appendix, you can apply a longitudinal scan, transverse scan, or oblique scan (Fig. 7) alternatively to find the tract of appendix.

Sequence of Examination

Occasionally, the exudate or pus accumulation in acute cholecystitis or in perforated peptic ulcers may downward shift to the right lower quadrant of the abdomen, which results in a false reading: McBurney point tenderness appears to mimic acute appendicitis. Therefore, the sequence of examination procedure begins from the epigastric area. Step one is to check the antrum, for the first portion of duodenum or for the presence of pneumoperitoneum. The second screening organ is the gallbladder. At this step, check the gallbladder for any inflammatory changes including wall thickness, triple layer, gallstone or fluid accumulation in the pericholecystic area. After screening the epigastric area and liver, right kidney and ascending colon. Along the descending colon downward toward the cecum, attention should be focused on the cecum, ileocecal area, ileum, appendix and adjacent bowel loops. Finally, the probe is shifted downward to the pelvic cavity to check the Douglas pouch, urinary bladder (male), and uterus and ovary (female).

Sonography of Normal Appendix

In a healthy person, the appendix is usually not visible during the sonographic screening. Nonetheless, in a very small percentage of patients, a normal appendix is visible with sonography. The appendix arises from the site at which three taenia unite and varies considerably in length and width, averaging 5 to 10 cm in length and the maximal diameter rarely exceeding 6 mm (Fig. 9). The normal appendix is a tubular structure that ends blindly in the longitudinal scan and is oval in the

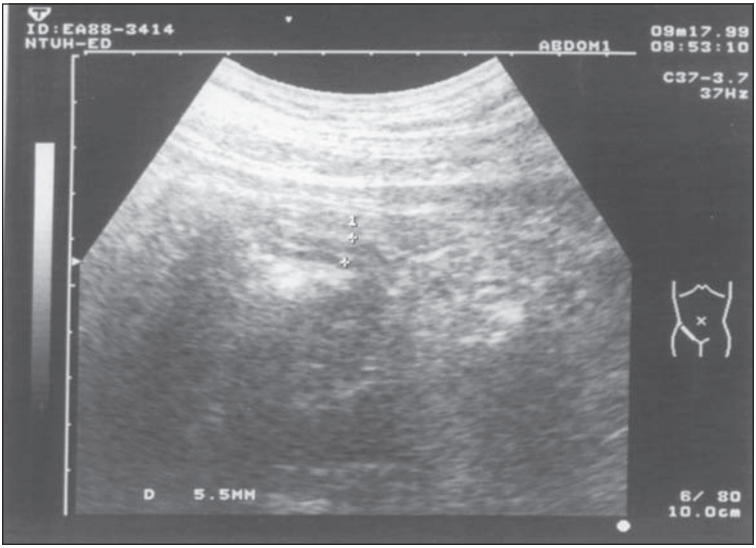

Figure 9. Normal appendix (arrow).

transverse scan. It is usually curved and maybe tortuous;. The normal appendix can be differentiated from the small bowel loops by the absence of peristalsis and intraluminal chylous flow and lack of changes in configuration over time. Sonographic appearance of a normal appendix is a thin, central echogenic region corresponding to the submucosa, surrounded by a hypoechogenic outer area representing the muscularis propria.

Sonographic Diagnosis of Appendicitis

Indication

Since the introduction of sonography, it has been widely used in diagnosis of the acute abdomen. In the past, to correctly use the medical resources and to prevent unnecessary examinations, every patient with an acute abdomen routinely received abdominal sonography examinations which is not recommended, today. A previous report recommended that patients with clinically diagnosed or suspected acute appendicitis should routinely receive an abdominal sonography examination to further decrease the negative appendectomy rates because typical symptoms of appendicitis did not completely confirm the diagnosis of acute appendicitis. It seems reasonable to define certain indications for sonographic diagnosis of acute appendicitis to thoughtful use of medical resources.

Sonography has the greatest potential in those patients in whom the clinical findings are equivocal. There is no doubt that those patients with clinically suspected acute appendicitis should receive sonographic examinations. Those patients with clinically diagnosed acute appendicitis but without noticeable sign of muscular rigidity or severe tenderness when palpating the right lower quadrant of abdomen should also undergo sonographic examinations.

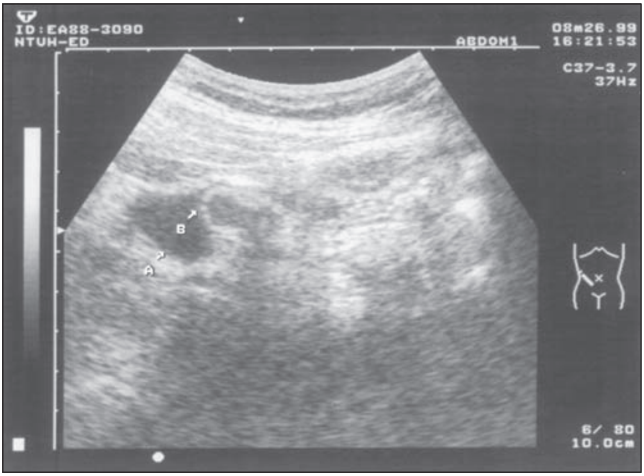

Figure 10. Longitudinal scan of the right lower abdomen shows abscess formation (A) and adjacent bowel loop (B).

Figure 11. Longitudinal scan of the right lower abdomen shows an enlarged appendix (arrow) with abscess formation.

Diagnostic Criteria

Adult

The sonographic criteria of acute appendicitis are a noncompressible appendix with an anteroposterior diameter that is consistently 7 mm or greater, an appendicolith, and an interruption in the continuity of the echogenic submucosa or a localized periappendiceal fluid collection (Figs. 10-13). Appendicoliths appear as

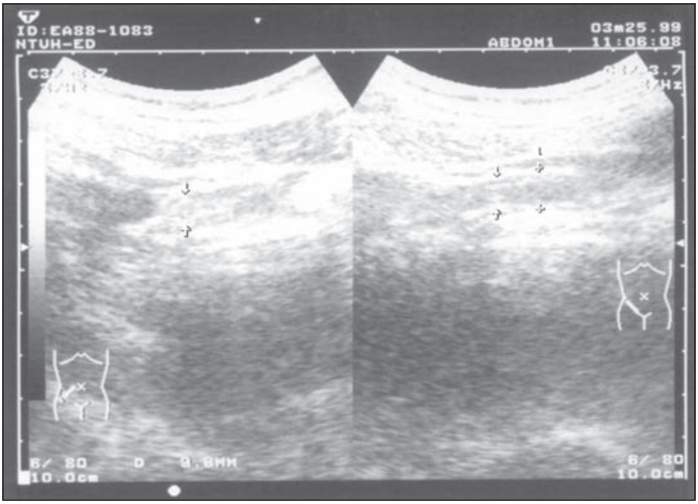

Figure 12. Transverse scan of the right lower abdomen shows an isoechogenic structure surrounded by a hypoechogenic ring (right). Longitudinal scan of the right lower abdomen shows an enlarged appendix (left) with fluid accumulation.

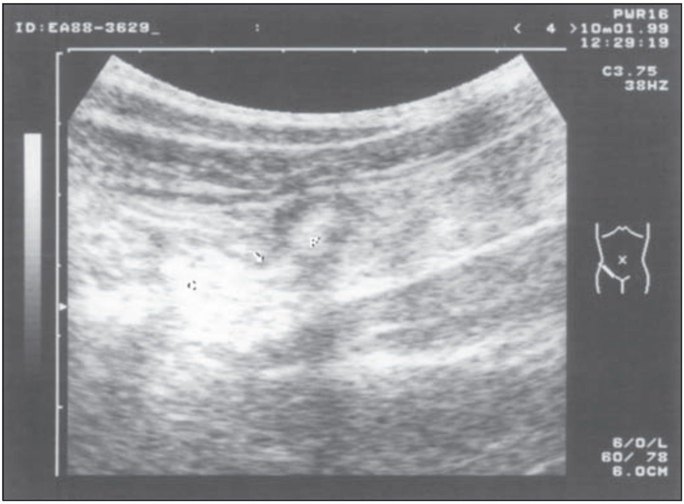

Figure 13. Longitudinal scan of the right lower abdomen shows an appendicolith (F) with acoustic shadow at distal end of appendix (oblique arrow) adjacent to cecum (C).

hyperechogenic foci with acoustic shadowing and vary in size, shape, and number. They may be seen within the appendiceal lumen or surrounded by a periappendiceal abscess after perforation without recognizable appendiceal landmarks. Local

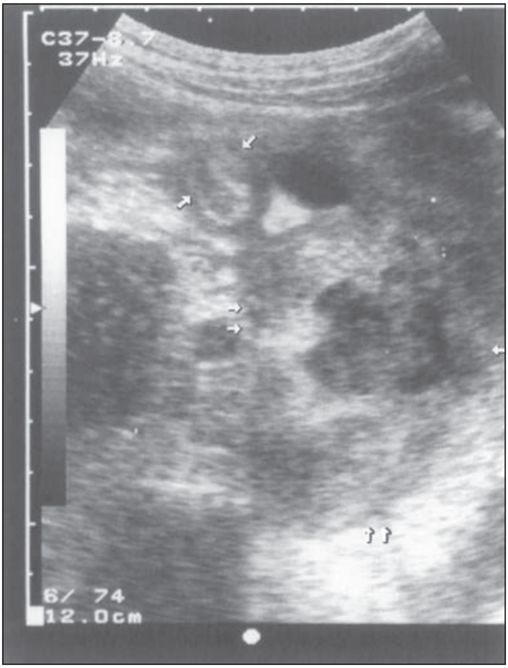

Figure 14. Longitudinal scan of the right lower abdomen shows a mass formation (oblique arrow) with air density adjacent to the cecum.

periappendiceal fluid collections are usually localized to the right lower quadrant of the abdomen or pelvis. They have a round configuration and have a mass effect on adjacent structures. The collections are anechogenic or hypoechoic structure. Loss of echogenic submucosal ring may be focal or diffuse. This finding may represent extension of the inflammatory process through the muscularis propria into the submucosa with subsequent submucosal ulceration and necrosis. A periappendiceal mass (Fig. 14) may have poorly defined borders representing thickness of adjacent atonic bowel loops or fluid pockets, phlegmon, or abscess. Occasionally, the appendix can not be seen by sonography.

Child

A sonogram was interpreted as appendicitis if one wall of the compressed appendix was more than 2 mm thick or the total outer wall to wall diameter of the appendix was more than 6 mm.

Pitfalls

False Positive Appendicitis

Occasionally, the normal appendix can have a diameter of more than 7 mm. This can be mistaken for an inflamed appendix. Spontaneously resolving appendicitis is one of the causes of false positive findings. The false positive sonographic findings may be attributed to the enlarged normal edematous changes in the lamina propria and/or the muscular wall and the absence of luminal distension, sonography can be used to differentiate a normal appendix from an acute appendicitis.

False Negative Appendicitis

The most significant limitation of sonographic diagnosis is the false negative findings. The much lower sensitivity rate of sonography in the diagnosis of perforated appendix has been widely reported. It is likely that focal peritonitis associated with perforation may lead to inadequate compression or that extensive necrosis of the appendix renders it difficult to visualize. Early focal appendicitis is another common false negative diagnosis. Early focal appendicitis may be limited to a slightly thickened appendiceal wall without significant edema or luminal distension. There is a need for repeated sonographic examinations to be incorporated into the patient's clinical signs and symptoms.

Prevention

A normal appendix, if seen, seldom exceeds 6 mm in maximal outer diameter, but it may be dilated with fecal materials and measure up to 7 mm or more. Many patients with this condition do not have appendicitis, but a close follow-up is recommended. Inflammation of the appendix may be more pronounced or localized to the distal end. Therefore, it is important to sonographically screen the entire length of the appendix to avoid false negative diagnoses. Increased pericecal echogenicity, an area of increased echogenicity greater than 1 cm in diameter, may be caused by inflamed material or omental fat secondarily to appendicitis. In these patients sonographic examinations revealed increased pericecal echogenicity or thickness of cecal wall not compressible tubular structure clinical findings should be reassessed or repeated sonographic examinations should be considered to prevent misdiagnoses.

Color Doppler

Simple measurement of the maximal diameter of the appendix is not a reliable indicator of appendicitis. In addition, criteria other than size should be considered. Although compressibility, peristalsis and the presence or absence of periappendiceal inflammation have been studied, these signs are subjective and do not always provide a reliable indicator of inflammation. Color Doppler thus, emerged as a supplemental diagnostic tool to the sonographic diagnosis of appendicitis. Color Doppler sonography was first used by Quillin and Siegel in 1992 to diagnose early appendicitis. Color Doppler sonography was considered positive for appendicitis if increased vascularity was noted in the appendiceal necrotic or perforated appendix. The depiction of hypervascularity in loculated periappendiceal fluid collections and periappendiceal soft tissues was also noted as confirmatory evidence of perforation (Figs. 15, 16). The results of color Doppler sonography may depend on the color sensitivity of the machine used. Because of the absence of vascularity, one cannot distinguish between a normal and abnormal appendix. As a result of the absence of vascularity, motion artifact mistaken as blood flow can be prevented. However, the sensitivity, specificity, and accuracy of color Doppler sonography in the diagnosis of acute appendicitis is similar to that of gray scale sonography, color Doppler sonography may be used in patients with enlarged appendixes either with equivocal size at gray scale sonography or without inflammatory signs.

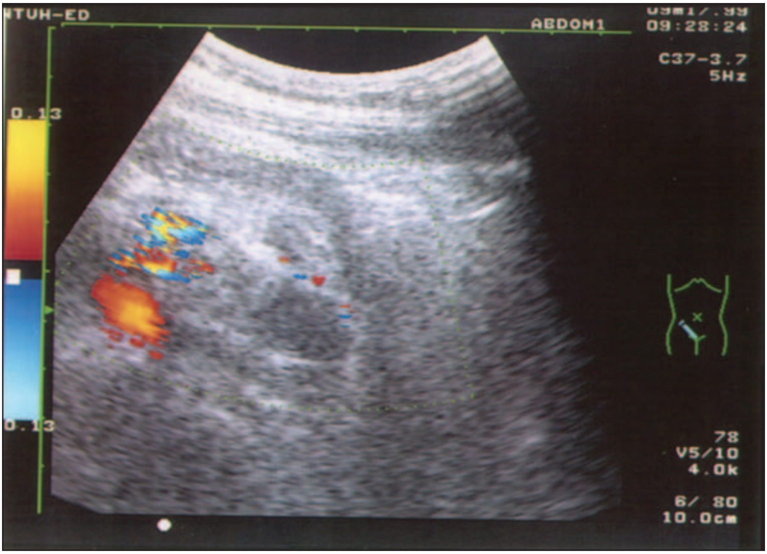

Figure 15. Color Doppler sonography shows increase vascularity over lower appendiceal wall.

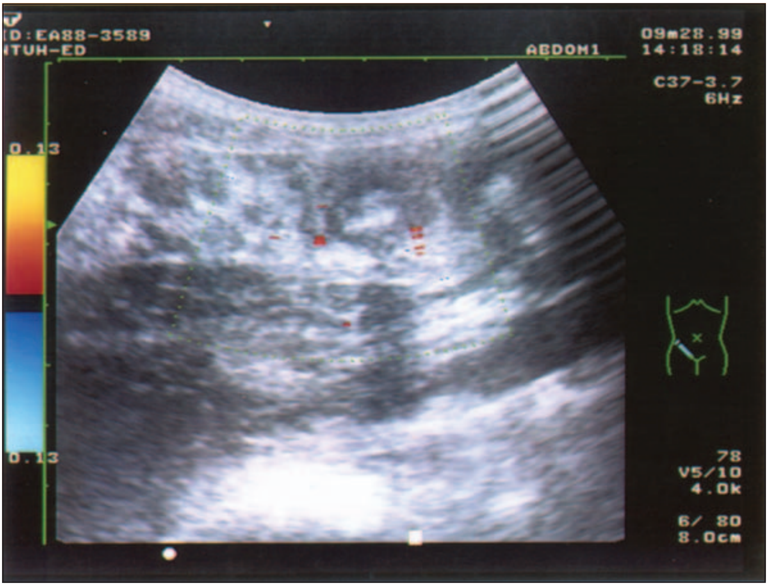

Figure 16. Color Doppler sonography shows increase vascularity in periappendiceal fluid.

Summary

Acute appendicitis is still the most common cause of emergency surgery of the abdomen. Many modalities have been used to aid in the diagnosis of acute appendicitis; however, these examinations are nonspecific. To date, there has been no definitive test to diagnose acute appendicitis. The diagnosis of acute appendicitis is still based on the results of history, physical examinations, and laboratory results. The promising value of abdominal sonography in the diagnosis of acute appendicitis has been well documented in recent years. As a general surgeon is more familiar with acute appendicitis than any other physician, he is more likely to accurately diagnose acute appendicitis. If a general surgeon can perform sonography, and the sonographic findings can be integrated into the patient's history, physical examination, and laboratory findings, the accuracy of diagnosing appendicitis will increase and the negative appendectomy rates will decrease. To decrease false positive and false negative findings, it is important to sonographically screen the entire length of the appendix and to distinguish between enlarged normal appendix, secondarily enlarged appendix, or fecal impaction. Repeated sonographic examinations in patients with equivocal sonographic findings and incorporating these findings with the patient's clinical signs and symptoms are key points in preventing misdiagnoses.

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Pediatric Applications

Oluyinka Olutoye, Richard Bellah and Perry Stafford

Introduction

Ultrasonography (US) can be a very useful tool for the pediatric surgeon. It offers the advantage of being able to provide a dynamic, sedation-free and radiation-free evaluation of the young surgical patient. In particular, the patient who is uncooperative and moving can be evaluated with ultrasound. Availability of the state-of-the-art, high-resolution ultrasound equipment in most hospitals that provide emergent care allows this technology to be used in the diagnostic evaluation of the 200-lb adolescent as well as the 3-kg neonate.

In this chapter, the common pediatric surgical conditions in which ultrasonography is commonly employed (acute appendicitis, pyloric stenosis, intussusception, testicular torsion, and trauma) will be discussed. Basic techniques and examples of normal and abnormal findings will be described.

Acute Appendicitis

Acute appendicitis is a common surgical disease with a lifetime risk of 6-20%. About 1% of children below the age of 15 years develop acute appendicitis. The diagnosis is made on the basis of the history and physical examination in the vast majority of cases. However, in children with an unusual presentation or atypical physical findings, further evaluation may be warranted. This is quite common in perimenarcheal/adolescent females in whom the symptoms and signs of acute appendicitis may be difficult to differentiate from those related to gynecological conditions.

Technique

The initial right lower quadrant ultrasound evaluation of acute appendicitis does not require a full bladder. However, teenage girls in whom the differential diagnoses include ovarian pathology, a full bladder is required for adequate visualization of the pelvic organs or pelvic abscesses (Fig. 1).

For a focused ultrasound examination of the appendix, a linear transducer is most often used. Gentle equated compression at the site of maximal tenderness is done. The normal or abnormal appendix appears as a blind ending tubular structure in the right lower quadrant. The normal appendix is actually rarely identifiable but should be compressible with the probe. An acutely inflamed appendix is more readily identifiable and appears as a noncompressible, blind ending tubular structure in the right lower quadrant (RLQ) often adjacent to the psoas muscle and iliac vessels (Fig. 2). An abnormal appendix usually has a wall thickness greater than 6 mm and may display hyperemia by Doppler ultrasound. On occasion, an appendicolith may be seen as an echogenic focus within the midportion of the appendix with posterior,

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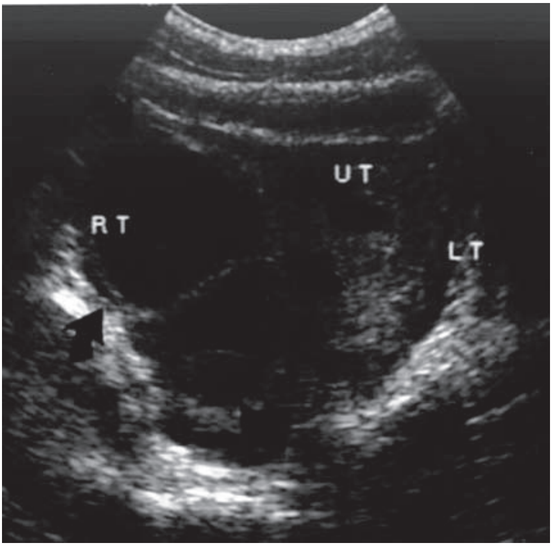

Figure 1. Tubo-ovarian abscess (transverse view). Ultrasound of the pelvis in an adolescent with pelvic pain. Complex mass (arrows) in right adnexum.

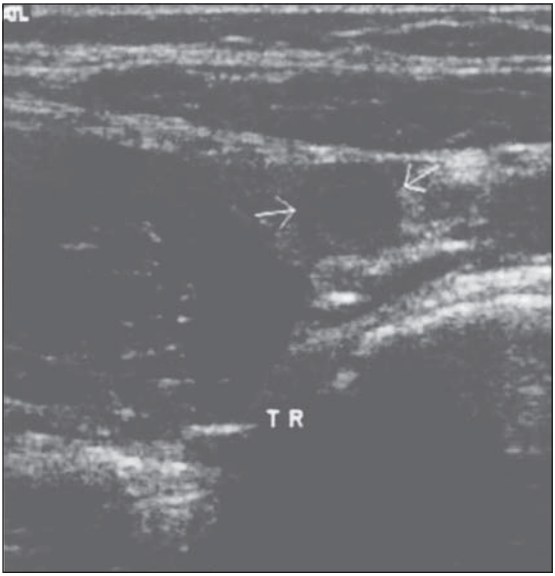

Figure 2. Appendicitis (transverse view). Tubular noncompressible structure (arrows) adjacent to right psoas muscle.

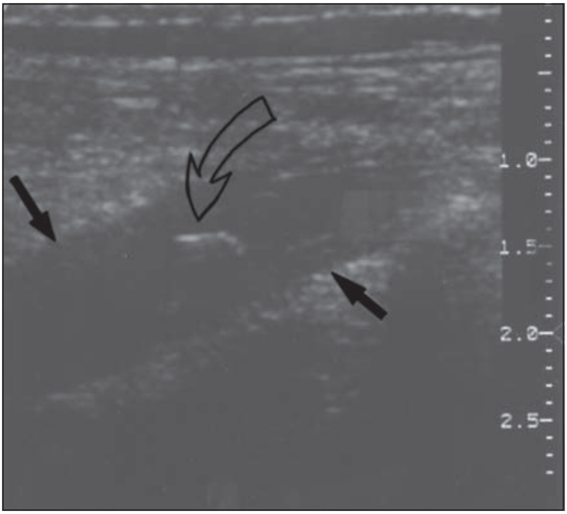

Figure 3. Appendicitis with appendicolith (sagittal view). Tubular structure (arrows) with linear echogenic focus—the appendicolith (curved arrow).

acoustic shadowing (Fig. 3). One should be careful to avoid confusing the appearance of the appendix with that of normal small bowel, which can also have a similar appearance, yet appear compressible and demonstrate peristalsis. With these criteria, ultrasound diagnosis of appendicitis in children has a sensitivity of 89-94% and a specificity of 92-94%.[1-2] Complex masses typical of an appendiceal abscess may also be identified and are more commonly seen in young children in whom the appendix has ruptured (Fig. 4). Other secondary features of inflammation in acute appendicitis can be seen on occasion that include thickening of the adjacent mesenteric fat or regional lyphadenopathy. In many cases where the clinical findings are equivocal, the only finding may be that of enlargement of mesenteric nodes. In the presence of mesenteric nodes, as well as free peritoneal fluid, one needs to take a careful look for the presence of a thickened appendix. However, at times the appendix, even when abnormal, can be obscured by bowel gas, particularly as the appendix is retrocecal in location. In the absence of an abnormal appendix and other signs of RLQ inflammation, mesenteric adenitis may be a plausible diagnosis. It should be again emphasized that a nonvisualized appendix does not necessarily mean a normal appendix because bowel gas or retrocecal location may obscure even the abnormal appendix. Clinical suspicion will then dictate the next step in the management i.e., CT scan, laparoscopy, or future clinical observation.

Hypertrophic Pyloric Stenosis (HPS)

HPS is a relatively common condition in otherwise healthy babies with an incidence of 0.1-1%. It typically presents between 3 and 8 weeks of age but can occur even in the younger infant. There is a 4:1 male preponderance. The history is usually that of an otherwise healthy child who has projectile, nonbilious postprandial emesis followed by a desire to refeed. By history, often several milk formulas would

Figure 4. Appendiceal abscess (transverse view). Complex mass (arrows) behind the bladder.

have been tried but to no avail. If the symptoms have been present for several weeks or days, the child may present with weight loss, dehydration, or with an electrolyte picture of hypochloremic metabolic alkalosis. Hydration should, therefore, take precedence over the initial diagnostic maneuvers.

The pathognomonic physical finding in HPS is the palpation of the hypertrophied pylorus, commonly referred to as the "olive." This structure is usually slightly to the right of the midline and may be high under the liver edge. Allowing the child to suck on a pacifier dipped in dextrose water or cherry syrup may permit the observation of peristaltic waves in the stomach that will direct the clinician to the location of the pylorus. If the olive is felt confidently, no additional diagnostic studies are necessary.

Technique

When the diagnosis of HPS is suspected but the olive is not felt, an ultrasound that looks for the thickened pyloric musculature has a greater than 90% predictive value.[3] A high-resolution (7.5-10 MHz) transducer is utilized. One looks with the ultrasound in the region of the gallbladder. It is helpful if there is a small amount of fluid in the gastric antrum, which fills out this portion and makes the thickened musculature more apparent at sonography. One can also assess whether any of this fluid empties through the pylorus, which would then appear to mitigate against the diagnosis of pyloric stenosis. When the "olive" is identified and the length and thickness of the pyloric musculature is determined sonographically, if one finds that the pyloric channel is greater than 17 mm in length and that the single muscular wall thickness is greater than 4 mm in thickness, one generally considers this diagnostic of HPS (Fig. 5).

In the hands of experienced sonographers, the sensitivity and specificity of ultrasonography for the diagnosis of hypertrophic pyloric stenosis is so good that it has

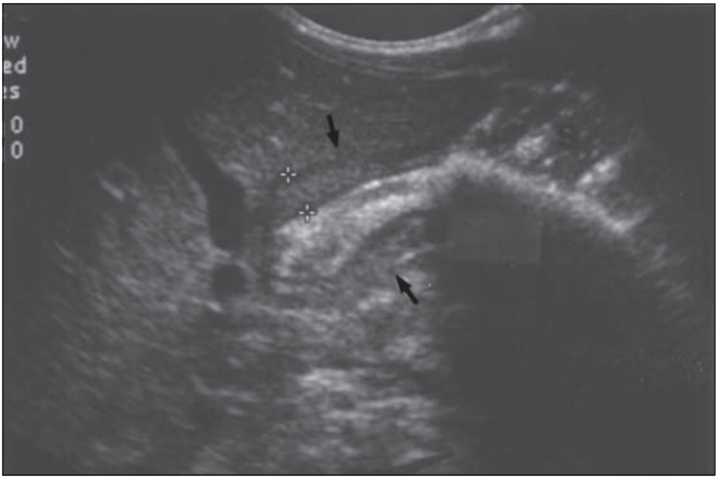

Figure 5. Hypertrophic pyloric stenosis (sagittal view). Focused ultrasound of the right upper quadrant shows an elongated pylorus (arrows) with thickened muscle (x-x = 4 mm). S = Stomach.

now replaced upper gastrointestinal contrast studies as a screening test for this condition. Ultrasound also has the advantage of avoiding the risk of vomiting/aspiration of contrast material. In a child in whom bilious emesis occurs and intestinal malrotation and midgut volvulus is a greater concern, an upper GI examination should be performed expeditiously, rather than an ultrasound. At upper GI series, if the patient does have pyloric stenosis, a long, narrow pyloric channel (the "string" sign) with convex indentation of the pyloric muscle into the antrum and duodenal bulb will be seen.

Treatment of HPS is hydration, correction of electrolyte anomalies and pyloromyotomy when the baby is ready for surgery.

Intussusception

Intussusception refers to the telescoping of bowel into bowel. Ileo-colic intussusception is by far the most common form of intussusception identified in young children and typically occurs between the ages 6 months and 18 months. In the child younger than two years, one should consider the "lead-point" of the intussusception is that of hypertrophy of Peyer's patches. In children who are older than 2-3 years of age with a "lead-point," this "lead point" may be secondary to a Meckel's diverticulum, a polyp, or tumor such as a lymphoma.

The children usually present with a history of colicky abdominal pain accompanied by cramping and drawing up of the legs. The pain is usually remittent with nausea and vomiting. Passage of the "red currant jelly stool," a mixture of blood and mucus from ischemic mucosal slough is usually a late sign. On physical examination, a child may appear lethargic, and a mass may be felt in the right upper or lower quadrant. The mass feels like a firm sausage and is usually nontender unless the bowel is compromised.

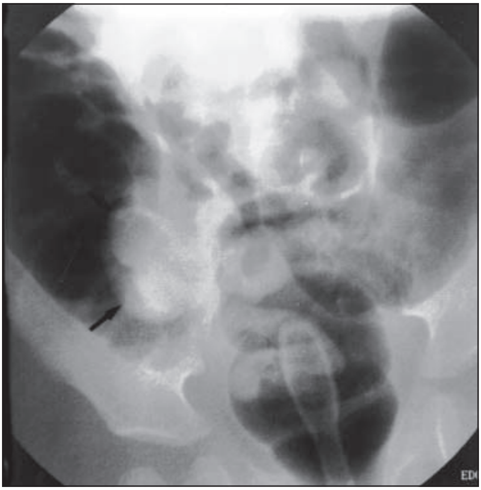

Figure 6. Intussusception. Air enema: AP view of the lower abdomen shows an intraluminal soft-tissue mass (arrows) near the ilea-cecal valve.

Plain films of the abdomen may show a paucity of gas in the right lower quadrant or at times, the mass itself. Proximal small bowel dilatation may also be seen. The diagnostic test of choice is an enema, which may be performed with either air (Fig. 6) or with positive contrast solution. Therapeutic hydrostatic reduction of the intussusception may also be achieved at the same time the diagnostic enema is performed.

In a patient in whom the diagnosis is uncertain, ultrasonography can identify the bowel wall thickening ("pseudokidney sign" or "target sign"), typical of the intussusception (Fig. 7). In some instances, a mass itself that serves as the "lead-point" may also be identified. Some investigators use Doppler ultrasound to assess the vascularity of the intussusceptum to predict reducibility.

Intestinal Malrotation

Ultrasonography is not the study of choice to evaluate a child with suspected intestinal malrotation either with or without volvulus. An urgent, limited, upper GI examination is preferred that adequately identifies the ligament of Treitz. However, during the course of an ultrasound exam of the abdomen, if one demonstrates reversal of the relationship of the superior mesenteric artery and superior mesenteric vein (in the transverse plane), one may then suggest the diagnosis of intestinal malrotation. Normally, the superior mesenteric vein is to the right of the superior mesenteric artery. When this relationship is reversed, the diagnosis of malrotation can be suggested (Fig. 8). When volvulus occurs, an actual "whirlpool" can be seen as a mass surrounding the axis of the superior mesenteric artery.

Testicular Torsion

Acute onset of a scrotal pain with nausea and vomiting in a young male always raises the concern for testicular torsion. The physical finding of a high-riding testicle with transverse lie, as well as loss of the cremasteric reflex are highly suggestive of the diagnosis. Ultrasonography can sometimes demonstrate torsion of the spermatic

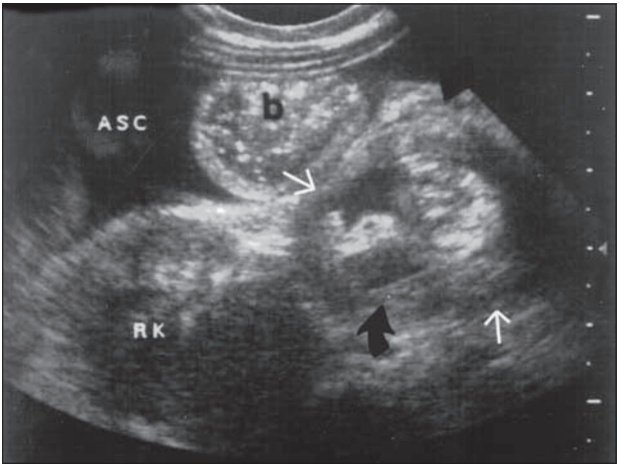

Figure 7. Intussusception: Ultrasound of the right abdomen shows a donut-shaped mass (arrows). Asc = ascites; RK = right kidney; b = dilated bowel loop.

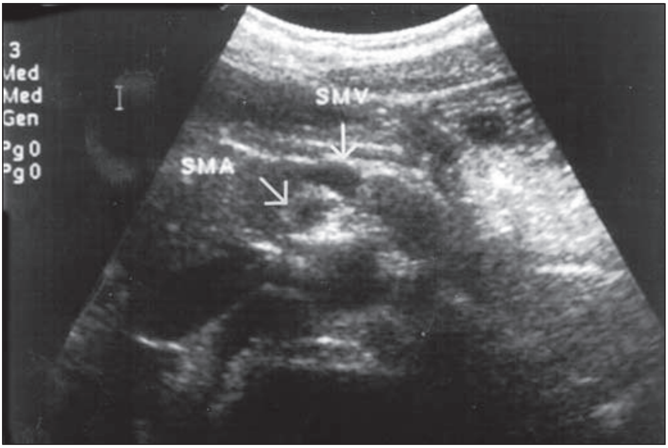

Figure 8. Midgut malrotation (transverse view). Reversal of relationship of the superior mesenteric artery (SMA) and vein (SMV) (arrows).

cord at the external ring, but more importantly, can demonstrate decreased or absence of blood flow in the affected testis (Fig. 9). Technically, a linear transducer with high frequency and good Doppler flow sensitivity is required for this examination. Comparison of the unaffected testis is also necessary. Decreased blood flow to the testis distinguishes testicular torsion from acute epididymorchitis in which there is actual hyperemia of the inflamed testis and epididymis (Fig. 10).

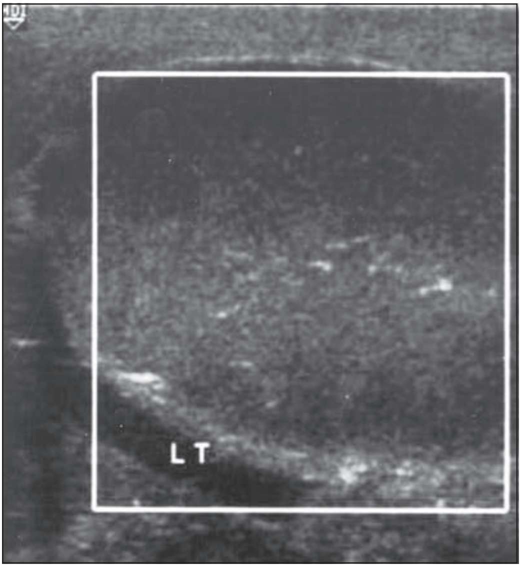

Figure 9. Torsion of the testis (transverse view). Color Doppler ultrasound shows no flow in enlarged hypoechoic left testis.

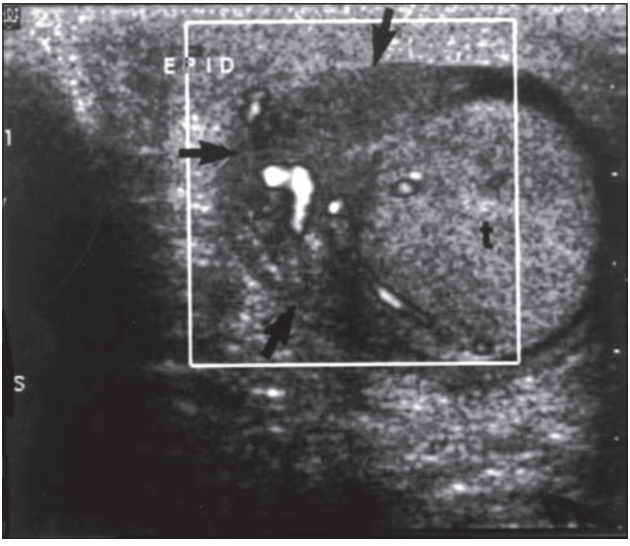

Figure 10. Epididymitis (transverse view). Color Doppler shows increased flow in enlarged epididymis (arrows). T = testis.

Trauma

Abdominal ultrasonography is being used increasingly in the evaluation of adult trauma patients. In the pediatric age group, a FAST study (Focused Abdominal Sonography for Trauma) has not enjoyed the same degree of popularity. The role of abdominal ultrasonography in trauma has been covered elsewhere in this book. Different styles of practice in different institutions may influence the utility of this diagnostic modality in the pediatric trauma patient.

Ultrasonography essentially replaces the role of diagnostic peritoneal lavage (DPL) in the evaluation of the trauma patient. Ultrasound easily detects free intraperitoneal fluid that will suggest intra-abdominal trauma. However, the disadvantage of ultrasound is that, while one may be able to readily detect the presence of fluid within the abdominal recesses that include Morrison's pouch, the pericolic gutters as well as the cul-de-sac, one cannot readily distinguish (with ultrasound) blood from urine from intraluminal intestinal contents. In addition, free peritoneal air cannot be easily detected with ultrasound.

A FAST study in the ED will accurately predict the presence of fluid in the peritoneal cavity in the adult trauma patient. The predictive value of FAST in pediatric patients has not been well studied and the possibility of a false-negative study may limit the utility of FAST as a triage tool for selection of children for CT scanning.

The presence of intraperitoneal fluid in a child with blunt abdominal trauma does not by itself mandate exploration. Clinical stability is used to make this decision. Anatomic detail and possible associated hollow viscus injuries are better evaluated by CT scanning.

A CT scan in a patient with abdominal trauma is better for identifying the type and extent of injury and is also more useful in looking in the retroperitoneum, especially the kidneys. While the vascular integrity of an organ can be assessed by Doppler sonography, actual visceral injury itself with laceration is not always as easily resolvable on ultrasound as it is in CT (Figs. 11A,B). In fact, ultrasound can often miss lacerations within solid viscera that are well seen at computed tomography.

Summary

Pediatric ultrasound has been an invaluable diagnostic imaging tool for pediatric surgeons and radiologists, and the increasing sophistication of the machines and transducers portend an increasing precision and accuracy in the coming decades. The typical pediatric patient with small size and limited body compartment volume surrounded by a thin body wall and little fat makes children an ideal candidate for this dynamic and safe imaging technology. However, the imagining techniques mentioned in this chapter are all very user-dependent and require a well-trained technician and an experienced ultrasonographer to obtain the results reported. Each pediatric surgeon must mold his imaging practices to the modalities best available in his own clinical environment. The utilization of ultrasound by the operating general surgeon in daily practice is an interesting recent development in US surgical education but has not yet fully penetrated clinical pediatric surgery. However, as the general surgery graduates in the next years enter pediatric surgery training and bring their experience with clinical ultrasonography with them into the pediatric surgery offices and operating rooms, this will be expected to change.

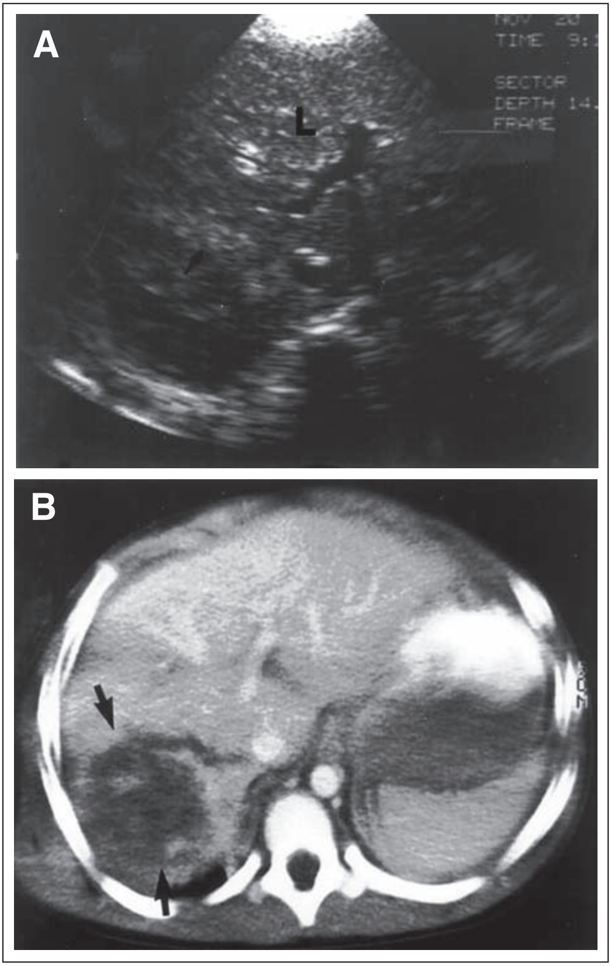

Figure 11. Liver laceration. A) Ultrasound of the liver (transverse view). Ill-defined hyperechoic area in right lobe of liver. B) CT scan (axial view, with intravenous contrast). Large area of low attenuation (arrows) consistent with laceration, better seen on CT.

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CHAPTER 7

Surveillance of Deep Vein Thrombosis (DVT)

Rajan Gupta and Jeffrey Carpenter

Introduction

The clinical evaluation of the peripheral venous system can be difficult. History and physical examination have a limited role in the accurate diagnosis of venous disease. Further diagnostic imaging is frequently required. Invasive techniques such as venography have been proven to be reliable and have become the "gold standard" against which all other techniques are measured. However, the expense and potential risks of such invasive studies have led to the development of noninvasive methods. Through recent technological advancements, ultrasound has emerged as a reliable and useful tool in the evaluation of the peripheral venous system. Its accuracy approaches that of venography, and its other benefits including portability and fewer potential risks have made it an attractive alternative to the "gold standard".

One of the most common manifestations of peripheral venous disease in surgical patients is venous thromboembolism. It is a dreaded complication seen in every surgical specialty; however, certain patient populations have been identified that seem to be at greater risk. The morbidity and mortality associated with this disease process have been well described. Intuitively, many of these patients are sicker and often are found in critical care units. Thus, many studies have examined the role of aggressive measures to prevent this serious complication in these potentially critically ill patients. The use of various interventions including pharmaceutical agents, mechanical devices, and early mobilization has been well established. Some studies advocate routine screening in select populations considered to be at extremely high risk for venous thromboembolism. The imaging modality most commonly used for this routine screening has been ultrasound. This chapter will review the role of ultrasound in screening and diagnosing this peripheral venous disease in select surgical patients. It will also review some of the important technical concepts in performing and interpreting an adequate study.

History and Indications

Venous thromboembolism is often clinically silent, and physical examination is an insensitive tool in the diagnosis of this disease. Several studies have demonstrated a relatively high incidence of occult deep venous thrombosis (DVT) and pulmonary embolus (PE) in select patients. This underscores the necessity for prophylaxis in these select patients. The 5th American College of Chest Physicians (ACCP) Consensus Conference on Antithrombotic Therapy report on the prevention of venous thromboembolism identifies risk factors and patient groups considered to be at high risk.[1] Any surgical procedure or disease process that exposes the patient to any of the risk factors described by Virchow's triad of stasis, endothelial damage, and hypercoagulability places that patient in a high risk population. Patients undergoing major

Ultrasound for Surgeons, edited by Heidi L. Frankel.

surgery to the abdomen, pelvis, and lower extremities, as well as patients with congestive heart failure, myocardial infarction, stroke, and fractures of the pelvis and lower extremities are all at risk for prolonged immobility. Prior venous thrombosis and the presence of indwelling venous catheters result in endothelial damage and increase the risk of further thromboembolism. Many clinical conditions predispose patients to a hypercoaguable state. Among these are the presence of cancer, estrogen use, and several hemostatic abnormalities including lupus anticoagulant, protein C and protein S deficiencies, antithrombin III deficiency, and factor V Leiden mutation. The ACCP Consensus Conference report cites the incidence of DVT in general surgery patients to be as high as 29%, and the incidence of PE to be as high as 1.6% (fatal PE: 0.9%). Current recommendations for prophylaxis include the use of low dose unfractionated heparin (LDUH), low molecular weight heparin (LMWH), or intermittent pneumatic compression devices (IPC). In patients undergoing orthopedic surgery for total hip or knee replacement as well as hip fracture, the incidence of DVT and PE are significantly higher (84% and 24% respectively). Current recommendations for prophylaxis include LMWH or warfarin. The incidence of DVT in patients suffering from myocardial infarction or stroke was noted to be as high as 24% for MI and 63% for stroke. Either full anticoagulation or LDUH is recommended for prophylaxis in patients with MI. For patients with stroke, both LDUH and LMWH are effective.

Patients sustaining multiple traumatic injuries often have a combination of prolonged immobility, endothelial injury, and a hypercoaguable state. This places trauma patients at significant risk for thromboembolic complications. A recent study demonstrated an incidence of 58% for all DVT and 18% for proximal DVT in 349 trauma patients.[2] Other studies have cited the incidence of fatal PE to be as high as 2%, and PE is the third most common cause of death in trauma patients who survive beyond the first day. Additionally, thromboembolic complications account for up to 9% of hospital readmissions following trauma. The incidence of post thrombotic syndrome is cited to be as high as 23%. Thus, an aggressive approach to the prevention and detection of DVT and PE in this select population appears to be warranted. A large prospective, randomized study compared the efficacy and safety of LDUH versus LMWH in select adult trauma patients.[3] Patients receiving LDUH had a significantly higher incidence of all DVT as well as proximal DVT. There was no significant difference in bleeding complications. Thus current recommendations from the ACCP Consensus Conference report suggest the use of LMWH in trauma patients unless contraindicated. Mechanical (IPC) devices are recommended for patients who cannot be anticoagulated.

Several studies have attempted to identify subsets of trauma patients that are at extremely high risk for venous thromboembolic complications. Patients with spinal cord injury, traumatic brain injury, pelvic and lower extremity fractures, advanced age, and either venous injury or indwelling venous catheters are at significantly increased risk. Many groups have advocated the use of surveillance ultrasound in this population to detect clinically occult DVT. Knudson and colleagues followed 251 trauma patients with serial duplex exams.[4] They noted an incidence of 6% for lower extremity DVT, of which the majority were clinically silent. Through risk factor analysis in their own patient cohort as well as a review of the existing literature, they identified the injury patterns listed above as factors that significantly increase the risk of thromboembolism. They concluded that surveillance with serial ultrasound exams in these patients allowed for prompt recognition and treatment of occult

DVT. Velmahos et al reported an incidence of 13% among 200 select trauma patients, despite prophylaxis.[5] All patients underwent serial Doppler exams weekly. Most of the DVT's were identified within the first two weeks of hospitalization, and most of them were identified in patients admitted to the critical care unit. They concluded that surveillance Doppler exams are justified in all critically injured patients. Others have argued that the sensitivity of noninvasive imaging is lower for asymptomatic disease as compared to symptomatic disease. Many patients cannot undergo adequate studies secondary to lower extremity injuries or lack of patient cooperation. Costs of serial exams may be prohibitive. Spain and colleagues performed a retrospective review of 280 trauma patients considered to be high risk by retrospective stratification.[6] They cited a DVT incidence of 5%, and a nonfatal PE incidence of 1.4%. Diagnosis was based on evaluation prompted by clinical exam. They concluded that routine screening would not have benefited 95% of their high-risk population, and thus was not warranted. The majority of venous thromboembolic disease in trauma patients is clinically silent, thus this group likely missed occult DVT in their study cohort. Additionally, because this retrospective review does not provide long-term follow-up, it cannot accurately report the outcome of the missed occult DVT population. Current recommendations by the ACCP Consensus Conference report suggest the development of guidelines for the prevention of thromboembolism for each trauma center. In patients at high risk, consideration should be given to screening with duplex ultrasound.

A study performed recently at the University of Pennsylvania examined the trauma center's experience with clinical management guideline directed duplex surveillance for DVT in high-risk patients.[7] Consecutive trauma patients were stratified into four different categories based upon presence of established risk factors. Patients in the high-risk group (age >50, ISS ≥16, AIS ≥3 in any body region, GCS ≤8, pelvis fracture, femur/tibia fracture, venous injury, or presence of venous catheter) received standard prophylaxis with either LMWH or IPC devices, and subsequently underwent a screening duplex examination within 48 hours of admission and weekly thereafter. The incidence of occult DVT in 169 patients was 17.2%. The mean age as well as the Injury Severity Score (ISS) were significantly higher in patients with DVT. Similar to the study by Velmahos, most of the DVT's were identified during the first two weeks of hospitalization, and the majority of the patients diagnosed with DVT had been admitted to the critical care unit. This study suggests that surveillance duplex in select high-risk patients is warranted. This appears to be especially true for patients admitted to a critical care unit. It may be feasible to limit these serial examinations to the first two weeks of hospitalization. In this study, as well as the one by Knudson, the incidence of PE was <1%. Although not conclusive, this suggests that aggressive screening protocols may have some impact on reducing the incidence of pulmonary embolus.

Technique and Pitfalls

Historically, venography has been the gold standard for diagnosis of peripheral venous disease. Recently, with the advent of real time B-mode imaging combined with color flow Doppler sonography, ultrasound has become the diagnostic tool of choice for the evaluation of venous thromboembolism. Its sensitivity and specificity are 95% and 99% respectively, and accuracy is 98%. It offers additional physiologic information on venous hemodynamics. It is a widely available technology that is portable and can be easily brought to the bedside. This avoids potentially dangerous intrahospital transports of critically ill patients. An ultrasound examination is not fraught with the potential risks of the invasive procedures including infection, phlebitis, and contrast reaction. It is also less expensive than venography.

Peripheral veins are relatively superficial structures, thus allowing for high-resolution imaging. Higher frequency transducers provide the highest resolution for superficial structures. Typically, a 5 MHz linear, phased array transducer is used to obtain optimal real time B-mode gray-scale imaging. A 7.5 MHz transducer can be used to assess the superficial system including the greater and lesser saphenous veins. A 3.5 MHz transducer may be necessary to adequately visualize the deeper iliac veins. B-mode imaging relies on the amplitude of the reflected signals to generate the gray scale image. This technique does not allow optimal visualization of rapidly moving targets (i.e., the blood cells within the vessels), which generally produce low amplitude echoes. Conversely, although the frequency of the reflected signals does not change with stationary interfaces, it does change measurably with moving targets. Doppler sonography combines duplex analysis with qualitative color flow ultrasound to detect such changes in frequency. The same linear, phased array transducers coupled with Doppler ultrasound may be used. Ideally, changes in frequency are best detected at zero degrees (target moving either directly towards or away from the transducer). These changes are essentially undetectable at 90-degrees. Only 50% of the frequency shift is detected at 60 degrees. Thus, shallower angles provide more accurate measurements in frequency shift. Many transducers can steer the Doppler beam angle independent of the imaging beam, thereby allowing for optimal gray scale imaging of the veins as well as accurate measurement of the blood flow within the vessels. Color flow sonography is the display of flow information obtained by Doppler in color superimposed on the gray-scale image. It provides a qualitative representation of relative blood velocity, direction of flow, and areas of flow disturbance.[8]

Evaluation of the deep venous system begins with the patient in the supine position. The lower extremity is abducted and externally rotated, with slight flexion of the knee. Examination begins with the common femoral vein (CFV) just distal to the inguinal ligament. This vein lies just medial and deep to the common femoral artery. Approximately 6-8 cm distal to the inguinal ligament, the vein bifurcates into the deep femoral vein (DFV) and the superficial femoral vein (SFV). It should be noted that the superficial femoral vein is indeed part of the deep venous system. The greater saphenous vein branches off the medial aspect of the CFV between the inguinal ligament and the bifurcation, and travels superficially along the medial aspect of the leg. This vein is considered to be part of the superficial venous system and does not carry much clinical significance in regards to DVT. The DFV travels deep and laterally along the medial aspect of its respective artery and branches frequently to drain the musculature of the thigh. Thus only the proximal portion of the DFV can be adequately evaluated by ultrasound. The SFV extends distally along the medial aspect of the superficial femoral artery into the adductor canal. The examination continues from the CFV along the SFV visualizing the vessels every 2-3 cm. Due to the anatomy of the adductor canal, visualization of the SFV can become difficult. As the vein exits the adductor canal, it becomes the popliteal vein, and extends through the popliteal fossa just superficial to the popliteal artery. This segment of vein is best visualized with the patient either in the prone position or in a lateral decubitus position. The first deep branch of the popliteal vein is the paired anterior tibial vein, which accompanies the corresponding artery along the anterior surface of the interosseous membrane in the anterior compartment of the calf. The tibioperoneal trunk bifurcates into paired peroneal and posterior tibial

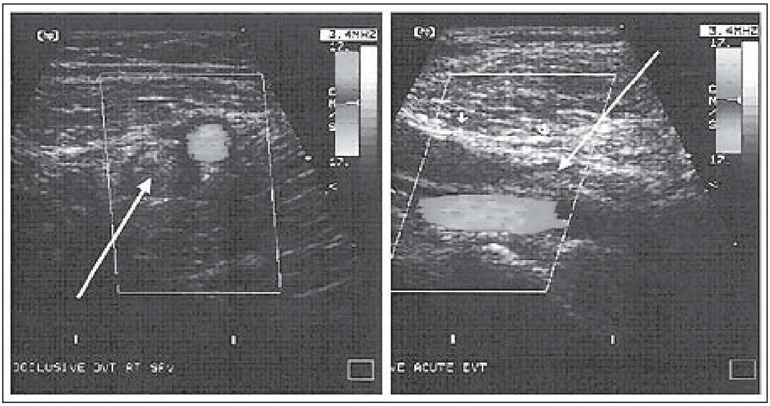

Figure 1. Occlusive DVT lower extremity.

veins. These extend distally with their respective arteries. Calf veins are best visualized with the patient in either the prone, lateral decubitus, or sitting positions. Placing the patient in reverse Trendelenburg will help distend the calf veins. The posterior tibial and peroneal veins are best seen with the transducer placed over the posterior calf. The anterior tibial veins are best evaluated from an anterior approach.

The ultrasound exam relies primarily upon gray-scale imaging with venous compression in the transverse plane. Thus, as the vessels are visualized every 2-3 cm, they must also be compressed with mild pressure applied by the transducer. A normal vein will collapse completely and the vein walls will coapt. Gray-scale image findings consistent with DVT include direct visualization of the thrombus and lack of venous compressibility (Fig. 1). Some acute thrombi can be anechoic, thus one must rely on lack of complete compression. In fact, abnormal venous compression is the hallmark finding of DVT. Venous distension secondary to thrombus may be evident acutely; however, this dissipates as the clot ages and becomes organized. Because pelvic veins cannot be readily visualized directly, an indirect assessment can be made using Doppler sonography of the common femoral vein and the Valsalva maneuver. In normal patients, there is constant antegrade venous flow with slight superimposed variation with each respiratory phase. During Valsalva the maneuver, there is a short period of flow reversal followed by no flow due to increased intra-abdominal pressure. When Valsalva maneuver is released, there is an abrupt increase in forward flow, which quickly returns to baseline. Patients with complete obstruction of the iliac venous system will have reduced or absent flow, and loss of variation with respiration. This spectral pattern does not change with a Valsalva maneuver. Although this technique can indirectly assess the pelvic venous system for occlusive thrombi, it will yield false-negative results for nonocclusive thrombi. A patient with a nonocclusive thrombus may respond normally to a Valsalva maneuver. Similarly, patients with well developed collaterals may also respond normally. In thin patients, the iliac vessels can sometime be directly visualized by gray-scale imaging using a 3.5 MHz transducer. However, compressibility remains difficult. Color flow Doppler sonography may be used to visualize venous segments that are difficult to see by standard gray-scale imaging because of vessel depth or patient size. Normally, color should fill the vessel lumen from wall to wall. Occasionally, flow augmentation by squeezing the calf may be necessary to produce complete color filling. A thrombus will manifest as either a persistent filling defect or absence of flow. Color flow Doppler sonography may also be helpful in the diagnosis of chronic DVT. Distinguishing between acute and chronic DVT is difficult and inaccurate using visualization and compressibility. As a thrombus ages, it undergoes fibroelastic organization, clot retraction, and eventually either chronic occlusion or wall thickening of the involved venous segment. This results in poor visualization and incomplete compression. Color flow Doppler imaging can suggest chronic disease by demonstrating irregular echogenic vein walls, thickening of the vein walls, decreased diameter, atretic segments, and well developed collaterals.

Summary

The evaluation and diagnosis of venous thromboembolism can be difficult. Often, this disease process is clinically silent. The potential sequelae of DVT and PE can be devastating. Thus aggressive measures to prevent and diagnose venous thromboembolism are warranted. The consensus conference of the ACCP presents evidenced-based recommendations regarding prophylaxis. Populations at increased risk have clearly been defined. Critically ill patients, especially trauma patients in the ICU, comprise one such population. The literature not only supports aggressive prophylaxis in these patients, but also recommends surveillance imaging with ultrasound.

Ultrasound has clearly emerged as the imaging modality of choice in the evaluation of peripheral venous disease. The combination of real-time B-mode imaging and color flow Doppler sonography make it the ideal tool. Diagnosis of DVT relies on direct visualization as well as vessel compressibility. Color flow Doppler can assist in evaluating vessels that are difficult to visualize or compress. Nonocclusive thrombi in pelvic veins may be difficult to diagnose with this modality. An understanding of the physics and instrumentation of ultrasound is vital to performing a reliable exam of the peripheral venous system.

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Insertion of Central Catheters

Tarek Razek and Michael Russell

Introduction

The technique of internal jugular and subclavian vein catheterization is indispensable to the clinician. The placement of central venous catheters is necessary for the administration of parenteral nutrition, long term antibiotics, central pressure monitoring, vasopressor therapy, chemotherapy and, in some circumstances, large volume resuscitation. The placement of these catheters is not without risk, and several investigators have studied the role of ultrasound guidance in decreasing this risk. This chapter will summarize the literature on the use of ultrasound as an aid to central venous cannulation and attempt to come to a conclusion on the role of this technology.

Background

Percutaneous cannulation of the central veins using external landmarks was first described in 1966,[1] with several million central venous catheters now placed using this technique in the United States each year. Reported complication rates range from 1-12%, depending on the experience of the physician and the definition of the complications.[2] Potential complications include failure to locate or cannulate the vein, puncture of the adjacent artery, local or mediastinal hematoma, injury to adjacent nerves, pneumothorax, hemothorax, and misplacement of the catheter. Inability to cannulate the vessels may occur in greater than 19% of cases.[3] Although the rate of complications is low and most are minor, some complications may be life threatening.

In an effort to reduce the incidence of complications and increase the rate of successful cannulation, the use of real-time ultrasound to assist with catheter placement was reported as early as 1984.[4] Since then several randomized, prospective studies have compared the use of ultrasound imaging and Doppler flow analysis, alone or in combination, to external landmarks alone.[5,6]

The Problem

Central venous access is often successful and uncomplicated. Although uncommon, complications may be severe. Many patients requiring central access have significant comorbid conditions and do not tolerate complications well. There is a population of patients in whom the cannulation of central veins is more difficult with greater risk of failure and complications.[2] Previous surgery or radiotherapy in region of attempted cannulation, previous central lines, and extremes of body-mass index all pose significant problems for central access. The incidence of complications has been shown to be significantly associated with failed attempts and the number of needle passes. In a study from Mansfield et al,[2] the complication rate increased from 4.3% with a single pass to 24% with more than two passes. When cannulation was attempted and failed, the complication rate was 28%.

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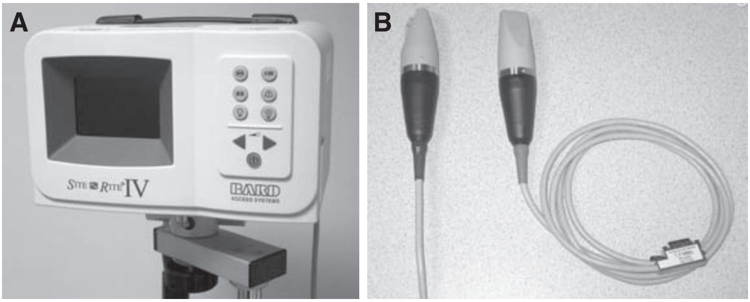

Figure 1. An example of a portable unltrasound unit (BArd) to facilitate vascular access (A) with 7.5 and 9.0 MHz transdurers (B).

Guided Techniques

A variety of ultrasound and Doppler based devices have been used to assist in the placement of central venous catheters. Some are simple imaging devices while others provide flow analysis with or without ultrasonic imaging. The literature is not uniform in the devices or specific techniques used. Imaging can be used to simply identify the vessel of interest before percutaneous needle insertion. Imaging can also be used concurrently with needle placement to provide direct visualization of the needle path. Finally, some systems provide Doppler flow analysis to distinguish venous from arterial flow with or without ultrasound imaging. The authors use a simple ultrasound imaging system which can be used for vessel identification or to provide real-time visualization of needle placement (Site-Rite®, Bard Access Systems). A 7.5 MHz transducer is covered with ultrasonic gel, wrapped in a sterile plastic bag, and connected to a two-dimensional ultrasound monitor. The probe is then placed on the skin prepared with ultrasonic coupling gel over the vessel of interest. The device is light-weight, portable, and battery powered with a 2 x 2 in. screen. Various high frequency transducers are available (Fig. 1A,B). A needle guide can be attached to the ultrasound transducer (Fig. 2). The angulation of the guide is such that the

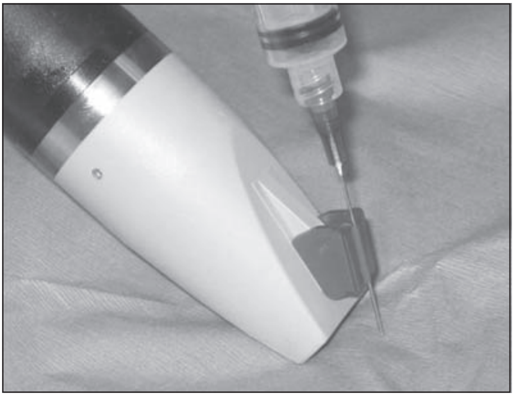

Figure 2. The needle guide attached to the high frequency transducer to facilitate image guided vascular access.

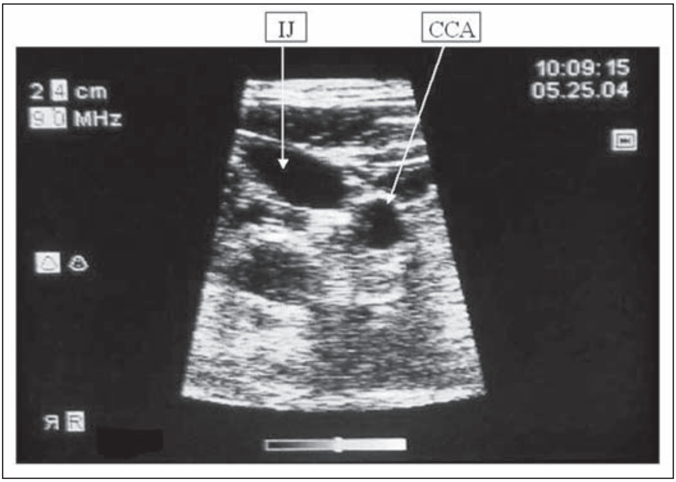

Figure 3. Image of internal jugular view (IJ) and common carotid artery (CCA) with 9.0 MHz transducer.

needle will intersect in the center of the ultrasound image 1.5 cm below the transducer surface. The internal jugular (or subclavian) vein is placed into the center of the screen to facilitate access (Fig. 3).

Ultrasound or Doppler devices can be used to facilitate cannulation of the internal jugular vein, the subclavian vein, and more peripheral veins in some troublesome intravenous access situations (i.e., morbid obesity).[7] The added benefit from the use of ultrasound guidance varies with the site chosen and the clinical situation.

In a meta-analysis of the literature examining ultrasound guidance for the placement of central venous catheters, Randolph et al[8] identified eight published randomized controlled trials that met their criteria. These trials all compared ultrasound guided needle placement to anatomic landmark techniques. From this analysis the authors concluded that guided techniques conferred several advantages. The number of catheter placement failures was significantly reduced using ultrasound or Doppler guidance. This was true for both internal jugular and subclavian vein placement. The number of complications, defined as arterial puncture, local hematoma, nerve injury, pneumothorax, and catheter malposition, was significantly reduced using guided techniques. Ultrasound guidance significantly reduced the number of attempts required before successful placement. These benefits were demonstrated for both experienced and inexperienced physicians (junior residents and attending anesthetists). However the amount of time required for successful catheter placement was heterogeneous over the studies included in the analysis and no clear advantage could be identified for guided placement.

As with meta-analysis in general, this study suffers from some limitations. The techniques and devices used in the primary articles varied considerably. Nonetheless, this analysis would indicate significant advantages for the use of some form of ultrasound imaging with or without Doppler flow analysis in many cases. The internal jugular vein was the site of cannulation in six of the eight studies included. The applicability of these results to subclavian catheterization is somewhat limited. Indeed some of the studies excluded from analysis, such as the one by Mansfield et al, involved the subclavian site and used ultrasound to identify the location of the vein prior to cannulation attempts but did not use ultrasound to guide the needle placement. The study was excluded for not using ultrasound to provide "real-time" guidance of needle placement, though two of the included studies limited to the internal jugular site also used imaging without real-time needle guidance. The literature on ultrasound/Doppler assisted approaches to subclavian catheterization is less uniform in design but, in general, does not support the use of ultrasound imaging alone.

Potential Disadvantages to the Routine Use of Ultrasound Guidance

Some clinicians have expressed concern that the use of ultrasound may increase the time required for catheter placement. There are studies showing both a decrease and a significant increase in the time to successful cannulation. Again, these studies are difficult to compare because the technique (ultrasound or Doppler) and site (internal jugular or subclavian vein) differ between studies. The biggest potential time savings may be related to the generally accepted reduction in the number of multiple attempts required for successful cannulation, rather than making a single attempt faster. Although there is minimal if any time delay associated with ultrasound guidance, one assumes the "clock" is started after all the equipment is preassembled in the elective scenario. It is unlikely that the equipment will be as readily available during an emergency situation (code, trauma) requiring central venous access. This environment has not been specifically studied.

Capital cost of the equipment, staff training, and maintenance of the machine all represent an expense. Randolph et al, in their meta-analysis, calculated the benefit (absolute risk reduction) based on the results of the papers reviewed. They calculated that guided techniques would need to be used, in place of the landmark technique, in seven patients to prevent one placement complication and in five patients to prevent more than one placement attempt. The "cost" of an "average" complication is difficult to estimate both in terms of monetary savings and quality of care relative to the added expense of the ultrasound technique.

Clinical Efficacy of Ultrasound Guided Central Venous Cannulation

In considering the potential benefit of new technology (or new applications of existing technology), the first question to be answered is whether clinical outcomes are changed by its use. In the case of ultrasound/Doppler guidance for central venous access, there are several relevant outcome considerations. These include increasing the frequency of cannulating the selected vessel successfully and reducing the complication rate from the procedure. Not unimportantly, such technology must not result in significant increases in the time necessary to achieve access. This is a significant issue in the case of central venous access lines that are often placed in emergent situations where immediate volume resuscitation is the indication for the procedure. While the use of ultrasound technology for central venous access may require time to gather the necessary equipment and supplies, if it reduces the number of attempts required for successful vessel cannulation the overall effect on the time required may be beneficial.

In the Randolph et al study, a clear benefit was found favoring a guided approach. In their analysis, the number of cannulation "failures" was significantly reduced by ultrasound/Doppler guidance, with a relative risk index of 0.32. The authors concluded that a benefit was found for both the internal jugular and subclavian sites, though the data would seem less robust for the subclavian site. However, the definition of cannulation failure varied considerably among studies. The procedure related complication rate was also lower using guided techniques, with a relative risk of 0.22 overall. Although the authors of the meta-analysis list several possible complications, the precise definition of what constituted a complication in the primary studies is not stated. A reduction in the number of attempts required before successful catheter placement was similarly achieved using guided techniques (relative risk of multiple attempts 0.6). No difference in total time to successful catheter placement was found between groups.

Unfortunately, this study suffers from several of the potential shortcomings of the meta-analysis approach. Most significant is that a variety of different technologies were actually used in the primary studies. Different combinations of technique were possible including imaging only, imaging plus Doppler flow analysis and needle Doppler technology, all with or without the use of needle guides. In addition, only two of the eight studies ultimately included in the analysis involved the subclavian vein, rendering the meta-analysis data valid only for the internal jugular vein. These reservations notwithstanding, the results of the Randolph et al analysis suggest strongly that real-time ultrasound/Doppler assisted central venous cannulation reduces failures and complications considerably without increasing the time required for the procedure. The cost of such technology is substantial and the "cost" of complications necessary to a formal cost/benefit analysis are obviously dependent on the definition of significant complications. The authors point out that such an analysis was not possible in their study and to date is not available.

Additional literature supports the use of ultrasonography for central venous cannulation, particularly of the internal jugular vein. Denys et al studied the use of real-time ultrasound guidance for jugular vein access and found a significant reduction in the time to successful cannulation. These investigators also found an improvement in overall success rate and a reduction in complications consistent with the meta-analysis of Randolph et al. The literature on ultrasound/Doppler assisted subclavian vein cannulation is more problematic. In a study by Gualtieri et al[9] the use of ultrasound favored successful cannulation only in the hands of less experienced operators. An additional benefit was an increase in successful cannulation when ultrasound was used as a "salvage" procedure following initially unsuccessful landmark attempts, even when performed by the same less experienced operator. Complications did not differ between the groups. A study using ultrasonography to localize the subclavian vein without using real-time visualization of needle entry into the vessel failed to show any effect on the rate of unsuccessful cannulation or complications. Experience of the operator appeared to be the factor most associated with the fewest failures or complications.

The Mansfield study did identify factors associated with failures and complications through a retrospective multivariate analysis. Prior surgery in the area, obesity as defined by body mass index, and previous catheterization where associated with failed attempts. Complications were also associated with failed attempts, rising from 4% with a single attempt to over 20% with more than two attempts. On balance, the literature on ultrasound/Doppler assisted subclavian cannulation suggests a more limited role compared to the internal jugular site, at least in the hands of experienced operators. However in clinical situations associated with a high likelihood of initial failure or if the person performing the procedure is relatively inexperienced, use of a guided technique in preference to reliance on landmarks alone may be advisable.

There are probably reasons to maintain the ability to place central venous catheters without resort to ultrasonographic or Doppler-based guided techniques. The most compelling is that these catheters are not uncommonly placed in emergent situations, such as cardiac arrest or massive exsanguinations, where immediate successful cannulation of the vessel may be life saving. Not all institutions may have the demand for central catheter placement that would warrant acquisition of a rarely used technology. Finally, all technology fails or is unavailable at some time. A recent article by Traber et al[10] suggests that physicians training in settings where a high reliance is placed on guided techniques may feel inadequately trained or experienced in landmark techniques. Perhaps a reasonable approach to the mastery of central venous access is to continue to use landmark techniques in patients at low risk for multiple attempts and subsequently increased likelihood of complications. It is also instructive to consider whether current teaching of catheter placement based on surface landmarks is consistent with improved understanding of the location of the vein given differences of position, degree of Trendelenburg positioning, and whether or not palpation of the adjacent artery during cannulation attempts, resulting in compression of the target vein, is maintained.[11] These are factors that make a more medial direction of the "finding needle" appropriate compared to the standard technique of aiming the needle toward the ipsilateral nipple for cannulation of the internal jugular vein, at least in the standard "apex approach".

Summary

There is good evidence that routine use of real-time ultrasound imaging guidance for the placement of internal jugular catheters is warranted. Whether similar results can be obtained using "vessel localization" imaging without real-time observation of needle entry remains to be determined. Finally, the routine use of imaging techniques over landmark techniques for cannulation of the subclavian vein remains an open question. It appears that the use of an imaging technique in patients at risk for multiple attempts (the obese, patients with previous surgery or radiation in the area, or previous cannulation of the target vein) and the consequent increased risk of procedure related complications is probably warranted. Practitioners with limited experience in central venous cannulation should consider an imaging technique. Where a previous "blind" technique has failed, imaging techniques may yield a high salvage rate. Finally, it is important to continue to teach landmark cannulation techniques as time and available resources may not always guarantee the availability of imaging technology.

The difficult area is the majority of central access scenarios, which are elective, and in patients without the predisposing factors that promote difficulty. More work is required to clarify the expense of guided techniques and the learning curve for trainees must be more clearly established. However, with the previously well documented decreases in the rates of complications, this technique may become the standard for the placement of central venous access in the elective setting.

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Transcranial Doppler

George Counelis and Grant Sinson

Introduction

Transcranial Doppler (TCD) ultrasonography is a technique that measures and records blood flow velocities in the major intracranial arteries at the base of the brain. Satomura and Kaneko were the first to measure the velocity of flowing blood using ultrasound in 1960. Doppler ultrasound was first shown to penetrate the cranium in 1981; and soon after, Aaslid introduced the first ultrasonic device capable of measuring the blood flow velocities of intracranial vessels. Since then, TCD has been utilized in neurosurgery and neurology for diagnostic and investigational purposes for a wide range of physiologic and pathophysiologic conditions of the cerebrovascular system. This chapter will review the basic principles of TCD and its applications for different pathophysiologic states commonly encountered in patients treated in the neurosurgical intensive care unit (ICU).

Several technological differences serve to distinguish TCD from Doppler ultrasound used for peripheral vascular purposes and to allow for recording velocities of intracranial arteries by penetrating the cranium. TCD uses a low (2 MHz) ultrasound frequency for increased bone penetration, as well as microprocessor controlled directional pulsed-wave adjustable hand-held probe, which can record range-gated transducer measurements at various depths (Fig. 1). These features allow for identification of individual vessels among the high density of arteries at the base of the brain by combining depth and direction of flow information. The microprocessor design is compact and provides bedside diagnostic capabilities through analysis of fast-Fourier transformed Doppler spectra for display and calculation of peak systolic, peak diastolic, and mean velocities and pulsatility indices (Fig. 2). An audio component is also continuously generated.

Technique

The TCD examination is performed by insonating the basal intracranial vessels through various cranial "windows." Cranial windows are specific points in the skull which allow for the ultrasound signal to be transmitted to the intracranial vessels (Fig. 3). Since ultrasound cannot be transmitted well through thick cortical bone, these windows are characteristically places where the bone is thinnest, e.g., temporal squamous area, or where foramina already exist, e.g., foramen magnum and orbits. The exact location and size of the cranial ultrasonic windows vary between individuals.[1] Examinations of the middle cerebral artery (MCA), the proximal anterior cerebral artery (ACA), the proximal posterior cerebral artery (PCA), as well as the distal internal cerebral artery (ICA) are approached through the transtemporal window.[2] The vertebrobasilar circulation is addressed through the transforaminal or

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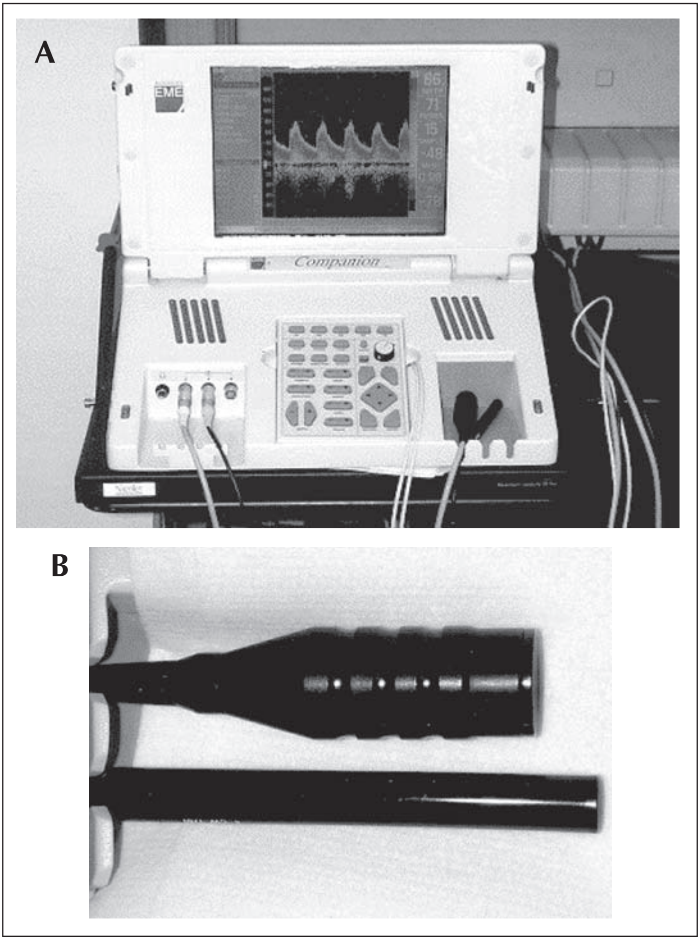

Figure 1. Picture of machine (A) and probe (B).

transoccipital window (through the foramen magnum) as described by Arnolds,[3] and the ophthalmic artery and carotid siphon are insonated through the transorbital window.[4] Vessel identification is accomplished by the examiner based on excellent knowledge of the intracranial anatomy, the window insonated, depth of insonation, direction of flow, traceability, angle of transducer, proximity to the ICA bifurcation, relative flow velocities, and response to ipsilateral carotid compression (Table 1).

Clinical Usage

As with all diagnostic tests, TCD has many advantages as well as disadvantages. TCD is an effective, noninvasive, portable testing modality that can be repeated safely and often. The test thereby can be administered in a serial fashion,

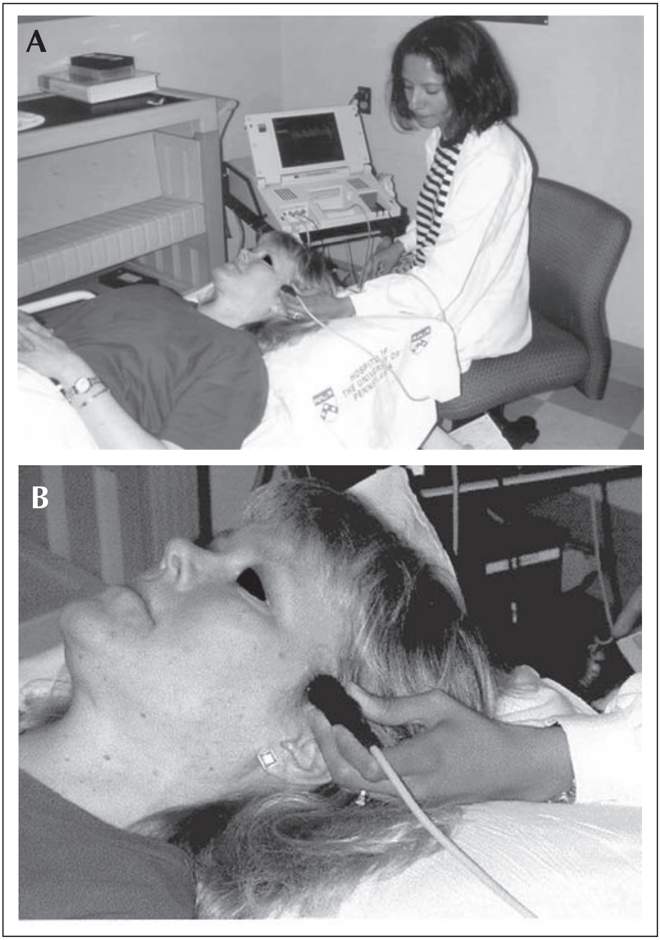

Figure 2. Photos of exam being performed.

allowing for detection of changes in a patient's flow velocities over time, and can be correlated with the clinical course as well as physiologic variations and pharmacological interventions. This aspect is especially important for its use in critically ill patients in an ICU setting. The continuous ultrasound signal allows for a real-time assessment not available with any other technique. Some alternatives for obtaining similar information are cerebral angiography, xenon computerized tomography (CT), single photon emission CT (SPECT) scan, and positron emission tomography (PET) scan. The accuracy and interpretation of TCD data are highly dependent upon the skills and experience of the technician and interpreter.[5] Many investigators have recorded normal values for the intracranial arteries in volunteers. A number of factors, anatomic and physiologic, contribute to changes

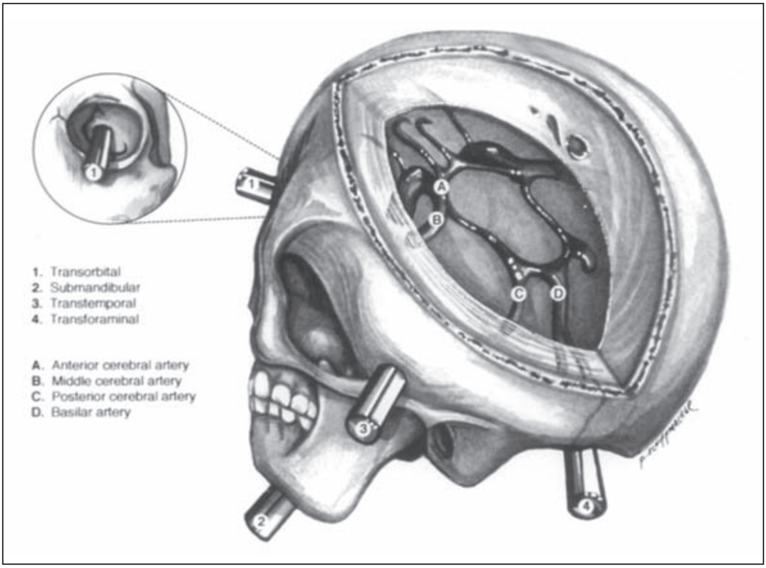

Figure 3. Schematic of probes/bone windows.

in these values from gender, hematocrit, and others that influence cerebral blood flow. Additionally, between 4 to 10% of adults have an absence of an adequate transcranial window that makes TCD testing impossible for these patients.[6] The predictive factors for successful insonation are primarily age, gender, and race, as has been shown by the range of success rates in the elderly from 80% in white males to 30% in black females to 17% in Japanese females, contrasted with 97% for a relatively young European population.[7]

Since its introduction, TCD has been used in many applications related to intracranial hemodynamics. Despite the extensive use of magnetic resonance imaging and conventional angiography, there are a few settings in which TCD can provide information not otherwise easily attainable and guide further diagnostic testing. The conditions of most interest to neurosurgeons that can be investigated by TCD can be grouped into two main categories: cerebrovascular disease and traumatic brain injury. TCD has been used to assess traumatic subarachnoid hemorrhage induced vasospasm, cerebral autoregulation, and relative cerebral blood flow (CBF) in conjunction with standard tissue flow techniques. TCD provides confirmatory information with regard to increased intracranial pressure and brain death.

Cerebrovascular Disease

In the realm of cerebrovascular disease, TCD has been used most extensively in the study of vasospasm secondary to aneurysmal subarachnoid hemorrhage. Identification of intracranial stenosis and measurements of cerebral vasoreactivity have also been useful applications for TCD.

Table 1. Normal parameters and velocities for intracranial vessels evaluated by TCD

Artery	Transducer Position	Depth of Sample Vol. (mm)	Direction of Flow	Spatial Relationship to ACA/MCA Birfurcation	Mean Velocity (cm/sec)	Response to Ipsilateral Carotid Compression
MCA (M1)	Transtemporal	30-60	Toward	Same	55 plus or minus 12	Obliteration Diminishment
ACA/MCA Bifurcation	Transtemporal	55-65	Bi-directional		50 plus or minus 11	Identical to ACA/MCA
ACA (A1)	Transtemporal	60-80	Away	Anterior and Superior	40 plus or minus 10	Obliteration Diminishment Reversal
PCA (P1)	Transtemporal	60-70	Toward	Posterior and Inferior	39 plus or minus 9	No Change Augmentation
PCA (P2)	Transtemporal	60-70	Away	Posterior and Inferior	40 plus or minus 10	No Change
TICA (C1)	Transtemporal	55-65	Toward	Inferior	39 plus or minus 9	Obliteration Reversal
OA	Transorbital	55-65	Toward		21 plus or minus 5	Obliteration
Carotid Siphon	Transorbital	60-80	Away Bi-directional Toward		41 plus or minus 11 47 plus or minus 14	Obliteration Reversal
VA	Transoccipital	60-90	Away		38 plus or minus 10	
BA	Transoccipital	80-120	Away		41 plus or minus 10	

Adapted from: Fujioka K: Chap 2: Anatomy and Freehand Examination Techniques in *Transcranial Doppler,* edited by DW Newell and R Aaslid Raven Press Ltd., New York.

Aneurysmal Subarachnoid Hemorrhage

Cerebral vasospasm secondary to aneurysmal subarachnoid hemorrhage is a common cause of morbidity and mortality for patients who survive their initial hemorrhage and come to neurosurgical attention. Metabolic products of hemoglobin surrounding the cerebral vasculature result in progressive narrowing of the arteries, limiting blood flow and can lead to neurological deficit and ischemic stroke. Treatment of cerebral vasospasm requires aggressively inducing hypertension and hypervolemia to improve blood flow. In some cases angioplasty and intra-arterial papaverine infusions are used to further improve flow. Approximately two-thirds of patients with subarachnoid hemorrhage will have vasospasm yet in many cases the decreased blood flow is not significant enough to cause ischemia and neuronal death. The use of TCDs helps guide the application of potentially harmful therapies (vasopressors, angioplasty, hypervolemia, etc.) in the subset of patients that appear to be nearing a critical decrease in blood flow due to vasospasm. The principle governing the utility of TCD for diagnosis of vasospasm is the exquisite sensitivity of the blood velocity to vessel narrowing. If flow is assumed to remain constant, a diameter decrease of only 30% will double the velocity, thereby making TCD a sensitive indicator of vasospasm and an even more important diagnostic tool by virtue of its noninvasive nature and the ability to be performed frequently at the bedside. Due to the complex physiologic changes occurring following subarachnoid hemorrhage, cerebral blood flow and vessel diameter may both vary and do not permit quantification of hemodynamically significant vasospasm from basic principles. Instead, empirically derived data from various centers have established mean MCA velocities which are consistent with mild (120 cm/sec), moderate (150 cm/sec), and severe (>200 cm/sec) vasospasm. Approximately 50% of patients with severe spasm will experience neurological symptoms e.g., focal neurological deficit or decreased level of consciousness. Of course the values for any one patient must be interpreted in the context of that individual's age and physiologic parameters. Calculation of the ratio of MCA to ipsilateral extracranial ICA velocities (hemispheric index) has been proposed to differentiate between vasospasm and hemispheric hyperemia. A hemispheric index >3 suggests mild spasm >6 suggests severe spasm.

The observed time course for vasospasm reveals an initial increase in velocities on post hemorrhage day 4, peaking at day 8, and resolving by two weeks. Protocols for TCD examinations have been based on this time course, with most centers obtaining an initial study as a baseline, followed by daily or every other day studies beginning on day 3. Decisions about the frequency and duration of studies are based on the study results, the neurological status of the patient, and the amount of initial subarachnoid blood demonstrated on the patient's admission CT scan. Generally patents with larger initial hemorrhages have an increased risk of developing symptomatic vasospasm.

In comparing TCD studies with angiography for the detection of MCA vasospasm, the sensitivity and specificity of TDC is high, ranging from 84-85% and 89-98% respectively. Additionally, the rate of velocity change over time can be prognostic, as rapid increases in velocity have been associated with the propensity to develop an neurological deficit and a worse prognosis. Early detection allows for prompt intervention in the stepwise institution of hypervolemia, hemodilution, and vasopressor therapy, with balloon angioplasty reserved for medically recalcitrant symptomatic vasospasm following aneurysmal subarachnoid hemorrhage, especially in the MCA.

Occlusive Disease

The etiology of cerebral ischemic events in the setting of carotid artery stenosis and occlusion includes thromboembolic factors, hemodynamic mechanisms and anatomical variability. Transient ischemic attacks often precede strokes and provide an opportunity for intervention prior to development of a permanent stroke. In the evaluation of these patients, determining the risks of thromboembolic stroke vs. hemodynamic compromise can be difficult. TCD provides clinically useful information in this setting by assessing the cerebriovascular reserve capacity (CVRC) through functional testing with a vasoreactive stimulus—either acetazolamide or CO_2 testing. When obstruction to blood flow occurs in a major artery supplying the brain, cerebral blood flow is sometimes maintained via collateral sources (e.g., the circle of Willis, leptomeningeal anastomoses, or natural anastomoses with the external circulation such as the ophthalmic artery). Some individuals have functionally insufficient collaterals, resulting in symptoms of cerebral ischemia. Therapy for these individuals (medical or surgical) must address improving cerebral perfusion pressure. Additionally, experimental evidence exists demonstrating that larger strokes can result from emboli in the setting of reduced baseline cerebral perfusion pressure.

In the course of attempting to identify stroke-prone individuals by detecting an exhausted cerebrovascular reserve, methods that have been employed include angiography, regional cerebral blood flow techniques, and positron emission tomography. TCD testing provides a safer (noninvasive, nonradioactive) and less expensive method which is very sensitive to the time resolution of blood flow changes. The principle guiding TCD testing of CVRC is that in a steady state the change in MCA velocity measured by TCD is proportional to the change in cerebral blood flow in the ipsilateral hemisphere. In order achieve steady state, variables that can influence MCA velocity or introduce error are controlled. The probes are placed at a fixed angle with the use of a head frame, blood pressure is monitored, hematocrit remains constant, and the diameter of the MCA is assumed to remain constant. Acetazolamide increases CBF by mechanisms not fully understood. CO_2 concentrations in the blood mainly act on the peripheral cerebrovascular bed, particularly the small cortical vessels, with increase in arteriolar diameter during hypercapnia and decreased diameter with hypocapnia. These changes are reflected in increased and decreased CBF and MCA velocities respectively. In a study to evaluate the CO_2-induced vasomotor reactivity of the cerebral vasculature, Ringlestein and colleagues[8] studied 40 normal individuals and 40 patients with unilateral carotid artery occlusions and 14 patients with bilateral internal carotid artery occlusions. They plotted the blood flow velocity changes as percent of normocapnic values against end-tidal CO_2 volume percent, defining the distance between the upper and lower asymptotes of the resulting biasymptotic curve as the vasomotor reactivity. For normal individuals the vasomotor reactivity was 85.63 plus or minus 15.96%. The blood flow velocity increased by 52.5% during hypercapnia and decreased by 35.3% during hypocapnia. These findings were in agreement with previous studies of CBF wherein CBF changed 3-5% per unit change in $PaCO_2$, as reviewed by Yonas.[9] Additionally, vasomotor reactivity was significantly lower than normal in both the occluded (45.2%) and nonoccluded (67.7%) sides in the internal carotid occlusion group as well as both sides (36.6%-44.9%) in the bilateral occlusion group. They also found a highly significant difference in vasomotor reactivity between the symptomatic and asymptomatic unilateral internal carotid occlusion patients (37.6% and 62.9% respectively.)

Arteriovenous Malformations

Cerebral arteriovenous malformations (AVMs) are congenital vascular lesions that represent direct high flow connections between the arterial and venous systems without an intervening capillary network. Clinically, these lesions present with hemorrhage, seizure, neurological deficits, headache, and/or a bruit. Hemodynamically, the arterial side has lower pressure and the venous side higher pressure compared to their normal pressure. The vessels have reduced CO_2 reactivity as well as decreased responsiveness to a variety of pharmacological agents. TCD has been used to document the decreased CO_2 reactivity as well as increased velocity in feeding vessels coupled with reduced pulsatility indices, reflective of increased flow with low resistance. This constellation of findings can be useful in detecting AVMs noninvasively. As with all cerebrovascular lesions, the gold standard remains cerebral angiography. Decreases in velocity and increases in pulsatility indices have been recorded by TCD following embolization or surgical excision as a means of noninvasively monitoring treatment by these modalities. Gradual normalization of these hemodynamic parameters has also been demonstrated following radiation therapy for these lesions.

Traumatic Brain Injury

The use of TCD in traumatic brain injury has mirrored that of cerebrovascular disease in many respects and this has been the subject of extensive investigation. TCD findings, in combination with cerebral blood flow (CBF) data, have documented a variety of hemodynamic disturbances that can lead to secondary damage to the brain following head injury. These hemodynamic disturbances can significantly affect outcome. Some of the conditions which can be detected using TCD in traumatic brain injury are: (1) vasospasm (2) hyperemia (3) arterial dissection, occlusion, and emboli (4) carotid-cavernous fistula (5) increased distal vascular resistance e.g., vasoconstriction due to hyperventilation or low cerebral metabolism (6) high ICP (7) cerebral circulatory arrest (Table 2).

Increases in velocity have been found commonly in head injured patients. The two most common causes are vasospasm, as in SAH, and hyperemia or increased CBF. To differentiate between the two, insonation of the ipsilateral extracranial ICA is performed, and a ratio of the V_{MCA}/V_{ICA} is measured. A ratio of ≥ 3 is consistent with vasospasm, while a ratio of <3 can indicate hyperemia. The ratio is used to correct for the effects of CBF on velocity. A temporal pattern of TCD velocities has been shown to correlate with simultaneous CBF measurements in these patients. Varying patterns have been detected and correlated with outcome data. Lee et al utilized TCD and $^{133}X_{enon}$-CBF measurements to define hemodynamically significant vasospasm in patients with traumatic brain injury. In a stepwise logistic regression analysis, hemodynamically significant vasospasm was shown to be a significant predictor of poor outcome at six months, independent of the effects of admission Glasgow Coma Scale score and age.[10]

Continuous TCD monitoring has been employed to test and quantify cerebral autoregulation and CO_2 reactivity. The loss of autoregulation and CO_2 reactivity can be linked to outcome measures and can reflect the degree of overall brain injury. Czosnyka et al[11] studied a group of 82 head injured patients with daily periods of synchronous and continuous TCD, ICP, and MAP monitoring. A PressureReactivity Index (PRx) was calculated as a moving correlation coefficient between ICP and MAP, reflecting dysautoregulation. Similarly, a second correlation coefficient (Mean Index) was calculated between spontaneous fluctuations in mean flow velocities,

Table 2. TCD findings in various traumatic brain injury induced pathophysiologies

Conditions Encountered in Head Injury	**TCD Correlate**
Vasospasm	Increased velocities, V_{MCA}/V_{ICA} is greater than or equal to 3
Hyperemia	Increased velocities, V_{MCA}/V_{ICA} is less than 3
Intracranial arterial occlusion	Absent or markedly reduced velocity in arterial trunk
Carotid-cavernous fistula	Increased velocity in extracranial carotid artery ipsilateral fistula
	Increased velocity in carotid siphon with marked turbulence
Increased distal vascular resistance	Increased pulsatility
Vasoconstriction due to hyperventilation or low cerebral metabolism	Increased pulsatility, decreased diastolic velocity
High ICP	Increased pulsatility, decreased diastolic velocity
Cerebral circulatory arrest	Increased pulsatility, absent or reversed diastolic velocity, reverberating pattern, small systolic peaks, absent signals

Adapted from: Newell DW, Aaslid R. Transcranial Doppler: Clinical and Experimental Uses. Cerebrovasc Brain Metav Rev 1992; 2(4):122-143.

as measured by continuous TCD, and CPP, reflecting cerebral blood flow autoregulation. A positive PRx was significantly correlated with high ICP, low admission GCS, and poor outcome at 6 months post injury. In the first two days post injury, the PRx was positive only in patients with unfavorable outcomes. The TCD-based Mean Index correlation with the PRx was highly significant ($P<0.0000001$), suggesting that computer analysis of this continuous index of cerebrovascular reactivity is of prognostic significance. Again, TCD provides a useful, noninvasive, convenient bedside study in this critically ill ICU patient population.

Intracranial Pressure and Brain Death

The effects of increased intracranial pressure (ICP) on the traumatically injured brain can cause further neurological damage and herniation. Specific ICP monitoring devices such as ventricular catheters and fiberoptic monitor systems provide a quantitative measure of ICP. TCD can provide data regarding the hemodynamic effects of increased ICP. Characteristic changes in the setting of increased ICP include increased pulsatility, progressive reduction in diastolic velocity, and decreased mean velocity. This constellation of changes may indicate effects of extrinsic compression and resultant increased vascular tone. Hassler and colleagues monitored 29 patients simultaneously with continuous ICP recordings, mean arterial blood pressure (MAP), and serial TCD exams.[12] These patients had intracranial hypertension as a result of either head injury or intracranial hemorrhage. A consistent relationship was found between cerebral perfusion pressure (CPP = MAP-ICP) and the shape of the velocity spectrum outline. Under normal conditions, the end-diastolic flow

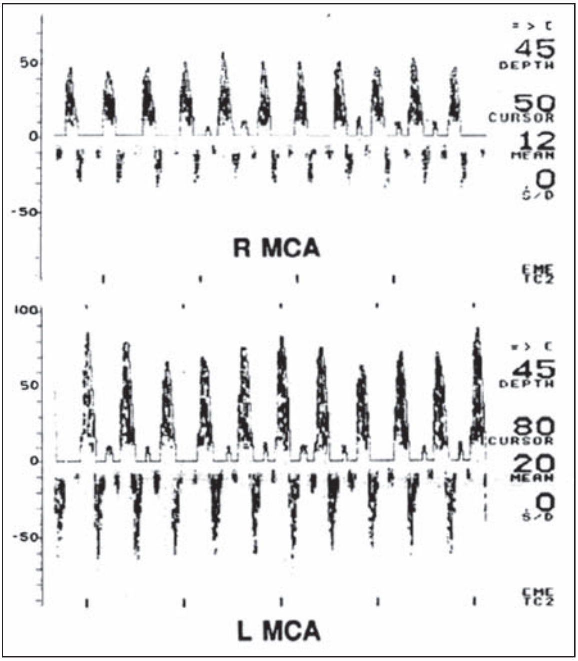

Figure 4. Cerebral circulatory arrest.

velocity is about 50% of the systolic peak value. With increasing ICP and resistance the end diastolic flow velocity decreases and the systolic peak become sharper, resulting in significant pulsatility increases. Once ICP approaches diastolic blood pressure, the diastolic portion of the TCD waveform approaches zero. With further drops in CPP, the diastolic peak reappears in a reversed direction of the flow. This to-and-fro pattern reflects severe impairment of intracranial circulation. At the point CPP becomes zero, three patterns were observed—no signal, very small systolic spikes, or oscillating flow. In their series, no patient with severe brain swelling and no localized mass with any one of these patterns survived. Their findings were confirmed by four-vessel angiography. Extreme hyperventilation and low cerebral metabolic rate can also produce increased pulsatility and decreased mean velocity. Therefore these TCD findings are not specific for increased ICP alone and they must be interpreted within the context that they were obtained.

Once ICP is high enough to produce brain tamponade, a characteristic TCD pattern can be seen and this is sensitive and specific for cerebral circulatory arrest, as described above (Fig. 4). TCD can be particularly useful in the setting where the clinical criteria for brain death cannot be applied, for example in a patient who has been treated with barbiturate coma. TCD provides a quick, noninvasive way to determine whether more definitive cerebral blood flow testing need be performed. For example, if the TCD exam does not show the characteristic to-and-from pattern indicative of brain death, then angiography or xenon-based CBF studies are unlikely to show a loss of cortical blood flow and transport of these critically ill patients becomes unnecessary.

Summary

TCD has been used for almost twenty years as a safe, noninvasive, and reproducible method to study intracranial cerebrovascular hemodynamics under a broad spectrum of physiologic and pathophysiologic conditions. The technique is operator dependent and requires a learning curve to become effective and accurate. Ongoing studies of cerebral hemodynamics and circulatory control are enhanced by the ability of continuous TCD to monitor instantaneous changes in relative cerebral blood flow.

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Diagnosis and Treatment of Fluid Collections and Other Pathology

Mark McKenney and Morad Hameed

Introduction

Hippocrates is known to have proposed the treatment of empyemas by the placement of metal drainage tubes, but over 2,400 years elapsed before percutaneous techniques established themselves as important diagnostic and therapeutic modalities. The recent refinement and broadening applications of such techniques have largely been the result of rapid advancements in diagnostic imaging technology. In 1967, Margulis[1] recognized interventional radiology as an important, emerging, diagnostic subspecialty. More recently, interventional radiology has also found therapeutic applications—Dondelinger[2] defined it as "minimally invasive closed percutaneous procedures for diagnosis or treatment, guided by imaging techniques." Although fluoroscopy, computed tomography, and ultrasonography have all been useful in the guidance of invasive procedures, ultrasound has proven to be the most powerful adjunct to the diagnostic and therapeutic armamentarium of surgical practice.

Ultrasound is an inexpensive, noninvasive, dynamic, repeatable and portable test. Computer-enhanced high-resolution imaging, and multifrequency specialized transducers have improved sensitivity and ease of interpretation. Ultrasound is increasingly becoming a versatile clinical tool, which is ideally suited to numerous surgical indications, both diagnostic and therapeutic. As a result, the surgeon's role has expanded to include that of interventional ultrasonographer. In this chapter, some of the basic techniques and common indications for the use of interventional ultrasound in surgical practice are discussed.

Technical Considerations

Percutaneous drainage or aspiration in the acute setting generally involves access to the chest (thoracentesis), abdomen (paracentesis), or gallbladder (percutaneous cholecystomy). Similar approaches are taken to all three types of drainage. Screening ultrasonography is used at the outset of the procedure in order to determine the general distribution of the fluid collection to be entered. The largest collection of fluid (or position of gallbladder) is localized, usually in the supine position. A site should be chosen for drainage that takes into account the minimal distance from the skin surface to the collection and the access route, which poses minimal threat of injury to intervening structures. Once the aspiration site is chosen, it should be imaged in both the longitudinal and transverse planes to clearly delineate the configuration of the collection. A depth measurement is obtained, determining the distance from the skin surface to the center of the fluid collection.

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This measurement is important for subsequent needle or catheter placement. Following successful localization and depth measurement, ultrasound-guided drainage can be performed under sterile conditions under direct, real-time visualization.

Percutaneous drainage can be accomplished through the use of one of three techniques: simple needle aspiration, trocar technique or Seldinger technique. All three techniques rely on the use of a sterile sleeve or "probe cover" that is placed over the ultrasound transducer or "probe" to aid in aseptic technique (a sterile glove can also serve as a probe cover). It is necessary to place the ultrasound acoustic gel inside the probe cover and ensure contact with the transducer head. Sterile acoustic gel or "surgilube" is also used outside the cover, on the patient's skin, to serve as a coupling medium for optimization of fluid collection imaging.

Simple needle aspiration is well suited to small, superficial fluid collections from which only small volume samples are needed. This technique allows freehand puncture with direct visualization of the needle as it is inserted into the fluid. The sterile transducer is placed over the previously chosen site with the nondominant hand. It is important to try to duplicate the transducer position as closely as possible to the initial scan. With the free dominant hand, the needle with attached syringe is passed in the same plane alongside the transducer into the fluid collection. The needle can be seen as an echogenic or bright structure entering the patient. At first it may be helpful to gently agitate the needle and observe the motion on the ultrasound screen to help visualize the needle. Once identified, the needle is easily followed as it enters the collection to the previously measured depth. Multiple passes, however, should be avoided because of the inadvertent introduction of "microbubbles". These small gas collections mimic the echogenic appearance of the needle making visualization difficult. Once in the collection, aspiration can be performed.

The second technique involves the use of a sterile trocar. This single step process for catheter drainage is best suited to the drainage of superficial collections with safe access. A catheter with a sharp inner stylet replaces the needle-syringe combination described for simple aspiration. Once the appropriate site is chosen, the catheter is directly inserted alongside the transducer. Due to the size of the catheter, a small skin incision and local dissection are required prior to insertion. As with needle aspiration, the catheter should be visualized as it enters the collection to the premeasured depth. Once inserted, the inner stylet is removed and a test aspiration is performed for confirmation. The catheter may then be deployed into the collection. Real-time imaging will demonstrate the coiled catheter in the fluid.

The Seldinger technique,[3] which is widely used by surgeons for vascular access, is also a useful technique for the placement of ultrasound-guided drainage catheters. An additional step utilizing a guidewire is involved in this procedure. As with the trocar technique, the fluid is imaged with the nondominant hand while the dominant hand is reserved for placement of a Seldinger needle (with inner stylet) into the fluid collection. For deep collections, a longer needle with inner stylet would be required. Great care is taken to ensure complete control of the trocar-mediated entry into the collection. Once the fluid collection is entered, the inner stylet of the needle is removed and a small amount of fluid is aspirated for confirmation. The ultrasound probe is released to allow the surgeon to place a guidewire with bimanual technique through the needle. The guidewire should enter the collection without resistance. The correct location of the needle and guidewire should be confirmed with ultrasound. The needle is then removed leaving the guidewire in place. A drainage catheter can then be introduced into the collection over the guidewire.

Again, correct positioning is confirmed with sonography. The Seldinger technique is well suited to the drainage of deep collections which are difficult to access.

Specific Applications—Indications, Methods, and Limitations

Advances in CT and ultrasound technology have allowed improved characterization of pleural and parenchymal disease processes, and, along with improvements in drainage catheter design and interventional techniques, have made image-guided management of inrathoracic collections a safe and effective alternative to traditional open surgical approaches. In fact, ultrasonography has become the technique of choice for the guidance of throracentesis for the drainage of peural effusions as well as for the management of some intrathoracic abscesses and pneumothoraces. This section reviews some of the primary indications for ultrasound-guided interventions for diseases of the chest.

Parapneumonic Effusions/Empyemas

Infected pleural effusions most commonly result from chest trauma, recent surgery, infection of an established hydrothorax or hemothorax, or as a complication of pulmonary infection. Effusions requiring drainage for definitive treatment are referred to as “complicated”—complicated effusions are further subclassified as empyema by most clinicians if they consist of frank pus. Exudative parapneumonic effusions (pH<7.20, LDH>1000 IU/L, glucose <40 mg/dL) have been observed to be less likely to respond to antibiotic therapy alone and frequently progress to fibrinopurulent and organized stages within days to weeks. Such effusions have been managed with external drainage by a variety of means including thoracentesis, image-guided catheter drainage, thoracostomy tube placement, thoractomy with debridement and directed chest tube placement, open pleural debridement and decortication, and by video-assisted thorascopic techniques.

Image-guided techniques have clear advantages in terms of invasiveness and convenience. As with standard thoracostomy, such techniques are of most benefit when used against free-flowing, easily aspirated effusions of short duration which are not associated with thick inflammatory peels. Patients with such effusions who can sit up or those with unilocular effusions contacting the chest wall, even those who are critically ill or hemodynamically unstable are readily approached sonographically. More complicated effusions may be better approached using CT-guided techniques. Postoperative empyema or empyema associated with bronchiopleural fistula respond poorly to chest tube drainage and frequently require open surgical procedures.

Catheters ranging from 8-30 French may be placed under sonographic guidance. Single lumen catheters are normally used to prevent air entry into the pleural space and to maximize opportunities for lung expansion and resultant obliteration of pleural collections. Serous collections are often drainable with 8-12 French catheters, while thicker collections may require 12-24 French catheters for adequate drainage. Most catheter tips have large side holes to promote drainage. Catheter tips may be pigtailed (Fig. 1) to improve the likelihood of retention, or gently curved to match the concavity of the pleural space.

Technique

As with other fluid collections, pleural fluid will appear anechoic while atelectatic lung can be identified as an echogenic structure adjacent to the fluid moving with respiration. Large collections are easily imaged with the patient in the supine position but having the patient in the decubitus position facilitates imaging and

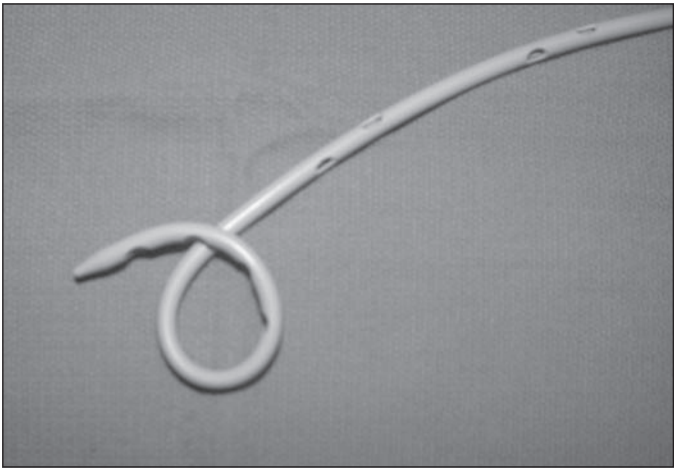

Figure 1. Pigtailed catheter that can be used to drain pleural effusions.

drainage of smaller collections. With larger collections the fluid can be accessed from the midaxillary line. The site is chosen and depth measurement obtained prior to the onset of the sterile technique. The transducer is covered with a sterile sleeve to provide imaging during the procedure. If only a diagnostic tap is required, the technique for simple aspiration can be used.

After adequate sonographic assessment of the collection as described above, and sterile preparation and draping of the proposed puncture site, an 18-gauge trocar needle is placed through the chest wall into the thickest part of the collection. Care is taken to pass the needle just over an underlying rib to avoid intercostal neurovascular injury. The sharp-tipped trocar is removed and fluid is aspirated through the 18-gauge needle. If no fluid is aspirable, despite confirmation of good catheter-tip placement, then the collection is not likely to be adequately addressed by simple closed techniques. Aspiration of pus or purulent fluid is an indication for placement of a drainage catheter.

Catheter placement may be accomplished by placement of a floppy-tipped guidewire through the needle, and coiling it in the collection. The needle is then removed, and the guidewire tract can be serially dilated using vascular dilators in increments of 2 French until the desired caliber drainage catheter can be comfortably introduced. Collections with broad chest wall contact areas can also be drained by trocar placement of the drainage catheter in tandem with the diagnostic needle. Once the drain is advanced to the correct depth, the inner trocar is removed, and fluid aspirated, If fluid is encountered after this maneuver, the catheter can be advanced off of the stiffening inner cannula into the collection. Ultrasound can be used to confirm the placement of the catheter and to assess the effect of aspiration of the collection through the newly placed drainage tube. The catheter can then be connected to a closed drainage system (e.g., pleurvac).

Most patients treated in this manner require 5-10 days of drainage, although duration of therapy can be shorter or longer. Daily assessment should be made of catheter patency, output, and clinical response to therapy (fever, WBC count). Drainage catheters may be removed when daily output falls below 10 cc, and there are no longer any clinical signs of sepsis.

Results

Several approaches may be taken when repeat imaging reveals inadequate drainage. Catheters can be repositioned, or wider bore catheters can be introduced via the same tracts. Intrapleural administration of streptokinase or urokinase (80,000-100,000 IU in 100 cc sterile water left in the pleural space for 2-12 hours) has had success rates of 77-92% in the drainage of difficult pleural collections. Overall success rates of drainage of pleural collections by image-guided techniques have been reported to be 72-88% in retrospective series. Ultimately, inadequate drainage by closed techniques should prompt the decision to proceed to more invasive thoracoscopic or open drainage techniques.

Complications of image-guided pleural drainage are infrequently encountered, but include intercostal vessel injury and pneumothorax.

Malignant Effusions

Malignant pleural effusions, most commonly from carcinoma of the breast and lymphoma, are frequently encountered in surgical practice. Although some of these effusions respond to treatment of the underlying malignancy, 90% of malignant effusions initially treated with large volume thoracentesis are believed to reaccumulate within months. Symptomatic patients who are expected to continue to survive for some time are candidates for drainage and obliteration of the pleural space. Numerous approaches have been used to achieve this end, including placement of tube thoracostomy with talc poudrage, thoracoscopy with pleurodesis, pleural decortication, and pleuroperitoneal shunting. However, image-guided catheter placement has largely supplanted surgical tube thoracostomy as the procedure of choice in the management of malignant pleural effusions.

Technique

As most malignant pleural effusions are free flowing, they are often easily accessed under sonographic guidance to direct the catheter to the central and most dependent part of the effusion. A small-bore catheter (8-12 F) is suitable for the drainage of most serous effusions. A direct trocar technique may be used in cases where the effusion is large and extensively in contact with the chest wall. Smaller effusions are better accessed using the Seldinger technique. It is interesting to note that rapid evacuation of effusions (>1.5 L at the first attempt) may create reexpansion pulmonary edema. Remaining fluid after the first procedure should be drained gradually, and the catheter should be removed when its daily output diminishes to 100 cc, which is usually within 5 days.

Complete evacuation of pleural fluid is required for pleural apposition and successful pleurodesis. Lung trapping, due to the presence of a thick inflammatory peel, as well as endobronchial obstruction and restrictive lung disease, which prevent full lung expansion, may also interfere with pleurodesis. If radiographic resolution of the effusion with minimal ongoing catheter drainage is achieved, chemical pleurodesis may be attempted.

As tetracycline is no longer commercially available for this purpose, doxycycline, minocycline, bleomycin, *Corynebacterium parvum*, and talc are all used as alternatives. Suspensions of talc are most often used for pleurodesis and are administered via the drainage catheter. The catheter can then be temporarily clamped, then reconnected to suction and ultimately removed the next day.

Results

Success rates (absence of symptomatic recurrence of effusions one month after pleurodesis) have been observed in various series to be 62-92%, and are comparable to those achieved using large caliber tubes.

Self-limited pneumothorax, infection and reexpansion pulmonary edema (as noted above) occur infrequently as a result of this procedure.

Percutaneous Paracentesis

Paracentesis is a familiar procedure to surgeons as it is commonly used for diagnostic purposes, as well as for the treatment of massive ascites. Although the performance of this procedure is generally straightforward, its clinical use can be limited by the theoretical risk of hollow viscus or solid organ injury, especially if the collection requiring drainage is small. When done blindly for therapeutic purposes, the endpoint of this procedure is often difficult to as ascertain there is no way to accurately quantify the extent of residual fluid. These considerations make percutaneous drainage of intraperitoneal fluid ideally suited to the application of dynamic imaging guidance with ultrasound.

Technique

An initial scan is performed to localize the intra-abdominal fluid. It is imperative to pick a location free of intervening bowel or solid organs as the drainage site. Generally, with ascites, the right or left lower quadrants of the abdomen will be the site of greatest fluid accumulation and safest route for drainage. For a diagnostic tap, simple aspiration of fluid under direct ultrasound guidance is the technique of choice. When a significant amount of fluid is present, simple needle aspiration can be performed at the site of easy access in any quadrant. In the trauma setting Rozycki[4] has shown that Morison's pouch (the subhepatic space) is the most frequent location for fluid accumulation, and that a diagnostic paracentesis at this site is potentially useful to differentiate blood from ascites or enteric contents. If therapeutic drainage of massive ascites or prolonged drainage is required, then either the trocar method or Seldinger technique may be employed for the introduction of drainage catheters.

Percutaneous Cholecystostomy (PC)

The first clinical description of gallstone disease is attributed to Galen, who in the second century AD differentiated the pain of biliary colic from that of pleurisy. By the seventeenth century, gallstones were noted to be the cause of a spectrum of illness (Schlerk, 1609). The first reported therapeutic approach to cholecystitis used by Joenisius in 1676, was cholecystolithotomy, which he performed through a fistula after gallbladder perforation. In 1743, Petit showed that the presence of adhesions allowed percutenaeous drainage of bile from an immobilized gallbladder. Carre, in 1833, described a technique of anterior abdominal wall cholecystopexy with subsequent cholecystostomy and stone removal. However, percutaneous cholecystostomy was not widely embraced, because of the risk of bile leakage and peritonitis, until the 1980s, when refinements in catheterization techniques and real-time ultrasonography made this a safe and effective procedure for certain indications.

Operative mortality for acute cholecystitis has been noted to be significantly higher in the elderly (age >65) than in the general population. High mortality rates are attributed to serious cardiovascular, pulmonary and renal comorbidities, as well as to diabetes mellitus, cirrhosis, sepsis, and multiple organ failure. Less invasive approaches to acute cholecystitis in these patient groups are potentially lifesaving – cholecystostomy with stone extraction can be followed by more definitive surgery at the time of resolution of acute illness and control of comorbid conditions.

Critically ill patients are susceptible to acalculous cholecystitis. Percutaneous cholecystostomy in such individuals often leads to dramatic resolution of sepsis, even in the absence of culture-positive bile. Percutaneous cholecystostomy and drainage have also been used with excellent results for empyema, hydrops, and frank perforation of the gallbladder, although such cases should be carefully selected and monitored for adequate control of intra-abdominal sepsis.

Technique

Sonography is well suited to the diagnosis and treatment of acalculous cholecystitis in the critically ill. Sonographic images reveal a distended gallbladder with or without sludge. In addition, there may be a gallbladder wall thickening, pericholecystic fluid, or a sonographic Murphy's sign. Unlike the clinical Murphy's sign, a sonographic Murphy's sign accurately localizes a patient's pain to the gallbladder. The point of maximum tenderness is identified when the transducer is directly over the gallbladder. In acute cholecystitis ultrasound is highly accurate but in the high-risk critically ill patient imaging accuracy of acalculus cholecystitis is below 60%. Since the diagnosis is difficult and treatment can be crucial some advocate early percutaneous cholecystostomy. The application of ultrasound in this setting allows safe and rapid gallbladder drainage at the bedside.

Blood pressure, pulse and oxygen saturation is monitored continuously during percutaneous gallbladder techniques. Intravenous access for sedation and administration of fluids is established. Occasionally, local anesthesia is sufficient for percutaneous cholecystostomy, but for introduction of wide bore catheters, or extensive gallbladder manipulation, intravenous narcotics and benzodiazepines can be titrated to patient comfort. Anesthesia standby should be arranged for high-risk patients. Vasovagal reactions are unusual, but atropine and dopamine should be made readily available.

Several routes of percutaneous access to the gallbladder are available depending on considerations of objective of intervention and individual patient anatomy. For decompression of the gallbladder in acute cholecystitis, hydrops, or biliary obstruction, the preferred route is transhepatic (rather than transperitoneal), traversing the "bare area" of the gallbladder. Such an approach does not cross the peritoneal cavity immediately prior to entry into the gallbladder, and therefore minimizes the risk of bile leakage at the time of catheter placement or withdrawal.

Using the trocar technique, a 6 French McGahan catheter can be placed into the gallbladder under direct real-time visualization after confirmation of gallbladder position by needle aspiration. The relatively small catheter allows drainage and cultures to be obtained. Transcholecystic cholangiography can be done as indicated via the newly placed catheter to detect the presence of gallstones or common bile duct stones. Catheters should be left in place for at least 2 to 4 weeks to allow a mature tract to form. Ultrasound guidance can also be used in the placement of pericholecystic drains if these are required.

If mechanical stone extraction is planned, some authors advocate a transperitoneal subhepatic approach, as passage of the extraction instruments would otherwise require dilation of the liver parenchyma up to 10 mm (30 F) diameter. Cannulation of the gallbladder by the subhepatic route can be accomplished by using fascial dilators or balloon dilatation, and stones are extracted through a sheath. The use of retaining T-fasteners has been advocated to approximate the gallbladder to the anterior abdominal wall, thereby reducing the likelihood of bile spillage when the subhepatic route application of this approach. In such cases, transhepatic drainage as outlined above, with gradual dilation of the parenchyma is an option. Alternatively, ultrasound-guided surgical "mini-cholecystostomy" is also an excellent option for definitive drainage and stone extraction.

Results

The combined success rate for percutaneous cholecystostomy for various indications is 95%. Reported causes of failure include lost access due to gallbladder mobility (subhepatic technique) and inability to place the catheter by trocar technique in uncooperative patients. Prompt resolution of the manifestations of acute cholecystitis (pain, fever, high WBC count) is reported to occur in 70-95% of patients, and 100% in one series. In-patients who recover, cholecystectomy can be performed semi-electively once stable conditions have been established, or the catheter can simply be removed after time has been allowed for tract maturation.

Reported complication rates are low considering that many patients subjected to percutaneous cholecystostomy are high operative risks. A meta-analysis, which included 231 emergency and elective cases from the literature, reported a morbidity rate of 7.8%. Complications included bile leakage, catheter misplacement or dislodgment, vagal responses, hemobilia, an duodenal puncture. Mortality associated with percutaneous cholecystostomy catheter placement is reported to be 6-30%, a range which compares favorably with conventional approaches to acute cholecystitis in this difficult patient population.

Placement of Suprapubic Catheters

Certain situations including trauma and urethral obstruction require the surgical team to be familiar with techniques of suprapubic catheter placement. Ultrasound is already frequently used in the trauma setting and is readily applied to the problem of difficult bladder catheterization. Techniques of bladder intubation by this method are similar in principle to those defined above. The bladder is carefully imaged in two dimensions. Under sterile conditions, the skin, subcutaneous tissue and abdominal wall are infiltrated with local anesthesia at a point in the midline approximately 2-3 cm above the superior aspect of the pubic symphysis. At this point, catheter placement should not traverse the peritoneal space, as the path would lie below the anterior peritoneal reflection of the bladder. A needle is introduced in the midline at this point and is directed perpendicularly to the skin and into the bladder under real-time ultrasound guidance. Care must be taken to keep the tract vertical so that the catheter can enter the bladder directly through the anterior abdominal wall by the shortest possible route. Some urine is aspirated and sent for analysis as necessary, and a guidewire is passed through the needle and coiled in the bladder. The guidewire tract can be sequentially dilated until a catheter can be easily passed. The catheter should be secured in such a way that its tip is not so far advanced as to irritate the trigone of the bladder.

Summary

Ultrasonography, by virtue of its portability, ease of interpretation for certain indications, and its dynamic and repeatable nature, is becoming an indispensable tool to the surgeon for the guidance of emergency procedures in unstable and nonreadily transportable patient populations. It converts many previously “blind” procedures to the safety of excellent visualization, and when used by the surgical team offers a means of rapid deployment of therapy in potentially urgent situations. Ultrasound has already been widely embraced by surgeons and has been shown to be an accurate and cost-effective imaging modality in the setting of trauma. Teaching of diagnostic techniques has become a requirement of surgical education programs, and the extension of this knowledge to interventional techniques will be a powerful addition to the therapeutic armamentarium of surgeons.

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CHAPTER 11

Open Applications

Paul V. Gallagher, David Wherry and Richard Charnley

Introduction

The use of ultrasound during surgical procedures was first attempted in the 1960s. It was not until improvements in equipment and the introduction of special probes in the 1970s, however, that its use became more common. Intraoperative ultrasound (IOUS) is now widely used in many surgical specialties. This chapter concentrates on the use of intraoperative ultrasound in abdominal surgery where it is principally used to image the liver, biliary tree and pancreas. Despite improvements in technology, these organs can be difficult to image reliably in the preoperative stage. IOUS can complement preoperative imaging modalities and can influence decision-making during surgery, either by diagnosing unforeseen conditions or by identifying the extent of already diagnosed pathology, most commonly tumors. The use of IOUS is well established.[1] The principal advantage of IOUS is the ability to place the probe in direct contact with the organ being examined. Areas inaccessible to conventional ultrasound can be examined with better resolution. The problems of artifacts and poor image quality associated with transabdominal ultrasonography are largely overcome. IOUS, however, still requires an open operation to be performed. When laparoscopy was introduced, clinicians were quickly made aware of its advantages in reducing the morbidity of a surgical procedure. With the development of special ultrasound probes that could fit through a laparoscopic port, the potential uses of ultrasound during surgery increased. The use of laparoscopic ultrasound (LUS) at the time of laparoscopy has meant that an ultrasound transducer can be delivered to the abdominal organs which can then be examined in detail without resorting to an open operation, albeit without the added bonus of palpation. Laparoscopic ultrasound can be used in similar applications to IOUS. With the addition of color Doppler ultrasound a powerful combination has now been produced. LUS will further be discussed in Chapter 12. This chapter will focus on the general principal of ultrasound common to both techniques.

General Indications for Intraoperative Ultrasound

Ultrasound was originally introduced into the operating theatre as a noninvasive alternative to other imaging modalities, such as cholangiography and arteriography.[2] Its potential use as an aid to palpation then became apparent. Surgeons realized that they were not able to palpate the organs of the abdomen as accurately as they had previously thought. This is especially true for solid organs, such as the liver and the pancreas, as well as those organs that are increased in size due to pathological processes, such as tumors. The relationship of tumors to vital

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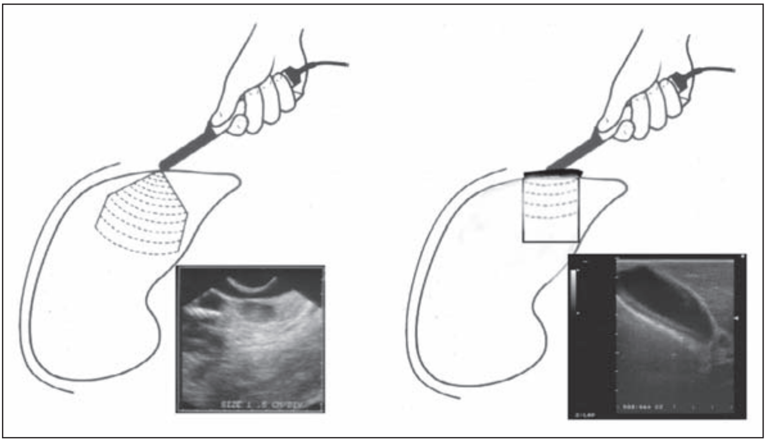

Figure 1. Ultrasound probes: Sector scanner (Bruel and Kjaer, Denmark), left. Linear array scanner, right.

structures is often difficult to determine at operation without extensive dissection but may be identified clearly by the use of intraoperative ultrasound. The presence and location of stones and strictures, particularly in the biliary tract and pancreatic duct can be confirmed, and this can reduce the need for cholangiography and pancreatography (see below).

Ultrasound Equipment for IOUS and LUS

For IOUS and LUS the intra-abdominal organs are usually examined by ultrasound transducers with frequencies ranging from 5 MHz to 7 MHz. There are two types of transducer. The sector scanner produces a wide field of view and is not so commonly used for intraoperative work. The linear array scanner produces a rectangular image (Fig. 1) and is probably more suited for examination of the solid organs of the abdomen by IOUS or LUS.

The linear array transducers are usually carried on a T-shaped or finger shaped probe for IOUS, both of which can easily be held in the examining hand (Fig. 2).

For LUS the transducer is usually carried on a long rod-like probe (Fig. 3) approximately 10 mm in diameter, which is then passed down a laparoscopic port. The laparoscopic probe may have a flexible tip which can allow the transducer to be moved to any position such as over the convex surface of the liver.

The color flow Doppler facility, available for IOUS and LUS, can measure blood flow and is particularly useful for the identification of vascular structures. This is a clear advantage, when one is examining the pancreas or liver, but use of the Doppler facility is technically more demanding and requires practice.

Many surgical units share ultrasound machines between departments so that the cost is shared. However, busy units, particularly those undertaking hepatobiliary and pancreatic procedures, are likely to require a dedicated ultrasound machine in the operating room since ultrasound is used during most of these operations. Smaller, portable machines are useful, but tend to have poorer image quality, and may not have a Doppler facility.

Figure 2. T-shaped IOUS probe on liver (Aloka).

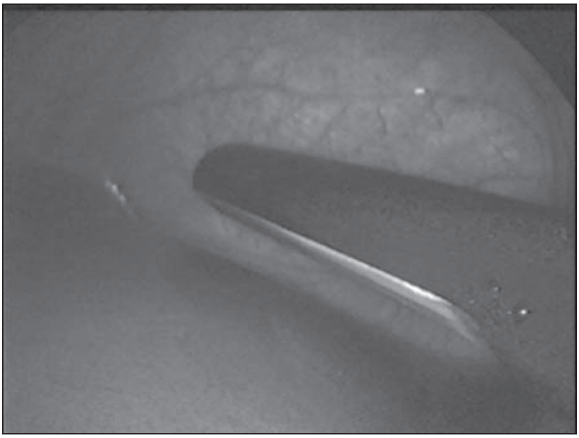

Figure 3. Laparoscopic probe (Aloka) above liver.

The Scope of Operative Ultrasound

The scope of ultrasound is dependent upon the tissue penetration of the sound waves and the resolution of the technique. If increased depth of tissue penetration is important as it is with external ultrasound, a lower frequency transducer must be used but this will result in poorer resolution. Using a higher frequency transducer increases resolution but tissue penetration is reduced. Placing a probe on the surface of an organ (known as contact ultrasound) means less tissue penetration is required and so a higher resolution transducer may be used. For instance, a 7 MHz transducer is appropriate for contact ultrasound of the liver where tissue penetration up to a depth of 6-8 cm is possible. External ultrasound of the liver commonly employs a 3.5 MHz transducer for greater penetration through subcutaneous tissues. In fat patients the structures of interest are even farther away from the probe limiting the accuracy in this group of patients. External ultrasound of the upper abdomen is also hampered by reduced access to the liver between the ribs. Overlying bowel gas may inhibit visualization of upper abdominal organs particularly the pancreas and distal bile duct. During open or laparoscopic surgery the appropriate ultrasound probe can be easily placed on the intra-abdominal organs unless they are surrounded by adhesions. It is not usually necessary to lubricate the probe but if the surface of the organ is irregular such as with a cirrhotic liver, it may be necessary to instill some sterile de-gassed water to improve tissue contact.

External abdominal ultrasound can provide an overall picture of the structures within the upper abdomen, such as the relationships of tumors to the major vessels. This overview may be lost when examining the patient by IOUS or LUS because of the close proximity to the organs. As experience is gained however, the operator can move the probe to build up a wider view of the upper abdomen. Lesions may also be missed by intraoperative ultrasound but these tend to be surface lesions such as small metastases on the liver capsule, which can usually be identified by palpation.

Intraoperative Ultrasound of the Liver

The indications for IOUS of the liver are shown in Table 1. The most important is as an aid during liver resection in demonstrating the extent of malignant disease in terms of the number of lesions, precise segmental location and relationships to intrahepatic vascular structures. At present the majority of liver operations are done at open surgery but there has been recent enthusiasm for laparoscopic liver resection. Planning laparoscopic liver resection is likely to become a new role for LUS.

Examining the Liver by IOUS—Technique

This following section on IOUS of the liver also applies to LUS of the liver with some subtle differences which are outlined at the end of this section. Prior to a liver resection the IOUS examination will be done at the start of the operation to fully assess the liver, and in this case full exposure of the liver will provide superb access for IOUS. During surgery for colorectal cancer, a lower abdominal incision may restrict surgical exposure to the lower abdomen, and the IOUS probe may have to be passed up under the abdominal wall onto the liver. Our experience is that this does not compromise access, and with care the ultrasound probe may be passed around the upper border of the liver, under the rib cage from a lower abdominal incision. The ultrasound examination is preceded by systematic and thorough palpation of the liver, anteriorly and posteriorly on both lobes, not forgetting the

Table 1. Indications for IOUS during liver surgery

- Identification of the full extent of a primary or metastatic tumor at the time of resection
- Identification of previously undetected lesions during liver surgery or during surgery for gastrointestinal cancer
- Differentiation of benign lesions from tumors
- Identification of involvement of intrahepatic ducts by cholangiocarcinoma
- Intraoperative insertion of transhepatic biliary drainage catheter
- Identification of extent of liver abscess

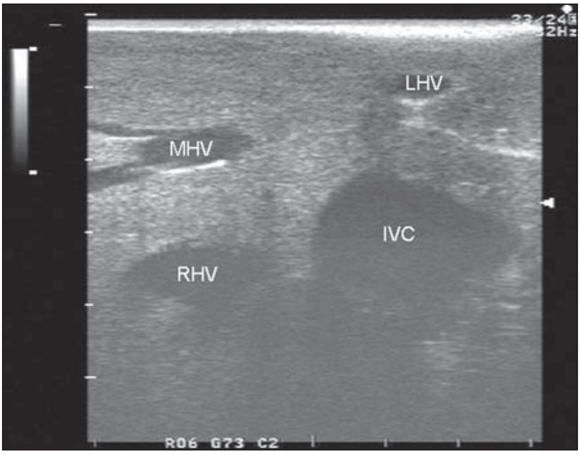

Figure 4. Transverse section at root of hepatic veins. IVC = inferior vena cava; RHV = right hepatic vein; MHV = middle hepatic vein; LHV = left hepatic vein.

caudate lobe. Extrahepatic structures including the portal and celiac regions are also palpated within the confines of the available access. The ultrasound probe is then placed on the anterior surface of the liver and the liver is fully examined. Detailed knowledge of the hepatic segmental anatomy is essential. The liver substance is crossed by a multitude of major and minor veins and portal structures. By identifying the larger structures and using these landmarks, the architecture of the liver can be successfully navigated. Practice is required to equate the three dimensional movements of the hand and probe with the two dimensional image on the ultrasound screen. There are three important sonographic images. Each has a black lumen with a wall of varying thickness. Firstly, the hepatic veins radiate from the center of the liver in a horizontal plane. They are thin-walled and may exhibit a transmitted pulsation (Fig. 4). Secondly, the portal structures may be visible as a triad. They are surrounded by a supporting cuff of hyperechoic connective tissue (Fig. 5). The portal structures radiate from the center of the liver in a vertical plane, somewhat perpendicular to the hepatic veins. Therefore, if a hepatic vein is seen in a longitudinal plane on the ultrasound screen, the portal structures are seen transversely (Fig. 6). Finally the gallbladder is usually obviously seen when the probe is lying over it, but may appear in the image if the liver is scanned from other directions and be mistaken for a vessel if the plane of the scan only partially transects the gallbladder lumen. It should be identified by its characteristic shape and the layers of its wall (Fig. 7).

It is important to use a systematic plan of examination to ensure no area of the liver is missed. The examination starts at the superior aspect of the liver where the inferior cava is joined by the three hepatic veins. The hepatic veins divide the liver into its sectors. (For a detailed description of hepatic anatomy the reader should refer to a specialized text of liver surgery[3]). The liver substance of the right posterior sector, which is posterior to the right hepatic vein (segments 6 and 7), is examined followed by the right anterior sector (segments 5 and 8), then segment 4 of the left lobe followed by segments 2 and 3. Finally the caudate lobe is scanned. Each part of

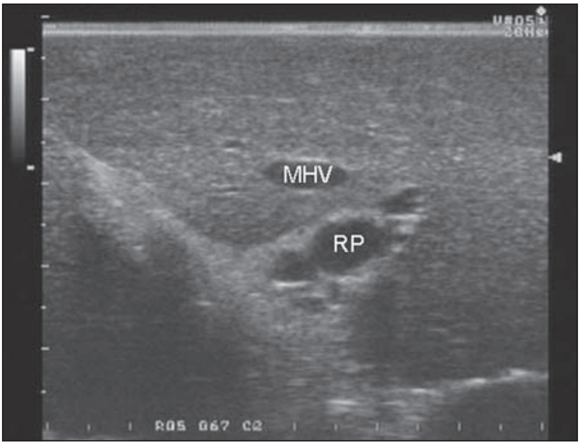

Figure 5. Right portal triad (RP) with middle hepatic vein (MHV).

the liver is scanned from anterior and posterior surfaces although this may at first be confusing since a scan performed from one angle may look very different from the opposite surface of the liver, with structures appearing inverted (Fig. 8). Systematic examination ensures that no part of the liver is overlooked (See below under "Pitfalls of IOUS of the liver").

Examination of the liver by LUS is carried out in the same fashion as at open surgery, but it is not so easy to move the probe around the liver as when the abdomen is open because the positions of the ports are fixed. It is common practice to examine the liver using two laparoscopic ports, normally one port at the umbilicus

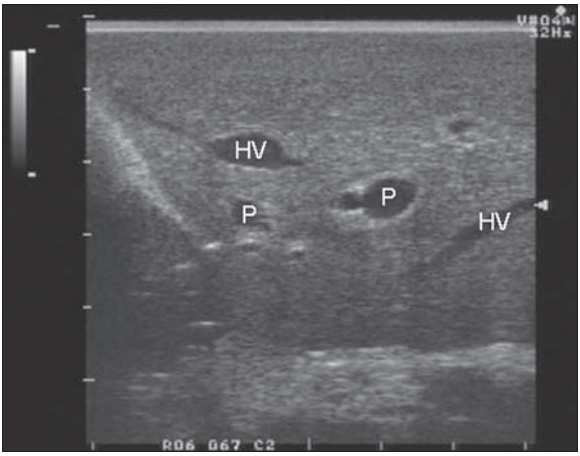

Figure 6. Hepatic vein tributaries (HV) and portal triads (P).

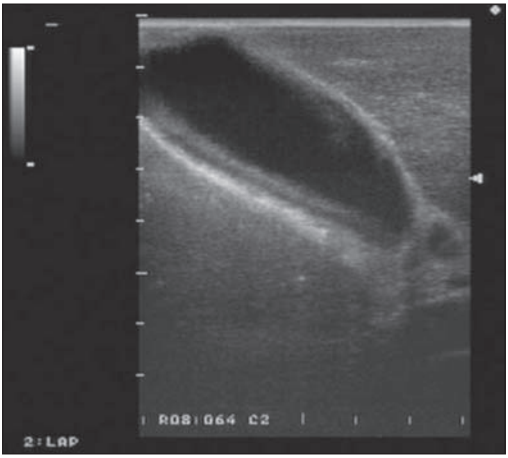

Figure 7. Gallbladder.

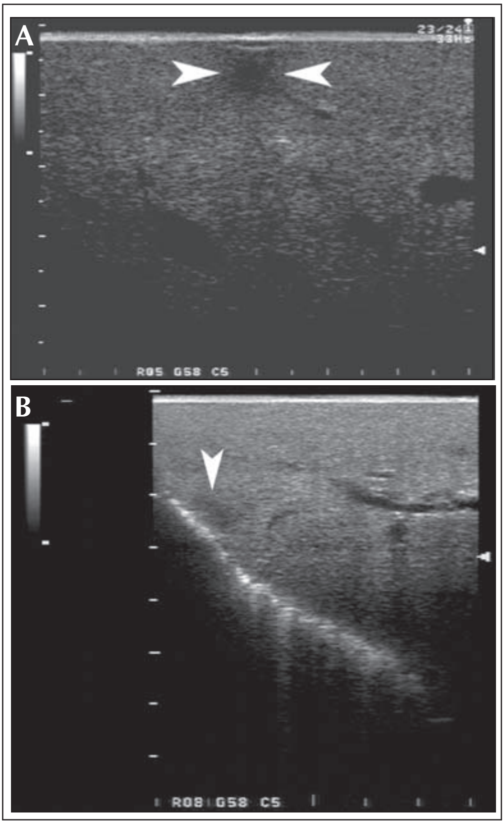

Figure 8. A) Small metastasis viewed from superior surface of liver and, B) the same lesion from the inferior surface.

and another in the right or left upper abdomen. Ports at all three positions may be necessary. A laparoscopic probe with a flexible tip facilitates a fuller examination of the liver. A degree of coordination is required with LUS. Although an image mixer can bring the two images closer together, the laparoscopic picture and the ultrasound image have to be viewed at the same time. As with IOUS a full methodical examination of the liver is carried out at laparoscopy using a segmental approach to the anatomy to ensure that all parts of the liver substance are fully examined.

IOUS of the Liver—Identification of Lesions

Liver lesions usually appear as spherical objects in the liver substance. They may be brighter than the surrounding liver substance (hyperechoic) the same brightness as the surrounding liver substance (isoechoic) or less bright than the surrounding liver (hypoechoic). Cysts appear as round black holes in the liver with a thin (usually invisible) wall (Fig. 9). Liver abscesses also appear as hypoechoic lesions in the liver, but they are not so uniformly dark and the edges are poorly demarcated. Haemangiomas (Fig. 10) are seen as uniformly bright lesions with little internal structure until they become large. Metastases (Fig. 11) may be of any echogenicity

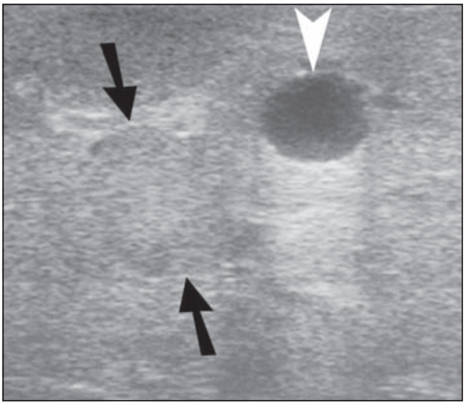

Figure 9. IOUS of cyst (white arrow) and liver metastasis (black arrows).

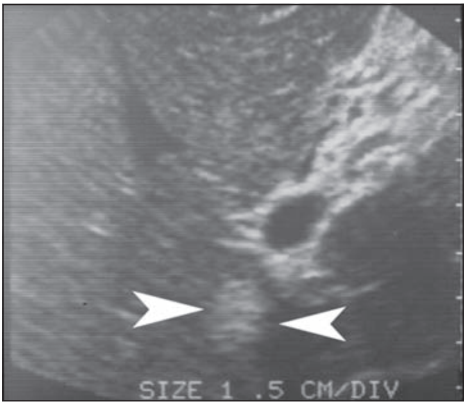

Figure 10. IOUS of a small hepatic haemagioma (arrows) close to the liver hilum.

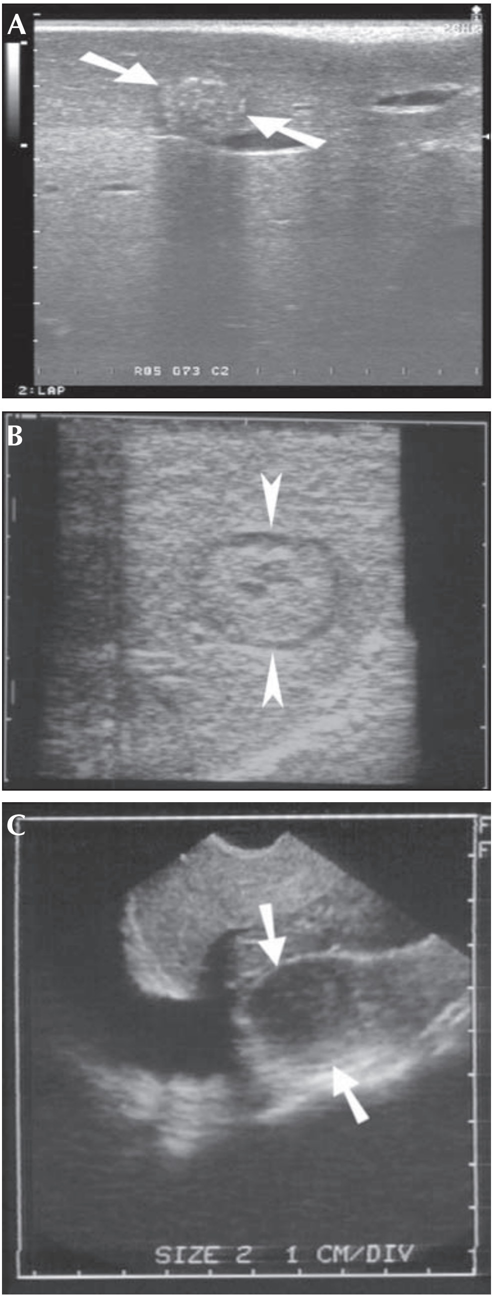

Figure 11. Liver metastases (arrowed); A) hyperechoic metastasis casting acoustic shadow, B) isoechoic metastasis showing target appearance, C) hypoechoic metastasis in the caudate lobe.

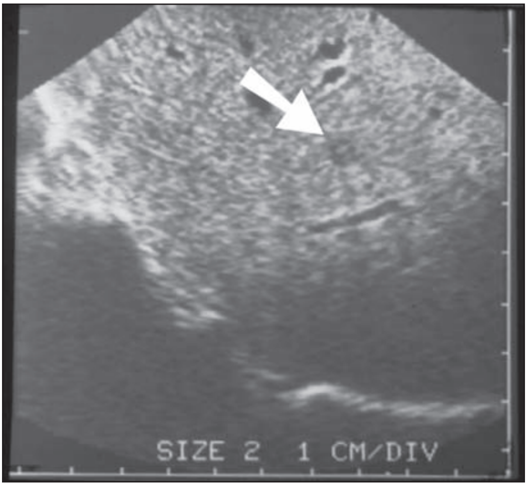

Figure 12. Small liver metastasis, 4 mm in diameter.

but characteristically exhibit a target appearance that is caused by the outer rim of neovascularisation and the inner core of necrosis. Although they begin as spherical lesions, their edges become irregular as they grow larger. Primary liver tumors have more irregular margins, even when small. As they enlarge they become even more irregular and heterogeneous and may be associated with large vessels.

During the examination the characteristics of all lesions are noted. Once a liver lesion is found, its segmental position is confirmed by determining its relationship to major hepatic vessels and portal branches. All lesions are scanned from different angles to gain maximum information about position and relationships to other structures. Lesions as small as 3-4 mm in diameter can be identified and characterized (Fig. 12).

The early publications on intraoperative ultrasound demonstrated the improvements in resolution, which could be obtained by the use of this technique compared to standard imaging methods.[4] There has been little further improvement in the resolution of intraoperative ultrasound over the last 10 years. Most recent publications on the use of spiral computerized topography (CT) and magnetic resonance imaging (MRI), however, have suggested that these axial imaging techniques may also now be approaching the resolution obtained by intraoperative ultrasound. Schmidt et al compared IOUS with CT arterioportography (CTAP).[5] Both had a similar sensitivity (100% vs. 98%) with IOUS having a greater specificity than CTAP (95% vs. 68%). IOUS also compares favorably with MRI. In a recent retrospective study IOUS was estimated to have changed management in only 5% of patients who had a preoperative MRI scan.[6] Currently, preoperative and intraoperative imaging play a complimentary rather than a mutually exclusive role.

Clearly, intraoperative ultrasound is only going to be used if the patient is having an open operation anyway. However, if a patient with malignancy is having surgery for a primary gastrointestinal tumor, it has been suggested that patients should undergo intraoperative ultrasound of the liver at the same time, and this seems particularly appropriate for patients with colorectal cancer where resection of liver metastases may improve patients' prognosis. Laparoscopic ultrasound has a clear advantage in staging these patients because full laparotomy is not necessary and may also be appropriate in patients undergoing laparoscopic colorectal resection.[7]

Examination of the Liver As Part of Resectional Liver Surgery

It is vital during liver resection to be aware of the numbers and characters of lesions and to know the relationships of each lesion to vascular structures and their precise segmental location within the liver. Additional lesions are also sought by a full examination of the liver substance. Each detected lesion is carefully examined from every angle. Particular attention is paid to ensuring that there are no detectable lesions within the part of the liver that is not being resected. The area of the potential resection margin is also carefully examined to ensure that all lesions are well clear of it. Once this has been done the resection can proceed according to the number and distribution of lesions. Routine use of IOUS is associated with an increased incidence of negative surgical margins.[8] For a segmental resection IOUS is used to note the surface markings of the segments according to the position of the hepatic veins and portal trunks. During the resection, intraoperative ultrasound should be used to check on the position of the resection plane and to check the position of portal structures and/or veins which the surgeon is hoping to preserve. This is particularly important in an extensive resection when only two or three segments may remain. Each segment must be supplied by an adequate portal inflow and adequately drained by hepatic veins.

Pitfalls of Intraoperative Ultrasound of the Liver

As alluded to earlier, the main difficulties arise if the liver is not fully mobilized resulting in parts of the liver being missed by the examination. If the procedure is being carried out during surgery for a colorectal primary cancer, then mobilization of the liver is not appropriate. However, if the procedure is being carried out as part of a liver operation then full mobilization of the liver is essential. Despite these precautions, small lesions close to the surface of the liver may still be missed. However, any lesion, which is missed by intraoperative ultrasound and is close to the surface, may be palpable, and it is important to palpate the liver carefully in every case, not missing any area of the liver surface. There are two parts of the liver where more care is required to ensure lesions are not missed. These are the caudate lobe and the posterior aspect of the right lobe, particularly that part of the right lobe close to the inferior vena cava where the liver is deep and tissue penetration by ultrasound may be reduced. Lesions here are also easily missed by LUS. The caudate lobe may need to be accessed laparoscopically by opening the lesser peritoneal sac through the lesser omentum. It is more difficult to ensure complete examination of the right lobe by LUS than it is by IOUS because of difficulty in positioning the tip of the probe posterior and lateral to the liver. However a careful approach ensures as complete an examination as possible.

Other Indications for IOUS of the Liver

There are numerous other indications for IOUS during liver surgery. If open drainage of liver abscesses is necessary, IOUS is useful to ensure complete drainage. Liver biopsy of lesions may be carried out under IOUS guidance although this is not recommended with resectable lesions since biopsy may result in dissemination of tumors within the peritoneal cavity.[9] IOUS is used in ablational techniques such as cryotherapy[10] and radiofrequency ablation.[11] Its use has also been described with laser hyperthermia,[12] but is less helpful in monitoring tissue destruction as with

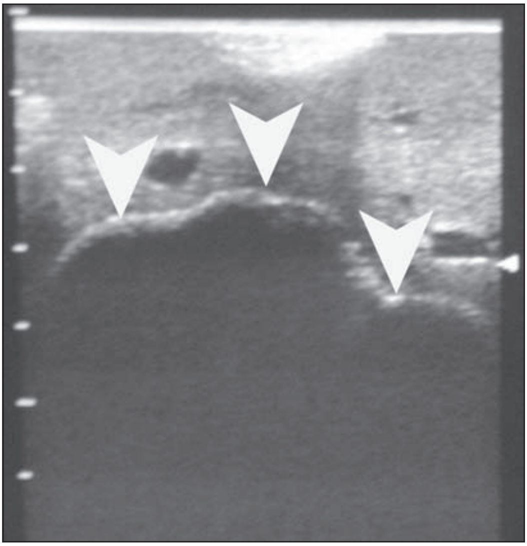

Figure 13. Edge of cryotherapy iceball (white arrows).

other techniques.[13] Monitoring of the size of the cryotherapy iceball is necessary to ensure destruction of the tumor. IOUS provides the necessary accuracy to ensure this.[14,15] Figure 13 shows the development of an iceball by cryotherapy that obliterates a tumor. It is also possible to perform cryotherapy laparoscopically, and again this can be monitored by laparoscopic ultrasound.[16] These techniques are also used with radiofrequency ablation of tumors.[17]

IOUS and LUS may also be used in the assessment of patients with hilar cholangiocarcinoma. The infiltrating edge of the tumor is often difficult to visualize, but it is easier to assess patients prior to biliary decompression.[18] Intraoperative transhepatic cholangiography is a technique that has been used to investigate the cause and level of biliary obstruction at open surgery, particularly in patients with hilar cholangiocarcinoma. The distribution of the dilated ducts is initially mapped out by IOUS. One or more transhepatic cholangiography catheters are then placed into the dilated bile ducts above the stricture to outline the top end of the stricture and confirm the precise position of the resection margins prior to surgical resection, which usually involves hepatectomy as well as hilar resection.[19]

IOUS is now commonly used during liver transplantation. It is particularly useful to record a positive Doppler reading from both branches of the hepatic artery and portal vein at the end of the procedure since technical problems may occur which can result in reduction in flow and so compromise hepatic perfusion.[20] IOUS is also used in live donor liver transplantation to confirm portal and hepatic venous anatomy.[21]

Intraoperative Ultrasound of the Pancreas

The pancreas, like the liver, is a solid organ, and palpation is generally an inaccurate method of identifying pancreatic pathology. Table 2 highlights the uses of IOUS during pancreatic surgery. At operation it may be difficult to differentiate chronic pancreatitis from pancreatic cancer particularly in patients with a mass in the head

Table 2. Uses of IOUS in pancreatic surgery

- Identification of vascular involvement by tumors
- Identification of small neuroendocrine tumors
- Extent of cyst formation and pancreatic duct dilatation in chronic pancreatitis
- Differentiating cysts from solid nodules
- Identifying the main pancreatic duct for drainage procedures
- Identification of venous thrombosis

of the pancreas. Because an inflammatory mass may have similar ultrasound appearances to a neoplastic mass, IOUS is not usually an accurate modality in distinguishing benign from malignant pancreatic masses.[22] Evidence of vascular involvement by tumors can however be identified clearly and may be an indication of unresectability. In many centers patients with pancreatic cancer undergo staging laparoscopy, including laparoscopic ultrasound, prior to surgical resection. The findings of metastases (usually peritoneal or small liver metastases missed on axial imaging) would render a patient unresectable and an unnecessary laparotomy may be avoided. Initial studies showed a clear benefit to this approach[23] but a larger study from Amsterdam[24] has suggested that the benefit of staging laparoscopy with LUS is marginal and restricted to approximately 15% of patients. Whereas peritoneal and liver metastases can be easily biopsied at laparoscopy, suspicious lymph nodes identified by laparoscopic ultrasound are more difficult to biopsy.

Insulinomas may be difficult to identify preoperatively and may also be missed by palpation. Insulinomas appear very clearly on IOUS as hypoechoic lesions (Fig. 14), and for this reason it is very important to have IOUS available for insulinoma surgery as clearly shown in several studies.[25-27]

Other types of neuroendocrine tumors within the pancreas are also easily identified by IOUS.[28] Lesions outside the pancreas, for instance, small gastrinomas in the

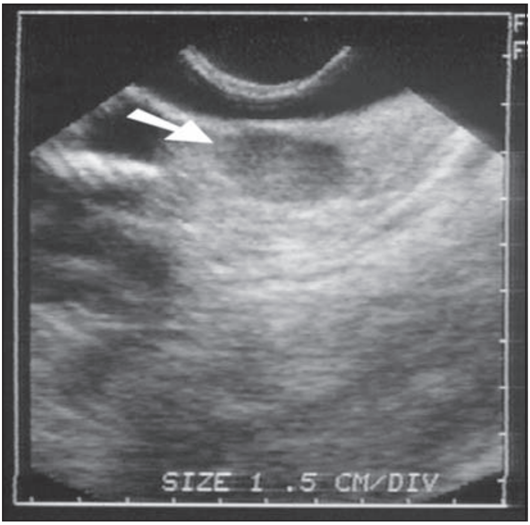

Figure 14. Insulinoma within body of pancreas.

wall of the duodenum are less easily detected by IOUS. Endoscopic ultrasound is the most useful technique in identifying lesions related to the wall of the stomach or duodenum.

In patients with chronic pancreatitis, preoperative imaging of the pancreas is achieved by a combination of external ultrasound, CT, MR, endoscopic ultrasound and ERCP. Despite the use of these valuable tests, it may be difficult to identify the full extent of the chronic pancreatitic process at operation. By using IOUS the extent of cyst formation and pancreatic duct dilatation may be clarified. The position of stones within ducts and within the parenchyma can also be clearly identified. The degree of portal and mesenteric vein thrombosis and the presence of collateral veins around the pancreas can be seen.

Technique of Examining the Pancreas by Intraoperative Ultrasound

The whole pancreas can usually be examined without exposing the organ completely. To examine the head of the pancreas, the probe is placed on the surface of the duodenum and the pancreas scanned through the duodenum. The uncinate process is more clearly seen with the probe in the infracolic position close to the superior mesenteric artery. The neck, body and tail of the pancreas are scanned by placing the probe over the greater curve of the stomach and scanning through the stomach. The normal caliber pancreatic duct is clearly seen, even more so if it is dilated. The superior mesenteric vein, portal vein and superior mesenteric artery and their relationships to the head of the pancreas and to any tumors are noted. Infiltration into these structures should be carefully sought since this may affect the extent of the pancreatic resection required to clear the tumor. Pancreatic adenocarcinomas usually appear as hypoechoic mass lesions with infiltrating margins. Invasion of a vessel in its early stages is usually seen as loss of the fat plane between the tumor and the vessel. As invasion of a vessel becomes more pronounced constriction of the lumen or tumor within the lumen of the vessel may be seen. Enlarged lymph nodes are clearly seen. Metastatic nodes are often hypoechoic and spherical whereas reactive nodes are more likely to be isoechoic and oval in shape. A plan for IOUS during surgery for pancreatic carcinoma is shown in Table 3.

Laparoscopic ultrasound of the pancreas is achieved by a two port approach. The camera is usually inserted at the umbilicus followed by insertion of the laparoscopic ultrasound probe in the left upper quadrant of the abdomen (some surgeons use umbilicus and right upper quadrant or even a three port approach). The laparoscopic probe is passed over the liver to look for metastases and to view the liver hilum. The tip of the probe is then placed over the duodenum and the head of the pancreas is examined. The probe is then passed over the left pancreas to examine the body and tail and the coeliac nodes are also examined. The operating table is then tilted head-down and the infracolic compartment is inspected visually particularly around

Table 3. IOUS during surgery for pancreatic cancer

- Appearance of primary tumor
- Vascular invasion (portal vein, superior mesenteric vein and superior mesenteric artery (SMA))
- Lymph nodes (portal, coeliac and SMA nodes)
- Liver metastases

the small bowel mesentery and duodeno-jejunal flexure where tumor infiltration may be seen. The tumor is then scanned from inferiorly with the laparoscopic probe placed across the uncinate process and superior mesenteric artery.

IOUS and LUS during Cholecystectomy

When imaging is required, intraoperative cholangiography has been the traditional modality used during cholecystectomy. The technique was adapted with the arrival of the laparoscopic era and the whole of the biliary tract may be examined with an accuracy rate of over 90%. Intraoperative cholangiography has the advantage of accurately imaging the whole biliary tract, and in addition, stones may be extracted laparoscopically, particularly by the transcystic route. The technique, however, requires a certain amount of expertise and results in radiation exposure, which does not occur with IOUS. During the open cholecystectomy era, the technique of biliary IOUS was introduced as early as the 1960s[29] and perfected by Jakimowicz amongst others. The technique is simple to perform. The IOUS probe is placed on the surface of the liver overlying the hilum and then is moved caudally and medially so that the common bile duct is scanned. Any duct dilatation or filling defects can be clearly identified. The position of the junction with the cystic duct can also be seen and with practice major duct anomalies can be identified although minor anomalies are likely to be missed. IOUS has been shown to compare very favorably with operative cholangiography in the identification of common bile duct stones.[30] Now that cholecystectomy is a laparoscopic operation, LUS has also been introduced as an alternative to laparoscopic cholangiography. When used in experienced hands LUS compares favorably with intraoperative cholangiography.[31,32] The principal advantage of LUS is the unlimited repetition of examinations. It is also quick to perform. Although common bile duct exploration can also be carried out under LUS control, this is a difficult technique and laparoscopic common bile duct exploration is easier under X-ray control. LUS is unlikely to be of benefit in recognizing bile duct injuries but may have the advantage that it may be possible to identify an incidental gallbladder carcinoma.[33] This would allow abandonment of the procedure or conversion to an open, curative procedure.

Other Indications of Intraoperative Ultrasound

The use of ultrasound has been described in many different fields of abdominal surgery. LUS in combination with laparoscopy decreases the number of patients undergoing unnecessary surgical procedures for upper gastrointestinal tumors. Small colonic tumors may be difficult to palpate at open surgery, IOUS can confirm their position. In renal surgery IOUS can facilitate nephron-sparing techniques in renal cancer management and in laparoscopic marsupialization of renal cysts. During surgery for adrenal masses, ultrasound is of use in determining the nature of the lesion prior to resection.

Summary

The use and scope of ultrasound during surgical procedures has dramatically increased, particularly in the last decade. Its use in hepatobiliary and pancreatic surgery has improved the intraoperative diagnosis and staging of tumors such that it is now a standard part of these operations. A wider dissemination of the techniques involved, coupled with improvements in technology, has allowed a broader group of specialties to employ intraoperative imaging. In the future its use is certain to expand. The laparoscopic revolution has brought great benefits to patients and driven the increase in laparoscopically performed procedures. The sense of touch is of necessity sacrificed, but ultrasound can in part act as a substitute to palpation during laparoscopy. Staging of tumors by IOUS and LUS is likely to become more commonplace.

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CHAPTER 12

Laparoscopic Applications

Raj R. Gandhi

Introduction

Laparoscopic ultrasound was first described in 1958. At that time, there was only A-mode ultrasound, and this technology was used to image intra-abdominal organs. In 1964 the imaging of the upper abdomen was described, and in 1972 imaging of the pelvis was described. These images were not of high resolution and use was limited until miniaturization of the electronics evolved. B-mode laparoscopic ultrasound was introduced in 1984. Use of ultrasound in laparoscopic procedures increased in the 1990s with the explosion in laparoscopic techniques. This expansion of surgical technique with refinements in real-time B-mode ultrasound equipment led to a marriage of ultrasound and laparoscopy. The introduction of laparoscopic ultrasound (LUS) was in laparoscopic cholecystectomy and was used to examine the bile ducts. This technique was then expanded to check the extent of tumors.

The most common use of LUS is in tumors of the biliary tract, liver and pancreas. This tool can also be used for other solid organ neoplasms. The sensitivity, specificity and overall accuracy of intraoperative ultrasound is about 94%. Note that the sensitivity of LUS is better than that of a trained surgeon to check for masses in the liver or pancreas.

The role of LUS has been expanded over time. LUS is used in adrenalectomy to localize tumor and the adrenal vein. Hepatic tumors have been localized by LUS and then ablated with radio-frequency thermal ablation. Ureters have been followed by LUS in hysterectomies. Pelvic lymphadenectomy has been done with LUS.

Indications for Use of LUS

LUS is indicated for staging of abdominal tumors prior to open laparotomy. Unresectability can be determined laparoscopically with the use of LUS. Patients may be spared the unwarranted celiotomy. The sensitivity of LUS is greater than that of the surgeon hands for small tumors of 5 mm round in size. In addition, LUS can detect tumor invasion of adjoining structures and vascular invasion. LUS can be used with laparoscopic liver biopsy to localize the appropriate masses for biopsy. LUS has been used in pelvic lymphadenectomy as well as liver and pancreas neoplasm surgery.

Instruments

The small parts scanner ultrasound system uses ultrasound at higher frequencies thus providing higher resolution but less penetration of tissue. The frequencies range from 3.5 to 20 MHz. Color and spectral Doppler imaging systems are available. Typically lesions of 3-5 mm in size can be found with this system. LUS probes are generally 10 mm diameter shafts that are 40 to 70 cm in length. There are rigid and flexible shafts available. The rigid shafts have a 20 mm linear array ultrasound panel

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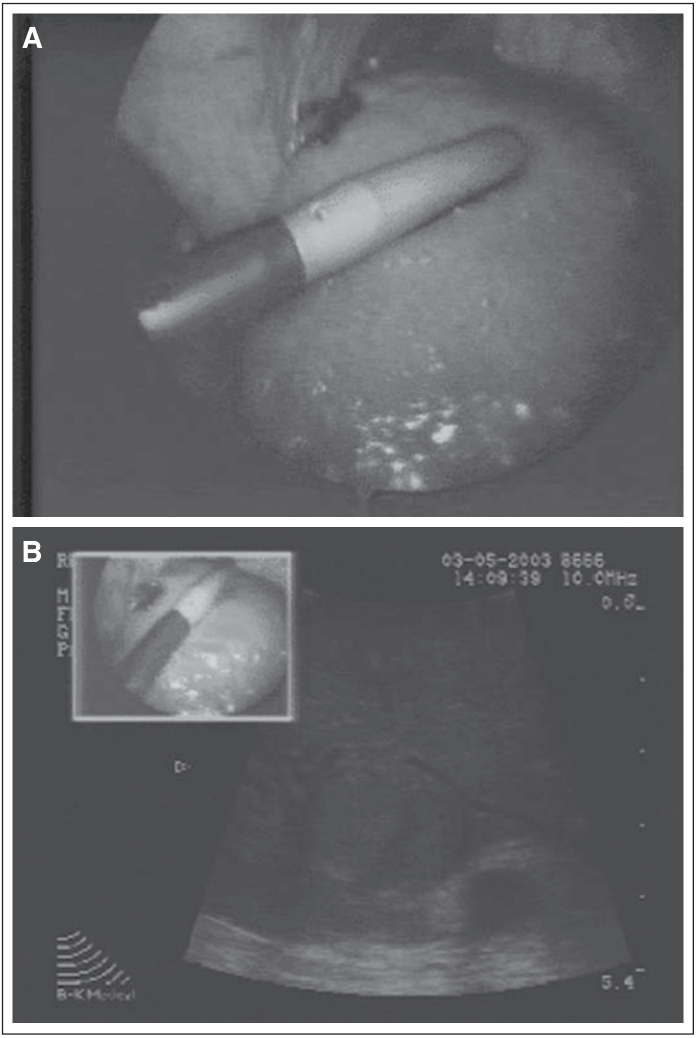

Figure 1. Laparoscopic probe (Aloka) above liver (A) and the associated ultrasound view (B). Images courtesy of Shea Gregg, M.D., Yale University and David Tannitti, M.D., Brown University.

at the very distal end. The flexible probes have both bi-directional and quad-directional configurations. The shafts go through 10-12 mm laparoscopic ports. The transducers available are linear-array, convex, or sector transducers. The probes are front-viewing or side-viewing. Front-viewing can be used to scan extrahepatic bile duct or pancreas. A side-viewing linear-array or convex probe is needed to scan the liver (Fig. 1).

Techniques

The LUS setup consists of the ultrasound machine and the probes. The machine cannot always be controlled by OR personnel that are operating. Thus one person needs to be available to maneuver the machine. The probe can be managed by the people on the operating field. Color Doppler modality can be used to differentiate between vessels and lymph nodes during LUS.

There are two essential parts to actually doing LUS scanning. The first is probe placement. The second is probe movement. The most common probe placement technique in LUS is contact scanning. This technique involves placing the probe directly on the tissue or organ of interest. The other technique is called probe-stand-off scanning in which the probe is place 1 cm away from the object of interest. The abdomen is filled with saline to help visualize the structures of interest.

Probe movement is the scanning of the target lesion from different positions in an organized fashion. The three probe movements are lateral, rotation, and angulation. Lateral movement is the simple movement of a direct contact probe from one side of the organ to another. Rotation refers to the clockwise or counter-clockwise rotation of the probe. Angulation has to do with the shaft of the probe being moved to differing areas and the transducer maintained over the same area. The paths of these probe movements maybe longitudinal (up and down), transverse (side-to-side) and oblique (diagonal).

The trocar sites for LUS is one of the most important aspects to LUS. The site has to be one that allows the probes to go to the desired areas. The trocar and probe should be placed so as to allow a parallel position to the organ of interest. Placement of trocars are thus individual and templates can lead to problems. Irrigation fluid may be used as a transmission medium. A 1-2 mm layer of fluid helps with transmission.

LUS: Specific Techniques and Applications

Liver

The 5.0 to 7.5 MHz probes have been found to be the most optimum for liver scanning. The liver is scanned in the following manner: first the flat probe is placed directly over the anterior surface of the liver. The surface is scanned posteriorly under the diaphragm. The posterior segment of the right lobe is examined by scanning inferiorly by lifting the anterior surface of the liver. Next, the hilum is found and the hepatic arteries and intrahepatic bile ducts are traced peripherally. The vena cava is found and the three main hepatic veins are followed peripherally. Thus, the segmental blood supply is identified for segmented resection. Finally, the entire liver is examined using lateral movement of the LUS probe.

Examination of the liver with LUS enables the surgeon to determine the extent of tumor. Vascular invasion and lymph node invasion may be imagined with LUS. This information can be used to plan the operative approach and resection. In some cases, a full laparotomy may be avoided due to the extent of tumor. Tumor identification can be done by use of LUS during biopsy to localize potential areas of tumor. Unresectable tumors may have radiofrequency thermal ablation, cryoablation or ethanol injection with LUS guidance.

Pancreas

The pancreas is best visualized through the lesser sac. Since the pancreas is posterior to the stomach, omentum, or mesocolon, visualization through these areas is also possible. The 5.0 to 7.5 MHz probes are useful for imaging this area. The entire pancreas can be visualized using longitudinal and transverse scanning with direct contact of the probe. The pancreatic head, uncinate process, main pancreatic duct and intrapancreatic bile duct can be seen by placing the probe on the right lateral or anterolateral side. Probe-standoff technique can also be used to visualize the superficial and deep portions of the pancreas.

LUS can be used to evaluate and localize masses, both solid and cystic, in the pancreas. Major vascular invasion or lymph node metastasis can also be found by LUS in this setting. Both needle insertion and biopsy may be done under LUS guidance.

Adrenal Glands

To image the adrenal gland, direct contact of the probe with the adrenal gland is needed. The adrenal gland is found superior to the kidney. The probe is placed in a position directly in line with the superior pole of the kidney. Both angulation and small transverse movement establishes the tumor extent over the adrenal gland. The adrenal vein is found inferiorly from the lateral or posterior vena cava. The advantage of LUS for adrenal vein localization is in identifying this structure among the retroperitoneal fat.

LUS of the adrenal gland can help distinquish the extent of tumor. Using LUS, dissection of the adrenal gland is less difficult. The extent of tumor is imaged with LUS. This imaging is helpful for pheochromocytomas also. Clipping of the adrenal vein may be done with LUS guidance. This technique is especially useful for clipping the left adrenal vein.

Gynecologic Surgery

LUS has been helpful in gynecologic laparoscopic surgery. LUS can image ovarian pathology well including endometriomas, cysts, or dermoids. The ovarian cysts can be viewed for papillation and septations. Uterine pathology is imaged for myomas, fibroids, and even uterine adhesions for lysis. The masses can be localized well with LUS. LUS has been used to assist in procedures to remove masses but this use has not been proven to be as beneficial as in the abdominal organs.

Other

Use of LUS in general laparoscopic evaluation of tumor is helpful. This role is important in staging lower esophageal and gastric cancers. Extensions of these tumors to adjacent tissue as well as to lymph nodes has been seen by LUS, Pelvic lymph node localization and dissection has been reported.

Future

With the increased use of laparoscopy in both general surgery and gynecology, it is easy to see that there will be an increase in the use of LUS. The technology continues to improve thus making it a modality almost anyone can learn and apply to everyday situations. With more sophisticated computer programs, there will be 3-dimentional component to ultrasound in the not too distant future.

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Breast Ultrasound

Sheryl Gabram and Nicos Labropoulos

Introduction

About 180,000 women will be diagnosed with invasive breast cancer on an annual basis in the United States and another 25,000 with ductal carcinoma in situ. The annual incidence increased over a forty-year interval from the 1950s to the early 1990s and recently has been plateauing. Breast cancer is currently the most common cancer in women, and overall survival has improved over the past decade because of earlier detection and improved treatment modalities.

Trends in treatment for undiagnosed nodules and breast cancer patients include: minimally invasive biopsy, breast conservation surgery, sentinel node biopsy, immediate reconstruction following mastectomy, genetic counseling/testing with emphasis on enhanced screening, chemoprevention or prophylactic mastectomy. Ultrasound provides a useful modality for many of these treatment trends as they evolve in breast care.

Historically, the role of breast ultrasound was to document whether a patient had a solid or cystic breast mass. Currently many uses for breast ultrasound exist and they include:[1]

- Evaluation of patients with palpable discrete and palpable non discrete “nodular” lesions.
- Minimally invasive biopsy of nonpalpable breast lesions
- Needle localization (either preoperative or intraoperative) for patients with nonpalpable breast masses undergoing breast conservation surgery
- Enhanced screening in young patient population with dense breast tissue (for targeted areas of concern)
- Evaluation of palpable or nonpalpable lesions on clinical or mammography screening to determine need for biopsy
- Evaluation of breast masses during pregnancy
- Evaluation of symptomatic breast implants
- Evaluation of patients with nipple discharge
- Percutaneous drainage of breast abscess or collection
- Postoperative insertion of brachtherapy balloon type catheters
- Radiofrequency ablation of tumors (preliminary work)

Biopsy Types

It is important to understand the role of ultrasound biopsy in the context of all breast biopsies that are performed. The methods of “visualization” as well as the “collection” device are useful ways to categorize different biopsies. Breast lesions are palpable (usually seen on mammography and/or ultrasound). Even when palpable, a lesion may be discrete or nondiscrete (nodular density).

Ultrasound for Surgeons, edited by Heidi L. Frankel.

The current radiological BI-RADS (Breast Imaging Reporting and Data System) classification of lesions developed by the American College of Radiology[2] provides a standardization of mammography reports that is helpful in decision analysis to perform a biopsy. This system incorporates a well-defined lexicon for various lesions identified on mammography. The principles of the system can also be applied to ultrasonography, i.e., recommendations are categorized in terms of need for immediate biopsy, short term interval follow-up or continue with regular mammography screening. Surgeons need to become familiar with the categories listed below:

- Birads 0: Incomplete exam, more mammography views or ultrasound necessary
- Birads 1: Negative mammogram
- Birads 2: Lesion present (described), absolutely benign
- Birads 3: Lesion present, probably benign (usually short term interval follow-up recommended, if the patient has significant history or clinical exam findings or is uncomfortable with follow-up—tissue sampling recommended)
- Birads 4: Lesion present, suspicious and biopsy indicated (70-80% chance that lesion is benign, 10-20% chance that lesion is malignant)
- Birads 5: Overwhelmingly malignant in appearance, biopsy or direct operative intervention (with intraoperative confirmation) is indicated

After fully understanding the visualization process used to determine the type of biopsy, the type of “collection” device needs to be selected. Methods of collection include: fine needle aspiration (21-25 gauge needle), incisional (core biopsy either 14 or 11 gauge are most common), and excisional (operative). The greater amount of tissue removed yields a lower false negative rate; however, since the vast number of biopsies performed are benign and ultrasound is complementary to mammography in characterizing palpable as well as nonpalpable lesions, a trend for noninvasive biopsies has emerged.

Fine needle aspiration can take place for palpable or nonpalpable lesions. The most simplistic form of fine needle aspiration is cyst evacuation. For solid lesions, cells are removed and examined for malignancy by experienced cytologists. To achieve the lowest false positive and false negative rates, the “triple test” is used in ultimately categorizing lesions.[3] Results of cytology (benign, suspicious, malignant) are combined with clinical exam results (low suspicion, indeterminate, and very suspicious) and image description (via mammography or ultrasound) to accurately describe a lesion. If the clinical exam and image modalities are suspicious and the fine needle aspiration suggests malignancy, this is a triple positive test with essentially 0% false positive rate. Likewise, if the clinical exam and the mammogram/ultrasound exhibit benign features combined with a “negative” cytology, the false negative rate is low and “observation” can be considered. These two examples describe “concordance” or agreement of all three modalities and yield very low false positive and false negative rates. When using fine needle aspiration, is nonconcordance exists, larger tissue sampling is recommended (core or excisional biopsy).

Core biopsies are generally performed with a hand held spring loaded 14 gauge device or a larger bore 11 gauge vacuum assisted device. The advantage of core biopsy over fine needle aspiration is the quantity of tissue sample and obtaining tissue so the architecture of the malignant cells can assessed. This is important in breast disease because preinvasive ductal carcinoma in situ (DCIS) will show “malignant” cells on fine needle aspiration. It is only on core or excisional biopsy that

DCIS can be accurately distinguished from invasive cancer. However, palpable DCIS is rare so if one uses the triple test, definitive surgical recommendation is often made with the combination of physical exam, imaging and fine needle aspiration with a high degree of accuracy.

Excisional biopsies provide the largest amount of tissue to be evaluated yet reports have shown that missed diagnoses, while unusual, still may occur. This is a result of either improper surgical excision or failure to assess the appropriate architecture on pathological review.

Given the extensive spectrum of treatment offered (from chemoprevention to surgery) for not only preinvasive and invasive breast disease, but also pathological diagnoses that place a woman at higher risk for the development of invasive cancer (lobularcarcinoma in situ and atypical hyperplasia), it is important that accurate tissue sampling takes place.

Biopsy Pearls

- Use of fine needle aspiration versus core biopsy is often dependent on the quality of cytopathology available at an institution. Trained cytopathologists are vital to accurate reporting of lesions.
- Ensure “concordance” for any lesion biopsied—results have to make sense. If a discrete solid lesion is biopsied and only fibrocystic changes are identified, results are nonconcordant with clinical and imaging finding.
- Obtain more tissue for nonconcordant findings—on occasion an open biopsy will be necessary to ensure adequate sampling
- Understand the BIRADS system for radiological interpretation of mammograms and apply principles to clinical care—for BIRADS “3” lesions, a short interval follow-up of 4-6 months is recommended. However, if the patient is overly concerned and unable to tolerate the interval wait, because of the 2-3% false negative rate, tissue biopsy can be offered.
- Do what you would have done without the core biopsy information if it is misleading or not helpful in resolving a clinical presentation.

Training and Credentialing

The role of ultrasound is well established in many surgical specialties, and its use to the surgeon will only increase over time. To optimally use this modality, surgeons must be appropriately qualified. The American College of Surgeons lists four components[4] to ensure high standards in ultrasound use: surgeons fulfilling educational/experience requirements, facilities and equipment meeting recommended standards, surgeons maintaining qualifications through experience and continuing medical education, and assessing experience through a continuous quality improvement program. For breast ultrasound the following steps are easily implemented in the preparation and getting started phase of ultrasound use in practice:

1. **Attend** a didactic and hands-on course in breast ultrasound: the American College of Surgeons has a Postgraduate Course specifically dedicated to breast ultrasound. As a prerequisite, the basic ultrasound course (or some equivalent) is required.
2. **Document** experience as a resident or fellow with a case log so credentialing in practice is easily established.
3. **Observe** techniques from individuals within the institution: this may include other surgeons who perform ultrasound, radiologists, and radiology technologists.

4. **Research** type of equipment available or necessary for practice: many models exist and since breast ultrasound is usually an office based practice, smaller more affordable high quality machines are available.
5. **Invite** the representative from the ultrasound vendor to provide an in-service and set up the ultrasound equipment with automatic settings so recalibration need not take place.
6. **Investigate** the process of credentialing in your practice setting (for university or hospital based practices, hospital owned equipment may be used). Documentation of course attendance is often necessary and letters of support from other surgeons may be requested through the "credentialing" process.
7. **Identify** a group of patients to volunteer for a free exam: practice the techniques described below prior to starting invasive work.
8. **Begin** invasive work with simple cyst aspiration or biopsy of palpable lesions. Transition to lesions easily identified on outside ultrasounds and continue to pursue more challenging cases on a step by step basis. Remember to always do what you would have normally done (perform excisional biopsy) if results are nonconcordant.
9. **Maintain** a log of experience and follow early patients closely.
10. **Network** with other surgeons performing ultrasound either locally or at national meetings as experience increases.
11. **Sign up** for continuing medical education courses (many available) as complexity of work increases.
12. **Participate** as an instructor in courses for residents in training or other surgeons.

Equipment and Technique

With the evolution of high-frequency transducers and improved computer enhancement, the use of ultrasound of the breast is increasing substantially.[5] At a minimum, a linear line array transducer of 7 to 7.5 MHz has been utilized. Resolution does increase at higher frequencies, but higher transducer frequency does not necessarily improve diagnostic accuracy.[6]

Image quality is determined by three parameters: image resolution, contrast resolution and uniformity throughout the field of view.[7] Image resolution is the ability to distinguish small structures with clarity (the smallest distance between two points). The image resolution depends on the axial and lateral resolution. The axial resolution refers to the ability to distinguish between two points along the axis of the ultrasound beam. It depends on the length of the ultrasound impulse. The higher the frequency used the smaller the impulse length and therefore, the better resolution. Lateral resolution is the ability to distinguish between two points that are vertical to the ultrasound beam. The smaller the width of the beam the better the lateral resolution. When the distance between two points is smaller than the resolution of the transducer used, then these two points appear as one. Contrast resolution differentiates tissue types and provides the ability to see subtle structures in the presence of very bright reflectors. Image uniformity refers to ability to provide detail and contrast resolution throughout the field of view. Displaying an optimal image depends on adjusting several features on the ultrasound equipment. Some of these include:

Depth of field: Adjust on the equipment to the optimal filed depth—usually 3-5 cm. Provides enhanced visualization of structures at this depth.

Transmit zone: Adjust the transmit focus function allowing for additional enhancement to structures adjacent to the transmit zone caret (often on the left hand side of the screen). At this level the beam is narrower and that improves the lateral resolution.

Focus: The portion of the ultrasound beam that has the narrowest width.

Time gain compensation: Adjust the gain to improve image quality—keep between the range of 40-60 dB. The gain can be changed accordingly at different depths to allow better contrast of areas of interest.

Brightness of Tissues

The brightness of the different tissues depends on their acoustic impedance. Acoustic impedance is characteristic for each medium, and it is derived from the density and stiffness of the medium. The denser and stiffer the material, the higher the acoustic impedance. Dense and stiff tissues appear bright, i.e., collagen, calcifications, and bone. Fat and fluid have much smaller impedance than the bone and appear dark. When the acoustic impedance is very high like in areas with dense calcification, or the ribs during breast imaging almost the entire ultrasound beam is reflected back and an acoustic shadow (dark) is seen under these areas. The brightness is paradoxically enhanced when the ultrasound beam travels from a tissue with low impedance to a tissue with higher impedance. This phenomenon is called acoustic impedance enhancement and is seen during imaging of fluid filled cysts.

Technique

The patient should be positioned in the supine position with the arm extended above the head on the ipsilateral side.[5] This position tightens the pectoralis muscle while spreading out the breast tissue to allow for optimal visualization. A pillow or towel roll is placed under the back to elevate the side of scanning.

A radial scanning technique is used and is performed by first placing the notched side of the transducer at the nipple areolar complex. This displays an image orienting the central portion of the breast in the upper left hand side of the screen. Starting at a given “clock” position of the breast, the transducer is then gradually advanced from the central toward the periphery and beyond the breast tissue. Using the descriptions in Table 1, the following structures should be identified (Fig. 1):

- Skin (hypoechoic thin strip separated from the subcutaneous fat by a bright hyperechoic echo)
- Glandular region
- Cooper’s ligaments (hyperechoic septum like structures)
- Pectoralis muscle and fascia (hypoechoic layer deep to the breast)
- Rib (hyperechoic crescents with dense posterior shadowing
- Pleura

After a quadrant is scanned in a radial fashion, transverse “sweeping” of the same area should be performed by horizontally moving the transducer. The nipple areolar complex is examined by placing the transducer adjacent to the anatomic structure and angling back and forth in the retro-areolar location. Depending on the indication for the ultrasound, transverse “sweeping” of the axilla is performed to examine for lymphadenopathy.

The site of a lesion is documented using three descriptions: position on the clock, distance from the edge of the areola, and depth. Lesions should also be imaged in both the transverse and longitudinal plans.[8]

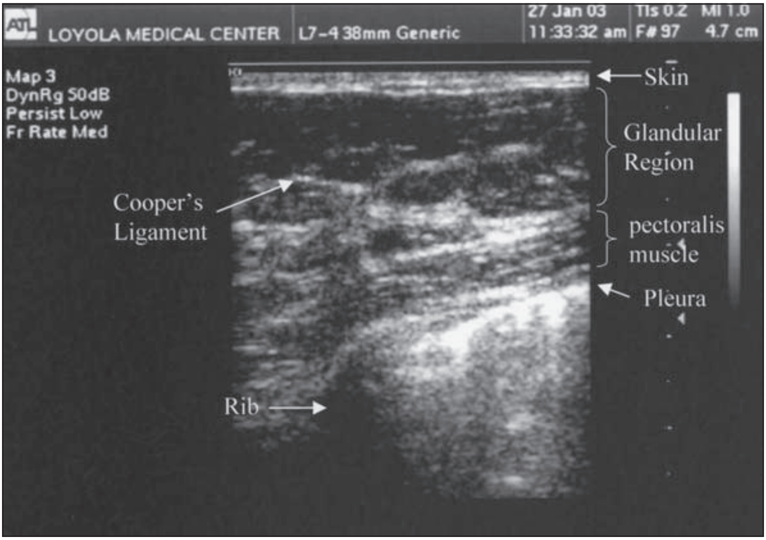

Figure 1. Breast sonogram.

Ultrasound Classification of Lesions

Once a lesion is identified it is characterized using nine features that include:[6] echogenicity, shape, margins (borders), lateral/anteroposterior dimension (depth to width ratio), internal echo pattern, edge shadows, retro-tumoral acoustic phenomena (posterior enhancement), compression effect on shape and internal echoes, and evaluation of secondary features.

Echogenicity: The degree of density of a focal lesion in relation to the echo characteristics of adjacent tissues. Anechoic (without echoes, solid black on scanning) is the distinguishing feature of cysts. Almost anechoic appears less echogenic than fat. Hypoechoic is less echogenic than glandular tissue but more echogenic than fat. Isoechoic is similar to adjacent glandular tissue and hyperechoic is a lesion that appears brighter than surrounding tissue.

Margins: The borders of a lesion are described as sharp or indistinct, smooth or jagged. Four combinations exist in this description.

Lateral/anteposterior dimension (width to depth ratio): This assesses the dimensions of a lesion either as wider than tall versus taller than wide lesions.

Internal echo pattern: This refers to the texture of echoes within a lesion. Lesions are described as nonhomogeneous or homogeneous.

Retrotumoral acoustic phenomena: Deep to the lesion three characteristics may occur and these include: strong posterior shadowing (heavy dark area underneath lesion), posterior enhancement (brighter area underneath lesion) or no change relative to the surrounding tissue.

Edge shadows: The edge of a lesion creates a shadow of either one or both sides.

Table 1. Guidelines for classifying lesions

Lesion Description	Malignant Features	Benign Features
Echogenicity	Almost anechoic, hypoechoic	Anechoic, hyperechoic
Margins	Indistinct jagged (microlobulations)	Indistinct smooth, sharp jagged, sharp and smooth
Lateral/Anteroposterior dimension	Less than one	Greater than one
Internal echo pattern	Non homogeneous	Homogeneous or no echoes
Retrotumoral acoustic pattern	Strong, moderate or slight shadowing	Posterior enhancement
Edge shadows	Lateral only	Bilateral
Compression effect	No change in shape or internal echoes	Changes in shape (compresses or becomes more homogeneous)
Effects on secondary structures	Invades or disrupts secondary structures	No disruption

Compression effect on shape and internal echoes: The lesion is compressed and changes in shape and internal echoes are described. Lesions either demonstrate no change, change in shape, or echoes become more homogeneous.

Effects on secondary structures: Structures such as the ducts and glandular tissue may be compressed or interrupted in the presence of a lesion or no change demonstrated at all.

For simplicity, lesions are categorized as benign, indeterminate, and suspicious. Benign lesions are observed unless the patient is symptomatic or she/he requests biopsy. Suspicious lesions require core biopsy with "confirmatory" results. If a lesion is suspicious and nonconcordant results are obtained (discrete mass on ultrasound but pathology reveals nonspecific findings), there should be strong consideration for an excisional biopsy. Indeterminate lesions require either aspiration to document a cystic structure or core biopsy.

In summary, Table 1 describes guidelines for classifying lesions. While each column contains characteristic features, none of the descriptions below exclude categorization in the opposite column. According to Stavoros et al,[9] if a lesion has any one "malignant" feature, a biopsy is required. Only three combinations of benign features allow categorization as a benign lesion and these include: lack of malignant findings plus, intense and uniform hyperechogenicity, ellipsoid shape plus a thin, echogenic capsule, and gentle lobulations (two or three) plus a thin echogenic capsule. Without these three combinations of benign features and absent malignant features, a lesion still is classified as indeterminate and biopsy recommended.

Noted "Pearls" When Considering Classification of Lesions and Biopsy

- Any palpable lesion that the patient states is new and different should be considered for biopsy.
- Simple cysts may be observed unless the patient is symptomatic and requesting aspiration. Fluid is not routinely sent for cytology for simple

cysts because of low yield. (Exceptions are if the aspirate is bloody or the patient requests cytological analysis.)

- Lesions identified as probable cysts that have atypical features such as internal septations, indistinct margins, irregular posterior enhancement, and inhomogeneous internal echo pattern suggesting an irregular interior should be classified as indeterminate (solid vs. cystic) and aspiration/core biopsy considered.
- Fine needle aspiration for categorizing a complex (or complicated) cyst as a nonsolid lesion is an acceptable diagnostic tool. Fluid is sent for cytological analysis if the cyst is “complex” or “complicated”.
- Mucinous or colloid carcinomas can present as “complex” appearing cysts.[10]
- Core biopsy is more accurate if the lesion is solid and results in a lower number of false negative cases.
- When in doubt, consider further tissue sampling (larger core or excisional biopsy)

Ultrasound Biopsy Technique

Three steps are recommended in performing ultrasound tissue sampling: become familiar with the equipment before the procedure, position the patient properly and characterize the lesion completely (see above descriptions), set up a sterile field and prep the patient for tissue biopsy. Depending on the area of the breast to be sampled, the surgeon may need to be at the right or left side of the patient or at the head of the bed. An assistant is often helpful especially during the sterile technique part of the procedure.

Equipment

7.5 or greater linear array transducer
Sterile gel
Betadine (or other prepping solution)
Sterile gloves
Sterile 4 x 4
Syringes (10 and 20 cc)
21 gauge 1 1/2 inch needle (for aspiration)
25 gauge 1 inch needle (for injection of local anesthetic)
11 blade scalpel
Biopsy guide (optional)
14 gauge core biopsy gun
Sterile jar (for cyst fluid analysis if fluid to be sent)
Formalin jar (for core biopsy samples)

To aspirate or biopsy a lesion, the ultrasound probe is held in one hand and the “needle” is introduced parallel to the transducer. At the beginning a biopsy guide can be used but with time the free hand technique is easily acquired. Often the probe will need to be continuously adjusted to keep the lesion in the field of view. For cyst aspiration, continuous suction is applied while the needle is advanced into the cyst. Complete evacuation can be observed on the ultrasound screen. For solid lesions, the needle should be advanced to the edge of the lesion, then pulled back a few millimeters prior to discharging the spring-loaded device. Documentation of sampling (the needle through the lesion) can be made by “painting”—tilting the transducer from side to side as a painter does with a paint brush, to visualize that in fact the needle has transversed the lesion. A static photo can be taken to document proper sampling.

Pressure should be held over the biopsy site for 10 minutes after sampling. If the site is still bleeding after compression, additional compression is applied until the site is no longer bleeding. Antibiotic ointment is applied followed by a sterile gauze and an ace wrap to secure the dressing and apply pressure. Generally the ace wrap is left in place for 48 hours to decrease the formation of hematoma.

Helpful Hints

- Have the patient's prior mammograms and ultrasounds mounted for reference during procedure.
- Start with aspiration of cysts to become familiar with ultrasound guided visualization and approach of lesions.
- Use ultrasound guidance even with palpable lesions-method to definitely confirm sampling of tissue (photo of needle should be taken) and may reduce potential complications of sampling lesions (those next to the chest wall)
- Ease into nonpalpable lesions by sampling those that are large and have documented outside films that clearly show the lesion.
- Perform excisional biopsy for those nonpalpable lesions that a true tissue diagnosis is nonconcordant with ultrasound findings.

Summary

The use of ultrasound in surgical practice will only increase with advancing technological developments. Many resources exist for surgeons in practice to acquire ultrasound skills and incorporate these skills into clinical care. For surgeons with busy breast practices, this skill is a necessity for future competence in the field of breast surgery. Residents and fellows in training should acquire such skills prior to entering practice. The current uses of ultrasound in breast practice are numerous. Future uses include an expanded role in the operative environment and because of this it will be essential for every practicing surgeon to acquire ultrasound abilities.

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Vascular

David Neschis and Jeffrey Carpenter

Duplex ultrasound has revolutionized vascular diagnostics. It is noninvasive, readily available, and inexpensive. In many cases duplex ultrasound has even replaced the reference standard of contrast angiography for the diagnosis and evaluation of vascular lesions. Duplex ultrasound is the combination of B-mode imaging (discussed elsewhere in this manual) and Doppler ultrasound. In a dedicated vascular laboratory, using carefully developed criteria, the data obtained with this modality are highly accurate and reliable. This chapter will serve as an introduction to Doppler ultrasound and describe the uses of duplex imaging in the evaluation of peripheral artery and carotid lesions, venous disorders, and bypass graft surveillance.

Doppler ultrasound imaging relies on the Doppler effect which is the change in the frequency of echo signals that occurs whenever there is relative motion between the sound source and the reflector. A common example of this is the sound of a train whistle while the train is in motion. The whistle is heard at a higher pitch as the train approaches a stationary observer and as the train passes and is moving away from the observer, is heard at a lower pitch. If one can measure the change in frequency of the whistle's sound waves, one can easily calculate the velocity of the train. Doppler imaging utilizes reflected ultrasound waves, and the velocity of moving blood cells can be measured. The Doppler equation is given below:

$\boldsymbol{\delta = 2F\,(v/c)\cos\theta}$ where c is the velocity of ultrasound in tissue.

v = velocity of flow in vessel
F = ultrasound frequency
δ = shift in frequency as a result of moving particles reflecting the ultrasound signal back to the transducer
θ = angle between the ultrasound beam and direction of blood flow

Using the above equation, the following conclusions can be made:

a. δF is directly proportional to the velocity of the particles
b. δF is nearest zero when the angle θ is 90°
c. δF is greatest when θ is zero, therefore the transducer must be at some angle with the vessel to achieve a strong signal

The simplest and least expensive Doppler instrument is the continuous wave device in which a continuous ultrasound wave is propagated, reflected back, and continuously detected by the receiver.[1] The echoed signals are then filtered such that only signals resulting from a Doppler shift emerge in the output. There are three components of the received signal prior to filtering. There are high intensity signals from stationary tissue, high intensity signals from slowly moving tissue, and low intensity signals from rapidly moving blood. The high intensity signals from tissue,

Ultrasound for Surgeons, edited by Heidi L. Frankel.

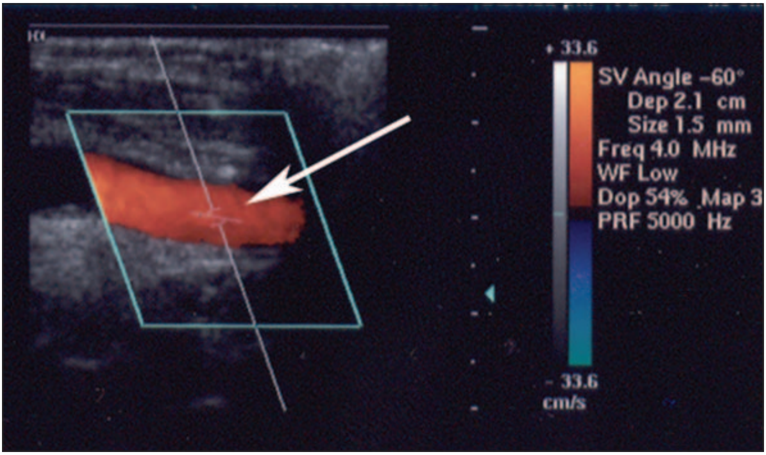

Figure 1. Duplex ultrasound image consisting of B mode imaging and color flow Doppler. The sample volume (arrow) can be positioned to determine the velocity at the center of the vessel lumen. Note how the angle of insonation is maintained at approximately 60 degrees.

important for B-mode imaging, are of no use for the Doppler sonogram and are removed and filtered. Continuous wave systems are available without B-mode imaging; this makes the system inexpensive, but its utility is limited to vessels with very well-defined locations such as the carotid artery since the device insonates everything in the ultrasound indiscriminately.

Pulsed wave systems are similar to continuous wave devices, except the ultrasound waves are transmitted as a series of regularly spaced pulses.[2] This allows the setting of the depth of interest as well as the range of depths for which the ultrasound signals are received. This range of depth is also known as the "gate". The advantage of pulsed wave systems is the ability to sample Doppler signals from a known depth. The disadvantage is that pulsed wave places an upper limit on the maximum detectable Doppler shift. The obvious advantage is that pulsed wave systems can be combined with B-mode imaging to select a vessel of interest and measure velocities in a defined volume of the selected vessel (Fig. 1).[3]

Spectral Analysis

In a blood vessel, the detected signal is very complex, composed of many individual single frequency signals. Spectral analysis separates the complicated signal into its individual frequency components and displays the relative contribution, or magnitude, of each frequency component. It is, therefore, an orderly display of the many frequencies that comprise the Doppler ultrasound signal in moving blood. The reason for multiple frequencies being generated by blood is because blood is pulsatile, not uniform in caliber, and the velocity is different in different portions of the lumen. Modern Doppler ultrasound machines perform this analysis rapidly enough to display in real-time without an appreciable delay. The most common

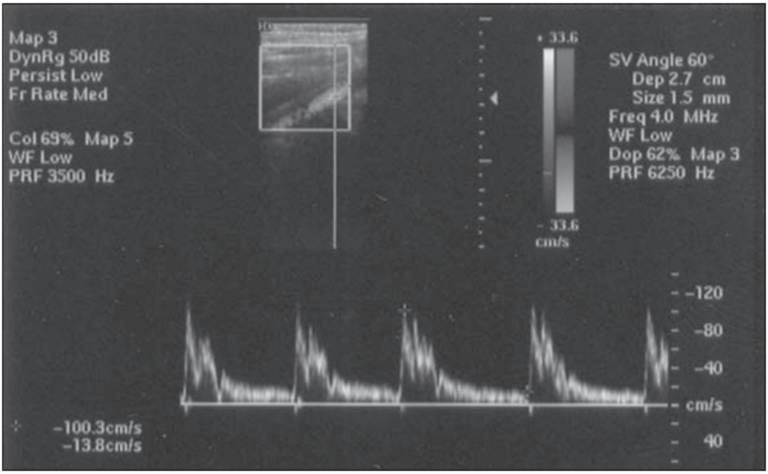

Figure 2. Duplex image and spectral analysis. The Y axis, (vertical) depicts the velocity of moving particles in the sample volume selected, with time represented on the X (horizontal) axis.

display depicts velocity on the vertical axis, time on the horizontal axis, and the relative amount of signal at a given velocity and time as a shade of gray with white being most intense and black representing no signal at that velocity at that time (Fig. 2).

As mentioned earlier, pulsed wave Doppler ultrasound is limited to a maximum frequency that can be successfully measured with the instrument. This limitation is known as aliasing and, if present, can lead to anomalies of the Doppler signal, particularly the artifactual generation of lower frequency components in the signal spectrum. The minimum repetition frequency of a pulsed Doppler instrument must be twice the frequency of the Doppler signal in order to avoid aliasing. However, the pulse repetition frequency is limited. The depth of the sample volume restricts the pulse repetition frequency because the greater the distance to the sample volume, the more time is required to pick up the echo, therefore limiting the pulse frequency. Additionally, as the biologic effects of diagnostic ultrasound are not well quantified, it seems intuitively safer to use the lowest practical acoustic exposure. A common way that aliasing presents on a Doppler spectral display is illustrated in Figure 3. On occasion, examination conditions are such that aliasing cannot be avoided.

In addition to the graphic display described above, spectral analysis can be displayed as a color-duplex image as well.[4] In this display, the direction of flow relative to the transducer is indicated by a specific color (red and blue most commonly used), and different frequency levels displayed as changes in shade. The color flow map helps direct the sonographer to the locations most appropriate to submit to further interrogation by spectral analysis. The graphic display provides critical quantitative information based on angle corrected velocity data and peak Doppler shifts.

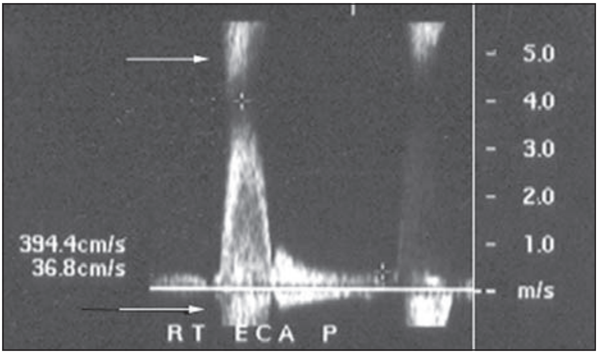

Figure 3. An example of aliasing (arrows). Pulsed wave Doppler ultrasound is limited to a maximum frequency that can be successfully measured with the instrument.

General Concepts Used in Evaluating the Vasculature with Doppler Ultrasound

This section will describe the basic features of normal and abnormal blood flow detected with Doppler equipment and their usefulness in clinical diagnosis. The first feature is that of flow direction. It must be remembered that flow direction is only in relation to the transducer and that the perceived direction can be reversed simply by turning the transducer. In spectral representation the flow in one direction is above the baseline, and flow in the opposite direction below the baseline. In the color spectrum display a different color is selected for each direction. If flow direction is a diagnostic issue, it must be confirmed by comparison with a known vessel such as the aorta or carotid artery.

The distribution of the returned signals is dependent on the orderliness of the particles flowing together in moving blood. If flow is orderly, i.e., most of the particles are moving at the same speed, the spectrum display is that of a sharp line outlining a clear space known as the spectral window (Fig. 4). The reason for this

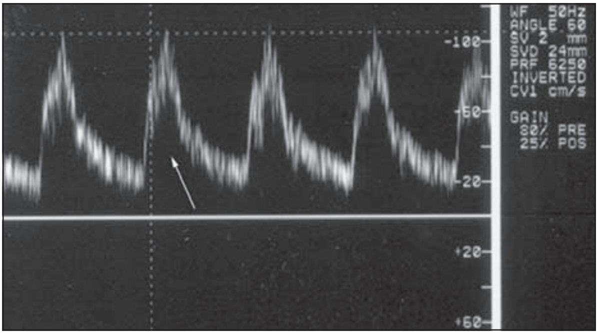

Figure 4. Spectral analysis taken from a relatively healthy, straight, artery, resulting in a crisp, “open” spectral window (arrow).

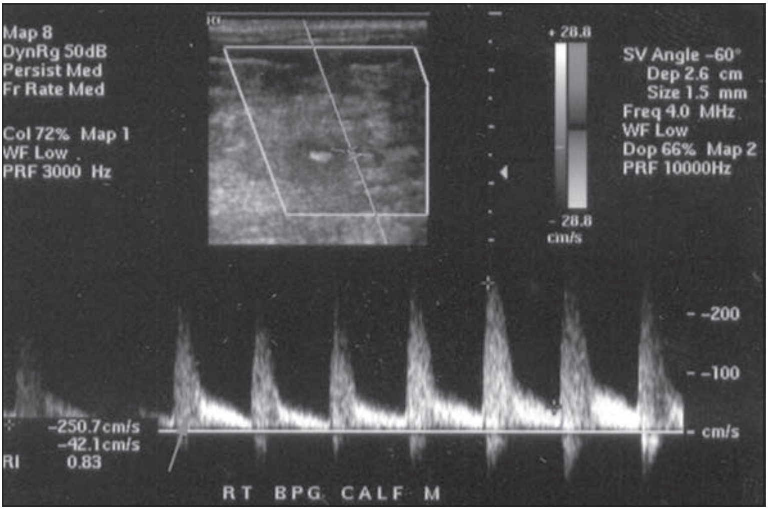

Figure 5. Duplex image and spectral analysis with the sample volume positioned just distal to a stenotic lesion, resulting in disturbed flow and "filling in" of the spectral window (arrow).

sharp appearance is that at any particular time the majority of particles are moving at the same speed, thereby all echoing the same frequency. This results in a thin line as there is little distribution of frequency signals, and the line is intense because of the large number of signals at that frequency. A narrow spectrum is seen in most normal vessels.

If flow is disturbed, usually as a result of a vascular lesion, the situation becomes one in which there are multiple particles moving at different speeds and directions.[5] This creates a wider distribution of reflected signals displayed as spectral broadening and filling in of the spectral window (Fig. 5). Minimal flow disturbances are revealed by spectral broadening occurring in late systole and early diastole. If flow is moderately disturbed, the spectral window is filled in, and in severely disturbed, i.e., turbulent flow, there is evidence of simultaneous forward and reversed flow. Not all flow disturbances are abnormal however; sites of normally disturbed flow include kinks, curves, branching, and sites of diameter change such as the carotid bulb. It must also be remembered that the distribution of signals may be increased by enlarging the sample volume size by increasing the number of particles included in the analysis.[5] This can vary among instruments and affects our ability to quantify and utilize spectral broadening clinically.

The normal Doppler velocity waveform demonstrates an abrupt increase in velocity in early systole, with a gradual return to baseline interrupted by the diacritic notch of diastole. If there is a site of flow obstruction proximal to the sample site (inflow obstruction), the systolic acceleration is slowed, and the maximum velocities are lower in both systole and diastole (Fig. 6). The resulting waveform is rounded and referred to as dampened.

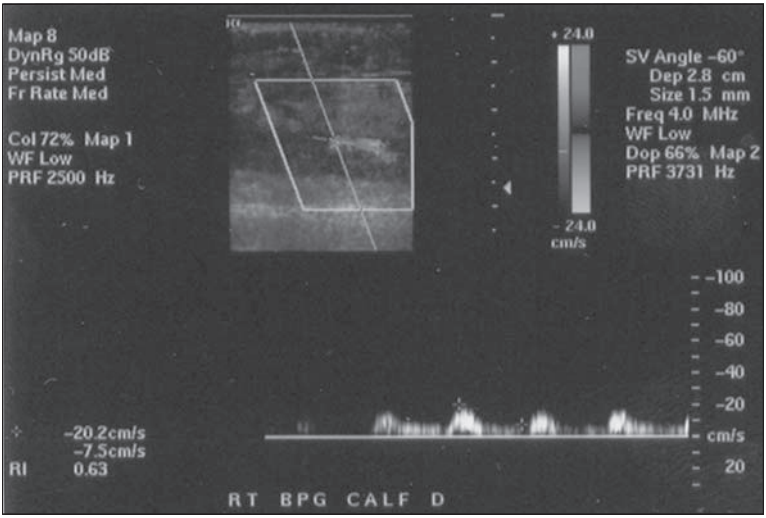

Figure 6. Duplex image and spectral analysis with the sample volume well distal to a high grade stenotic lesion, resulting in decreased velocities in both systole and diastole with "blunting" of the waveform.

The rate of outflow from a vessel is dependent on the resistance distal to the site measured. In vessels with very low resistances, such as the internal carotid, renal and celiac arteries, the systolic peak is broad, and there is continuous flow through out diastole. This flow is also described as monophasic. In vessels with moderate resistance, such as the external carotid artery, the systolic peak is sharper and narrow and there is less flow in diastole, giving a biphasic signal. In vessels with the highest resistance such as in the extremities, there is also a sharp and narrow systolic peak, frank reversal of flow in early diastole, followed by forward flow in later diastole. This flow pattern generates a triphasic signal.

Effects of Stenoses

Five key parameters are measured to determine the severity of an arterial stenosis:

- Peak Systolic Velocity
- End-Diastolic Velocity
- Systolic Velocity Ratio
- Diastolic Velocity Ratio
- Poststenotic Flow Disturbance

Peak Systolic Velocity is the first parameter to become abnormal as the severity of a stenosis increases. Since blood must flow faster to get a given mass through a smaller aperture, a high-grade stenosis will create a more jet like flow pattern with a high peak systolic velocity.

End Diastolic Velocity increases as stenosis severity increases. Usually with minimal stenosis of <50% diameter reduction, the flow velocities in diastole are relatively normal. In moderate to severe stenoses (approximately 65% diameter reduction), end diastolic velocities are slightly elevated. In severe stenoses, (70-90% diameter reduction), diastolic velocities remain high.[6]

The relative change in systolic and diastolic velocities of stenotic areas as compared to normal portions of the same vessel are very useful, particularly in correction for a variety of hemodynamic variables (cardiac output, blood pressure, etc).

Another useful relationship is that the severity of a stenosis is related to the resultant poststenotic flow disturbance. This is normally useful in detecting severe stenoses generating large flow disturbances.

Specific Indications for Use of Duplex Ultrasound in the Office Setting

Duplex Evaluation of the Carotid Artery

Stroke continues to be a major cause of death and serious morbidity in the western world. A large percentage of strokes are attributable to lesions of the carotid artery, most commonly of the internal carotid at the bifurcation.[7] A review of stroke and carotid disease is beyond the scope of this chapter, but some important points will be discussed. Disease at the carotid bifurcation, usually due to atherosclerosis, can lead to stroke by limiting flow to the brain resulting in ischemia, or much more commonly, act as a source of distal embolization of atheromatous material to end arteries of the brain.[8] Often such events are heralded by transient ischemic attacks (TIA), lasting by definition for less than one hour, or transient monocular blindness known as amaurosis fugax, but this is not always the case. It is well accepted that the risk of stroke is related to the degree of stenosis of the internal carotid artery, and that operative repair, in particular carotid endarterectomy, reduces the risk of stroke in appropriately selected patients.[9,10] Although the traditional reference standard in the evaluation of carotid stenosis has been arteriography, duplex ultrasound has evolved as a highly accurate, cost effective and noninvasive alternative.[11]

The role of duplex ultrasound is to evaluate the location, quality, and degree of stenoses of the carotid artery in selected patients and to follow patients after endarterectomy for evidence of recurrence. Indications for carotid duplex ultrasonography include: TIAs, amaurosis fugax, retinal vessel occlusion, asymptomatic bruit, follow-up s/p carotid endarterectomy, and possibly in the evaluation of patients prior to major surgery, particularly patients with a history of vascular disease, or those undergoing cardiac or aortic procedures.[12] A key goal is to detect lesions of the internal carotid artery creating a significant stenosis with maximal sensitivity and specificity.

The equipment used for ultrasound of the carotid arteries include high-frequency transducers with short focal distances for near-field work, a pulsed directional Doppler with velocity measurement capabilities and a variable sample volume, and on-line spectral analysis. The carotid bifurcation is imaged in a posterolateral and anterolateral transducer position as well as in a transverse plane. The high-resistance flow pattern of the external carotid artery and the low resistance pattern of the internal carotid artery are the key ways to distinguish these two vessels from each other. Other features to distinguish the two vessels include the relatively smaller size of the external carotid and the presence of branch vessels. The external carotid is usually oriented anteriorly, toward the face. The internal carotid artery is oriented posteriorly, toward the mastoid process and has no extracranial branches.

The most common lesion evaluated by duplex ultrasound of the carotid is the atherosclerotic plaque, which appears as echogenic material that encroaches on the arterial lumen and produces a flow void on the duplex image. The fibrofatty plaque, which contains a large amount of lipid material, is the least echogenic type of plaque. As the collagen content of a plaque increases, so does its echogenicity. The strongest echogenicity is produced by calcium, which also creates distal acoustic shadowing.[13] If vessel wall calcification and acoustic shadowing are extreme, accurate assessment of luminal velocities may be impossible. Theoretically, duplex scanning should give accurate images regarding plaque surface characteristics; however with current technology this is not nearly as reliable as would be expected.

Other features that can be evaluated with duplex ultrasound include complete occlusion, which is represented by the following: absence of arterial pulsations, lumen filled with echogenic material, subnormal vessel size (chronic occlusion), and absence of flow (color duplex or Doppler signals).[14] False positive findings of occlusion are possible, particularly in the setting of low velocity flow in a small lumen evaluated with instrumentation set for high flow rates. Other causes of a false positive diagnosis of occlusion include a calcified artery being obscured by acoustic shadowing, poor image quality, or a weak Doppler signal. It is crucial to differentiate between a critically high-grade stenosis and occlusion since high-grade stenosis is surgically correctable and the occlusion is not. Dissection of the carotid artery can be detected with duplex ultrasound as well.[15]

Duplex Surveillance of Lower Extremity Bypass Grafts

The most common cause of graft failure in the immediate or early phase following bypass is largely related to technical or judgmental errors. In the intermediate period, i.e., within the first two years following placement of a bypass graft, myointimal hyperplasia seems to play a large role in the failure of affected grafts. It has been demonstrated that close to a third of vein bypass grafts develop a significant stricture. Grafts with these lesions are at a much higher risk of occlusion. It has also been demonstrated that grafts that undergo occlusion have a much lower patency rate following revision than a graft that is revised prior to occlusion. Therefore, a program of surveillance with the goal of detecting significant lesions in lower extremity bypass grafts is followed by most vascular surgeons. A program of surveillance is designed with the intent of addressing significantly stenotic lesions by either PTA or surgical revision.

Most vascular surgeons will consider graft revision of further investigation with angiography or MRI in the following situations: new ischemic symptoms, loss of a previously palpable pulse, an ankle brachial index which is reduced by more than 0.2 from the highest postoperative value, and on the basis of duplex criteria. The most commonly used duplex criteria that suggest a significant stenosis worthy of further follow-up are as follows: (1) peak systolic velocity greater than 150 cm/sec; (2) velocity ratio across the lesion of >2; (3) peak velocities within the remainder of the graft of <45 cm/sec, suggesting a low flow state at risk for thrombosis; (4) a greater than 30 cm/sec decrease in peak systolic velocities along the graft (Fig. 7).

It can be expected that a rigorous program of graft surveillance followed by further investigation and graft revision in selected patients can significantly improve long-term graft patency.[16] A commonly followed protocol involves a graft study in the early postoperative period, and at six weeks following grafting. Thereafter, surveillance continues at 3-month intervals for 2 years and every 6 months thereafter.

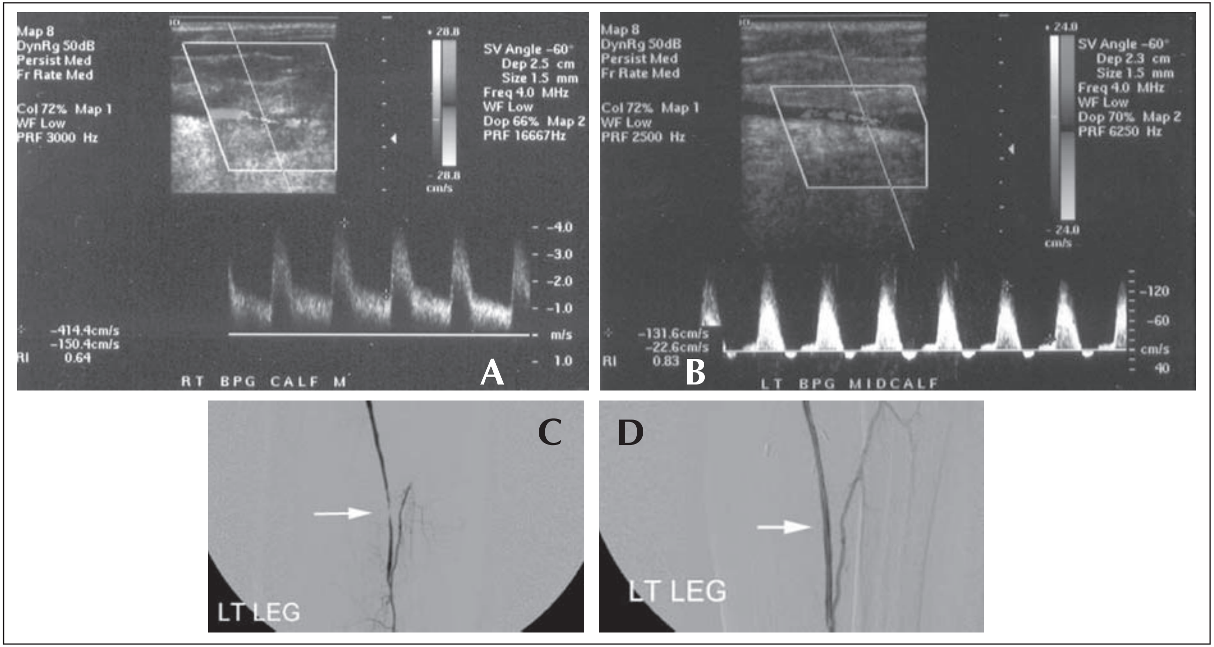

Figure 7. A) Duplex image and spectral analysis of a high grade stenotic lesion in a vein graft with resulting elevated peak systolic velocity (414 cm/sec). B) Same patient and location as in A, following balloon angioplasty of vein graft stenosis. Note significant reduction in peak systolic velocity (132 cm/sec). C) Angiogram of vein graft stenosis depicted in A. D) Angiogram of vein graft stenosis following balloon angioplasty. Obtaining concurrent duplex images facilitates follow-up of the treated area with sequential non-invasive imaging

All surgeons who perform peripheral bypass grafting should be familiar with the concepts of duplex imaging and result interpretation.

Duplex Evaluation of the Peripheral Arteries

Duplex evaluation has met with particular success in evaluation of the carotid arteries owing largely to the predictably focal and superficial location of significant lesions. With increasing experience and the advent of lower frequency transducers, evaluation of arteries at other locations such as the lower extremity has become feasible.

It is usually possible to assess the severity, location, and need for intervention of vascular lesions based on history, physical examination, and the results of noninvasive studies such as pulse volume recordings and segmental Doppler pressures. An entire duplex evaluation of the lower extremity arterial system is both complex and time consuming. It is beyond the resources of most vascular laboratories to perform a duplex evaluation of the lower extremities of all patients with symptoms suggesting vascular disease. However, duplex imaging may still be helpful in selected situations.

Normal lower extremity vessels demonstrate peak velocities ranging from approximately 120 cm/sec in the external iliac to 70 cm/sec in the popliteal.[17] Waveforms demonstrate an initial high velocity forward flow, corresponding to cardiac systole. This is followed by a brief period of reversed flow corresponding to early diastole; this is in turn followed by a low velocity forward flow phase corresponding to late diastole. The period of reversed flow is due to the relatively high resistance of distal extremity vessels and becomes less marked with distal vasodilatation following exercise, or obliterated if measured distal to a severe stenotic lesion. The normally triphasic spectral waveform is narrow and has a clear area under the systolic peak, as it represents blood cells all flowing at similar velocities (nearly laminar flow).

Stenotic lesions will disturb flow and alter the corresponding spectral analysis. Changes in the spectral waveform include loss of triphasic signal, spectral broadening, due to a wider range of velocities in more turbulent flow, and changes in the peak velocities. A significant (i.e., >50% stenosis) will demonstrate a monophasic waveform, loss of reversal of flow in early diastole, extensive spectral broadening, a >100% increase in peak systolic flow relative to an adjacent proximal segment, and monophasic waveform with reduced velocities in segments distal to the lesion.

In summary, duplex evaluation of the arteries of the lower extremities may be accurate and helpful in selected clinical situations. These studies, however, are complex and time consuming and may not be appropriate for routine evaluation in most vascular laboratories. Additionally, experience with imaging of infrageniculate is limited and criteria for these vessels have not been established.

Duplex Evaluation of the Venous System

A basic understanding of the anatomy of the lower extremity venous system is essential in the intelligent ordering and interpretation of venous duplex studies. In the leg, the venous system is divided into superficial and deep systems. A system of perforating veins runs perpendicular to the deep and superficial system, connecting them at intervals. Essentially all the veins of the lower extremity have valves that, in the normal individual, ensure that blood flows from distal to proximal and from superficial to deep.

The superficial system consists mainly of the greater saphenous vein which runs almost the entire length of the leg and empties into the common femoral vein several centimeters below the inguinal ligament and the lesser saphenous vein which drains the superficial tissues of the posterior calf and empties into the popliteal vein. The deep venous system, for the most part, parallels the arterial system; however the anterior tibial, posterior tibial, and peroneal veins are paired structures for most of their length. These paired veins converge into the popliteal vein that drains into the superficial femoral vein. The superficial femoral vein is joined by the deep femoral vein the proximal thigh to exit the leg as the common femoral vein.

The vast majority of venous disorders are either due to reflux, as a result of valvular incompetence, or to obstruction, usually due to thrombosis. The main goal of the duplex evaluation is to determine the presence of either obstruction or reflux, and the specific location (i.e., proximal or distal, or in the superficial, deep, or perforating systems).

Accurate information helps guide proper therapy. As an example, it would probably be unwise to perform a greater saphenous vein stripping for varicose veins in the setting of complete obstruction of the deep venous system, as the superficial system is probably the only good source of venous outflow from that extremity. Such anatomy should be readily uncovered by routine venous duplex evaluation. Venous duplex has, in recent years, developed into a highly accurate and noninvasive modality that has supplanted venography as the reference standard for a variety of venous disorders including deep venous thrombosis.

Duplex evaluation of the venous system requires instrumentation with features including: ultrasound frequencies in the 5 to 10 MHz range, excellent gray scale resolution, and sufficient sensitivity to detect low flow velocities.

The normal vein lumen is echo-free, with a smooth surfaced interior vein wall. The number of valves increases from proximal to distal. Valve cusps should be curvilinear and coapt in the center of the vessel. Unlike arteries, veins should be easily compressible by pressure with the instrument. An artery should be somewhat more difficult to compress but should be easily distorted by pressure. A thrombosed vein will not readily distort or compress with pressure. The veins are in general somewhat larger than the corresponding artery; however, if the vein is more than twice the diameter of the artery, one should suspect potential thrombus. It should be noted however that a number or physiologic conditions might alter vein size. Congestive heart failure, venous reflux, or proximal venous obstruction may cause the evaluated vein to dilate, while dehydration or other causes of vasoconstriction may cause vein diameter to be small.

There are a number of useful duplex characteristics that normal veins have in common. Spontaneous flow is usually present in larger veins; however, flow in smaller veins in the calf or foot might not be spontaneous. Flow in normal veins is phasic, such that the flow velocities change in response to respiration. If flow is present, but not phasic, it is described as continuous. Such a flow pattern suggests obstruction in the system. Unfortunately, the presence of phasic flow does not rule out a partial thrombosis of a vein lumen. Similarly a Valsalva maneuver normally creates a prompt cessation of flow in large and medium-sized veins. This is a particularly useful in evaluating patency of veins proximal to the thigh that are difficult to assess directly. Augmentation is a normal characteristic that involves increased venous flow when the extremity distal to the site being evaluated is compressed manually (i.e., squeezing the calf). The absence of augmentation suggests significant obstruction between the two sites. Again, the presence of augmentation does not totally rule out some degrees of obstruction. When the venous valves are competent, flow is unidirectional. Therefore, the presence of reflux is demonstrated by retrograde flow with a Valsalva maneuver.

It should be noted, however, that venous duplex does have its limitations. In general, the iliac veins or IVC can be difficult to visualize and a determination of their status is often based on indirect data. Additionally, duplex studies are highly operator-dependent and require significant training and patience.

The duplex venous exam should confirm or rule out reflux in the superficial and/or deep system and in the perforator system. Disorders such as varicose veins are usually due to reflux at the saphenofemoral junction causing increased pressure in the saphenous system with consequent dilatation.

Duplex evaluation is also frequently requested to rule out deep venous thrombosis.[18] Here, duplex imaging is also helpful in assessing the relative chronicity of the thrombotic lesion. Features of an acute thrombus, that is one that is hours to days old, including the generation of low-level echoes and often can only be visualized by a flow void on color duplex. Additionally, the involved vein may be dilated, and there is loss of compressibility as discussed above. On occasion, a free-floating thrombus may be visualized. This situation suggests a higher risk of embolization and should be addressed aggressively.

As thrombus persists in the vein lumen, there is a gradual increase in echogenicity, as the vein retracts and becomes smaller in overall diameter, a corresponding decrease in vein diameter, and eventually, recanalization and restoration of flow. Long term sequellae of a deep venous thrombosis include vein wall irregularities and venous valve damage.

In summary, duplex technology has allowed accurate, noninvasive, and cost effective evaluation of the arteries and veins in a variety of settings. Additionally, this modality can be utilized in the office setting both for diagnostic purposes as well as continued surveillance to optimize long term results.

Summary

Duplex ultrasound has revolutionized vascular diagnostics. It is noninvasive, readily available, and inexpensive. In many areas duplex ultrasound has even replaced the reference standard of contrast angiography for the diagnosis and evaluation of vascular lesions. Duplex ultrasound is the combination of B-mode imaging (discussed elsewhere in this manual) and Doppler ultrasound. In a dedicated vascular laboratory, using carefully developed criteria, the data obtained with this modality are highly accurate and reliable. This chapter will serve as an introduction to Doppler ultrasound and describe the uses of duplex imaging in the evaluation of peripheral artery and carotid lesions, venous disorders, and bypass graft surveillance.

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Rectal

John Winston and Lee E. Smith

Introduction

Ultrasound is used to provide objective data about numerous anorectal conditions. Rectal cancer was the first colorectal disease studied by rectal ultrasound, and it is still the most frequent indication. Rectal cancer is 34% of 134,000 colorectal cancers per year. The probability of developing colorectal cancer in the United States and Canada is about 6%. Additionally the prevalence of anal incontinence among those greater than 64 years of age has been estimated as 10.9 per 1000 in males and 13.3 per 1000 in females.[1] Hence, the assessment of the anal sphincter is another major use. Another use is for people of all ages who are afflicted with abscesses or fistulas. Anorectal ultrasound is useful to identify the sites and tracts of these diseases. In general, anorectal ultrasound can give quick, objective information at the hands of the evaluating surgeon in the office or operating room with minimal expense and morbidity.

Indications

There are some specific indications for anorectal ultrasound.[2-3] In general they are grouped as malignant vs. benign and rectal vs. anal. See Table 1 for a concise listing. There are no absolute contraindications for anorectal ultrasound. Pain may prevent acceptance of any anorectal manipulation.

Although there are several companies which produce ultrasound machines designed with anorectal applications, the basic components are similar. These include the keyboard, anorectal transducer/probe, plastic cap or balloon, the monitor and the printer (Figs. 1, 2). Because these components differ widely among the brands, it is wise to refer to the manuals and become familiar with the equipment before attempting an exam.

For anorectal studies the transducer is usually a 360 degree rotating array which is best for initial studies. There are also sector probes with linear and curved array transducers with 120-210 degree fields of view which may be used for biopsies. Probes may also be biplanar.

The optimal transducer frequencies have been defined by the site of use. It may be between 5 and 10 MHz. Anorectal transducers are usually 7 or 10 MHz with 2-5 cm or 1-4 cm focal lengths respectively. The 10 MHz transducer probes are best for detailed examinations of the anus and sphincters. This better detail is at the cost of less depth of penetration. The 7 MHz transducers are best for the evaluation of rectal lesions with localization of deeper, surrounding disease.

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Table 1. Indications for anorectal ultrasound

Malignant	Benign
Cancer	Abscesses
Retrorectal tumors	Fistulas
Recurrent cancer	Anal injuries

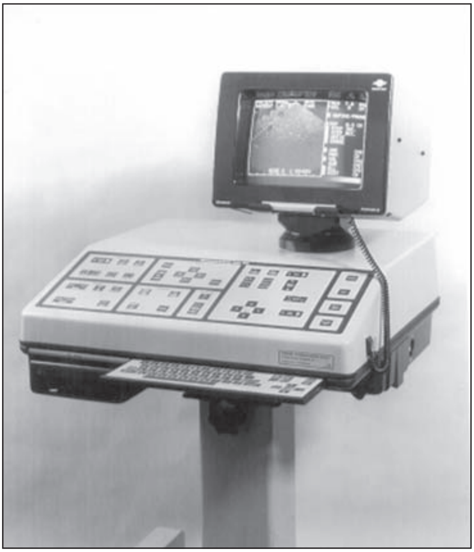

Figure 1. Anorectal ultrasound keyboard, panel and monitor.

Figure 2. Anorectal probe and transducer.

Preparation and Technique

Before any examination or biopsy is carried out, informed consent demands open discussion. The patient should be informed regarding the rationale, options, risks and benefits and be allowed to ask questions.

The anorectum is usually prepared with two small enemas two hours before the examination. The patient need not be made NPO. However, only a light meal before the exam is suggested. If the patient is on medications that affect coagulation, e.g., aspirin or coumadin, biopsies should not be performed and the examination deferred for several days to allow correction of the coagulopathy. They may be resumed after the biopsy. Oral antibiotics should be considered in patients at high risk for infection (e.g., HIV, diabetes, heart valves, prosthetics) before biopsies.

The patient is placed in the left lateral decubitus position for anorectal ultrasound examination. When a transvaginal study is anticipated, the patient is turned and placed in stirrups in the dorsal lithotomy position. Some examination tables allow patients to be positioned prone on the examination table with knees and hips flexed. The patient and the examiner must both be comfortable.

A digital rectal examination and rigid sigmoidoscopy should be performed to observe the position, distance and possible obstructive nature of the lesion. Biopsies should be avoided immediately before the examination because of the potential artifact from hemorrhage.

Documentation is important in pretreatment or preoperative planning. By convention, the probe is oriented so that the top of the screen or picture is anterior and the right side of the screen or image is the patient's left. Video tapes may be made with some units. Most units allow pictures to be labeled. If not, label the picture clearly with permanent ink with the patient's name, identifying numbers and any pertinent normal or pathological findings. Not only is this important for medicolegal reasons but for long term follow-up and planning.

The computer is set for a specific transducer. The transducer is covered by the plastic cap for anal examination or balloon for rectal examination and filled with degassed water. Using a 50 cc syringe filled with water, the probe's channel and the cap or balloon are filled. The probe is positioned so that the air bubbles can be aspirated. Air bubbles produce major artifacts in the image. To prevent contamination, a condom containing some ultrasound gel is placed over the probe. The outside of the condom is lubricated for easy insertion.

Patients must be talked through the examination at each manipulation. A digital examination is performed to look for lumen direction, masses or strictures. The patient should be forewarned, and the well-lubricated probe introduced into the anal canal by first directing it anteriorly for 4 cm toward the umbilicus and then posterior along the hollow of the sacrum. If resistance is encountered, withdraw slightly and approach at a different angle. Do not persist in near obstructing lesions. Force should not be used. If necessary, a transvaginal examination may be carried out. This may yield useful information regarding the invasiveness of a tumor.

The probe is gently inserted past the area of interest. It is then withdrawn slowly without totally removing it and note made of any sites of concern. It should be reinserted and withdrawn at 1 cm intervals as marked on the shaft; it may be withdrawn at 0.5 cm intervals across the tumor. The level of the tumor and depth of the tumor should be documented. The analysis is made in real time, even though representative hard copy images may be taken.

Anatomy

Ultrasonographic anatomy is straightforward. Preview pelvic anatomy and form a mental image of the relationship of pelvic structures.

The upper part of the anal canal is defined by the presence of the puborectalis roughly 3-4 cm from the anal verge.[5] Also, probe contact with the plastic cap is lost as one proceeds proximally entering the wide rectum. In the upper anus, the horseshoe-shaped puborectalis can be seen posteriorly as a striped hyperechoic or heterogeneous structure. Anteriorly, the vagina appears as a hypoechoic air-filled lumen with a hyperechoic curvilinear lining.[2,3,5] The mucosa-submucosa complex is typically hyperechoic. The outer ring which is the external sphincter is striped and heterogeneous.[2] The inner ring is black (hypoechoic) representing the internal sphincter[2,6] (Fig. 3A,B). In Figure 3B, the arrow points to the puborectalis.

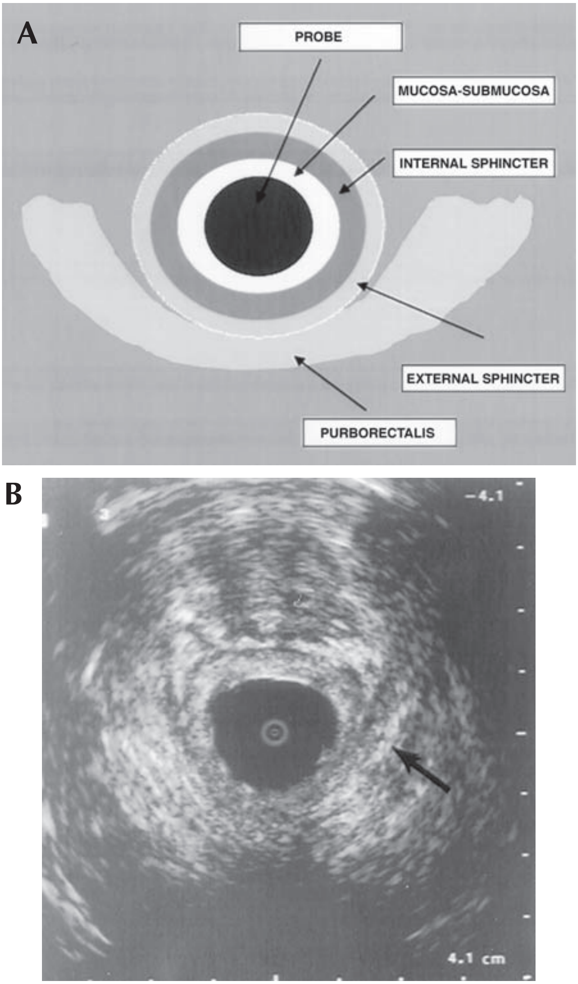

Figure 3. A) Upper anal canal. B) Arrow points at the puborectalis.

The midanal canal is the area at which the sphincters are at their thickest, usually at 2-3 cm from the anal verge.[2] Again, the outer ring (which is the external sphincter) is striped and heterogeneous. The inner ring is black (hypoechoic) and represents the internal sphincter which has been said to be 1.5 to 4 mm thick with an average of 2.8 mm.[2] Inside this ring is the mucosa and submucosa which is a white (hyperechoic) ring. In the upper and middle canal the external sphincter does not travel the entire circumference. It blends with the puborectalis (Fig. 4A,B). In Figure 4B, the arrow points to the internal anal sphincter.

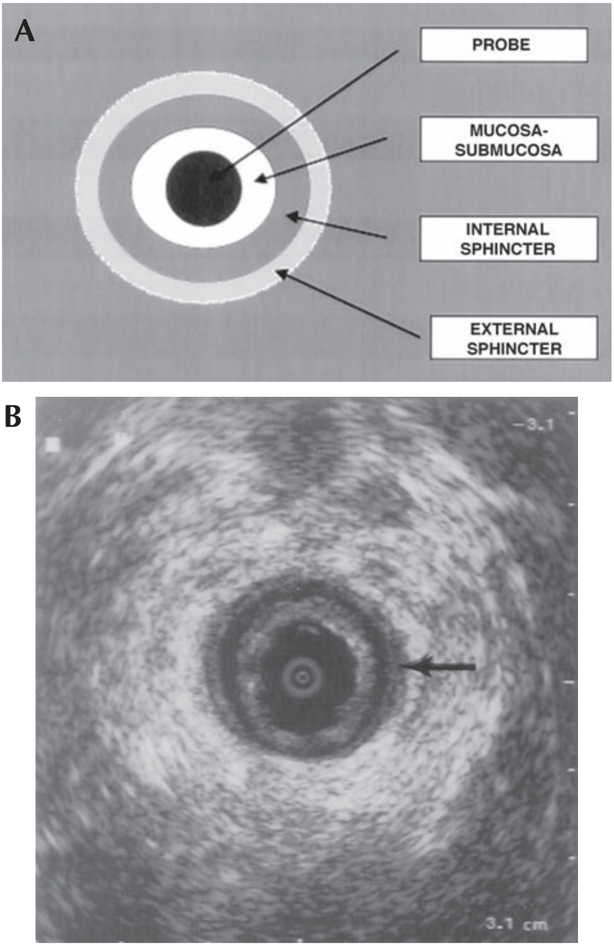

Figure 4. A) Midanal canal. B) The arrow points at the internal anal sphincter.

At 1-2 cm from the anal verge, the internal sphincter starts to disappear.[2,5] The lower anal canal reveals a distinct hypoechoic (black) internal sphincter and a heterogeneous external sphincter. The anterior fibers of the external sphincter blend into the perineal body which is hypoechoic. It is this distal area that commonly is involved in obstetrical injuries.

The wall of the rectum is represented by five layers of alternating white (hyperechoic) and black (hypoechoic) rings. The innermost ring (white) is the interface between the transducer and mucosa. The next ring (black) is the mucosa and muscularis mucosa. The next ring (white) is the submucosa. The next ring (black) is

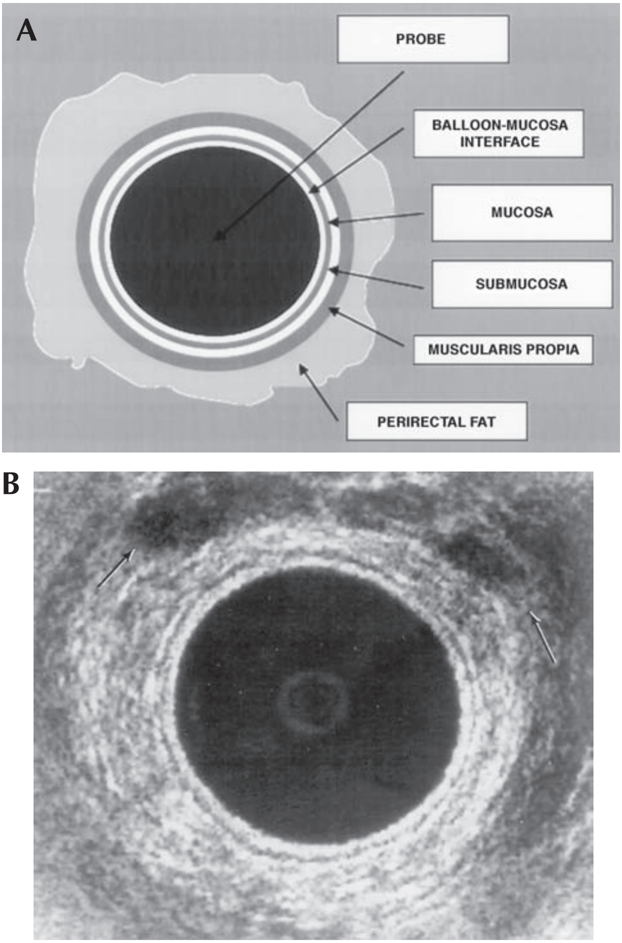

Figure 5. A) Layers of the rectal wall. B) The arrow shows the seminal vesicles.

the muscularis propia. The outermost ring (white) is the perirectal fat.[2] In this fat normal lymph nodes usually do not appear (Fig. 5A,B). Figure 5B also shows the seminal vesicle indicated by the arrows. Hypoechoic, circular structures are blood vessels or lymph nodes. If these structures seem to branch on further investigation they are probably vessels. Anterior to the low rectum the prostate and bladder may be found. The bladder is a fluid-filled, hypoechoic, thick walled organ.

During the learning phase take the opportunity to perform a full anorectal examination on all patients. Thus a knowledge base of the normal anatomy is obtained so that when pathology is encountered it will be recognized.

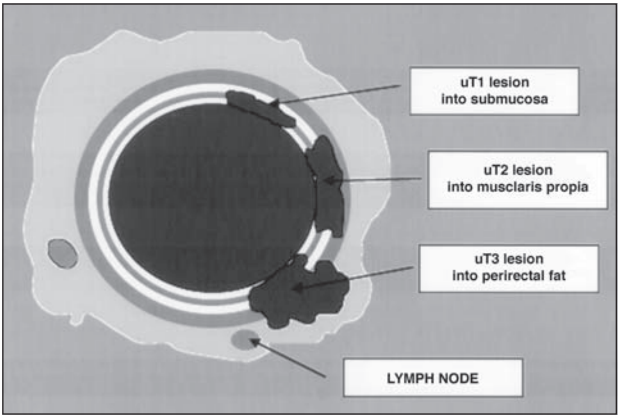

Figure 6. Local staging of tumors of the rectal wall.

Staging of Carcinomas

The critical role for anorectal ultrasound is the staging of tumors preoperatively including what is though to be a benign villous adenoma.[8] The staging parallels the pathological ("p") TNM classification for depth but is denoted with a prefix "u" (uT1-uT4 vs. pT1-pT4). The depth of invasion of the tumor is represented as the point to which the tumor extends into the submucosa, muscularis propria or perirectal fat (Fig. 6).

If the middle white circle (submucosa) is broken, the cancer has invaded into the submucosa which is a uT1 lesion (Fig. 7). If the outer dark circle (muscularis propria) shows fullness, but the outer white circle (perirectal fat) is intact, it is a uT2 lesion (Fig. 8). A break into the outer white line (perirectal fat) denotes a uT3 lesion[2,8] (Fig. 9). Invasion of surrounding structures can be identified. For example, invasion of Denonvilliers fascia (hyperechoic line) between the rectal wall and the prostate and seminal vesicles indicates uT4 disease.[2,8] Invasion of the vagina shows a hypoechoic signal in the vaginal wall which may best be seen on transvaginal examination.[8]

The staging of anal carcinoma allows response to chemoradiation to be followed by serial ultrasound. Recurrences may be detected by serial anal ultrasound and biopsied.[7]

Controversy surrounds the identification of nodal disease. Normal lymph nodes may not be seen on ultrasound. Hyperplastic or inflamed nodes are enlarged and oval. Size alone should not be used to diagnose metastatic nodes because this results in over-reading and increases the incidence of false positive nodes.[8] Metastatic nodes appear as enlarged, round or irregular structures which are hypoechoic.[2,8]

Sphincter Injuries

Obstetrical injuries from tears due to forceps delivery, breech birth, abnormal presentations and/or extended episiotomy are the most common causes of incontinence. Also, iatrogenic injuries from transanal surgery such as hemorrhoidectomy or fistulectomy are common causes of incontinence. Fistula surgery is the number

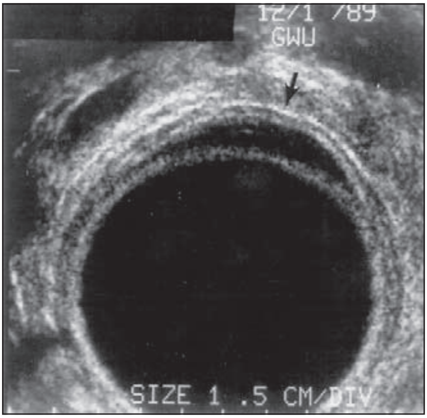

Figure 7. uT1 lesion.

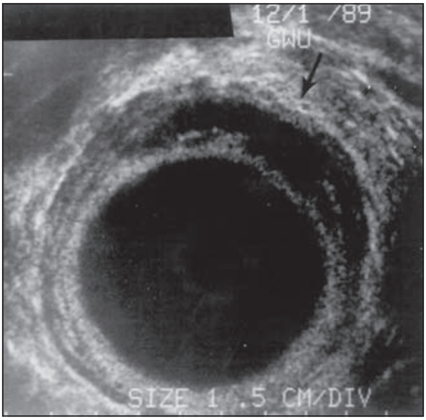

Figure 8. uT2 lesion.

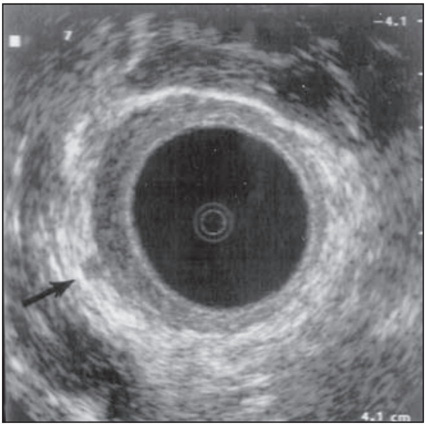

Figure 9. uT3 lesion. The arrow points to the point of invasion.

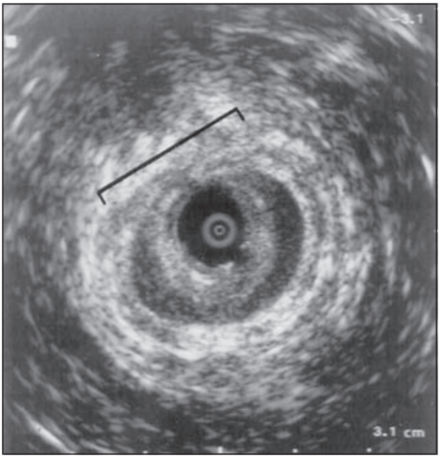

Figure 10. Break in the internal and external anal sphincters. The bracket shows the defects.

one etiology of iatrogenic injuries. Sphincter defects are usually located in the middle or lower anal canal. They are represented as a gap in the normal sphincteric ring. Defects in the external sphincter are hypoechoic in most cases; however, they may appear as any alteration in the texture of the sphincter being heterogeneous or even hyperechoic. Discontinuity in the internal sphincter is suspicious as well.[6] (Fig. 10) The bracket shows a defect in the internal and external sphincters in a young female with an obstetrical injury.

Some patients present with no obvious history of insult to their sphincter. Occult defects may be detected when ultrasound is utilized for patients with idiopathic incontinence. Remember that ultrasound demonstrates only anatomical defects. Neurogenic or physiological etiologies may be investigated by physiological testing with pudendal nerve studies, electromyography (EMG) and manometry.

Even though there is accurate correlation between ultrasound and mapping EMG, it is noted that ultrasound has essentially supplanted EMGs in the workup of incontinence.[2,6,9] Needle EMGs are painful and require advanced training.[3,6,9] However, EMG is useful when anal ultrasound is ambiguous e.g., females with a posterior defect which could be the coccyx or anococcygeal raphe.[6] In order to yield good results ultrasound is used in combination with a history and physical exam and perhaps physiological tests.

Abscesses and Fistulas

Most abscesses and fistulas need not be evaluated by anorectal ultrasound. Although anorectal sepsis can be straightforward, complex or recurrent cases may be elucidated by ultrasonographic study. It can detect occult areas especially high lesions.[2] Transrectal ultrasound may indicate the relative location of sphincters to fistulas an abscesses, thus the surgical plan can be tailored.[3,5] As well it is relatively cheap, has little morbidity, is less painful and does not require exposure to radiation. Since it is portable and easily mastered by the operative surgeon, it can be used in the operating room in difficult cases.

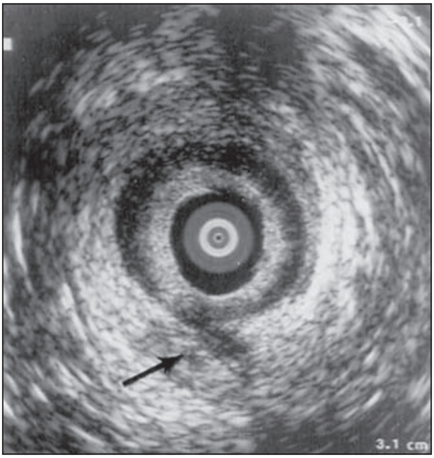

Figure 11. Fistula tract in the midanal canal.. The arrow shows the primary tract.

Abscesses and fistula tracts are hypoechoic. Fistulas typically originate in the anal crypts and traverse the intersphincteric plane and can be followed to their opening (Fig. 11). The arrow shows the tract in a patient with a complicated history of fistulas. One must be careful to follow breaks in the submucosal layer, internal anal sphincter and the intersphincteric plane to find the course of the tracts and internal opening which can be successfully found in 80% of cases using the above criteria.[5]

Abscesses and fluid collections are typically easier to locate than fistulas.[5] Abscesses are represented by hyperechoic areas often with air in the abscess. Certainly combining anorectal ultrasound and examination gives the best diagnosis.

Even though computed tomography shows the sphincters poorly, when evaluating fistulas and abscesses it may be considered in difficult cases. MRI has proven to be more accurate in these cases, but it is expensive.[5] Because both of these studies are expensive and not portable, ultrasound has a permanent place in the surgeons armamentarium.

Follow-Up of Tumors

Follow-up of benign or malignant neoplasms after initial management is an indication for anorectal ultrasound. The recurrence rate after surgery for rectal cancer is 16-38%.[7-10] Using a combination of history, physical examination, endoscopy, ultrasound and laboratory studies may enhance the rate of early detection. Serial ultrasounds enable the physician to study inaccessible areas like scars and deep tissue which evade the examining finger.[2] Ultrasound may detect disease that other studies do not.[2] Enlarging lesions are suspicious for cancer while a mass that decreases or is stable in size likely benign. Granulation or scar tissue are examples of a stable mass.[7] Any lesion that is of concern should be biopsied to confirm its nature.

Ultrasound patterns of recurrence have been described. They include mucosal or muscular disruption which may appear hypoechoic like a primary cancer.[7] Also new nodes or perirectal masses should be biopsied.[7] As with primary cancer, documentation is important. All lesions should be measured and the location well noted. Hard copy photographs are helpful in serial comparison.

Retrorectal Tumors and Biopsies

Retrorectal tumors are rare. It has been stated that they occur in 1 of 40,000 general hospital admissions.[1] They include the categories of congenital, inflammatory, osseous, neurogenic or miscellaneous tumors. Retrorectal tumors can be cystic or solid and of any echogenicity. Ultrasound is valuable in determining whether a lesion is cystic and will aid in biopsing.

These tumors are posterior to the rectum and generally peripheral to the rectal wall and muscularis propria. They are identified as echo signals differing from the surrounding perirectal fat and rectal wall. Transrectal biopsy should be avoided to prevent seeding of the tract or infection of cystic tumors. An extrarectal approach is preferred if the rectal wall is not in direct continuity.

CT or MRI are more useful in studying these tumors. Whether transrectal ultrasound will play a significant role remains to be seen.

Biopsies

Biopsies of a primary lesion, a recurrent lesion or lymph nodes may be biopsied under ultrasound guidance. However, lesions visible at endoscopy are biopsied at the time of discovery. Biopsy may be difficult for flat or deep lesions, therefore a sector probe with biplanar ability may be used. Also, there are probes with guidance systems which direct spring loaded or manual core needles. Several biopsies should be taken of any suspicious findings. Record the exact level on the probe and the tumor's relative location (posterior, right lateral, left lateral, anterior).

Complications are rare after lymph node biopsies. Complications may be bleeding and infection. Biopsies of lymph nodes should not be performed through the primary lesion because this may lead to false positive results or seeding of the tract.[4] The patient should be counseled regarding possible complications and risks. Be familiar with the biopsy instruments before attempting biopsies. Refer to the manuals supplied with the the unitand biopsy needles.

Results, Accuracy, Sensitivity and Specificity

Pretreatment or preoperative staging of carcinomas by ultrasound has been extensively studied and compared to rectal exam and other radiological studies. Digital examination is poor at detecting depth in early lesions being only 39% accurate as compared to US at 79%.[8] Computed tomography has been stated to be 70% accurate compared with ultrasound at 85%.[8] MRI may prove to be superior to these studies, but it is expensive.

Since the mid 1980s several studies have revealed the accuracy of US in predicting depth of penetration. It is in the range of 81-94%.[8] Problems occur with over-and-understaging which is usually due to inflammation, preoperative chemoradiation, and hemorrhage which can all be hypoechoic like cancer. Studies have revealed that ultrasound overstages in 0-12% of cases and understages in 1-9% of cases.[8]

A recent review of the literature combining the raw data from several studies with a total 873 patients revealed the sensitivity and specificity to be 76-96% and 85-100 depending on the depth of penetration. The positive predictive value and negative predictive value were 84-95% and 92-98% respectively.[10]

The detection of pararectal lymph nodes is also in debate. CT and MRI are poor compared with ultrasound.[10] The accuracy, sensitivity, specificity, positive predictive value and negative predictive value of ultrasound have been studied. The accuracy is 58-83%. The sensitivity is 59-89%. The specificity is 64-87%. The positive predictive value is 50-78%. The negative predictive value is 70-90% respectively.[8-10]

In studying sphincter injuries in incontinence ultrasound correlates well at surgery and with mapping EMG.[3-6] Ultrasound predicted 100% of injuries with a history of obstetrical injury.[6] The thickness of the internal sphincter may also help elucidate the cause of incontinence as studies have shown that it is directly related to resting pressures.[9]

The accuracy of ultrasound as compared with surgery when looking for the internal opening of fistulas is 10-66%. The accuracy in finding the tract is 92-100%. Abscesses and fluid collections are accurately found in 75-100% of cases. There is excellent correlation in finding the internal opening or primary tract when MRI is compared to ultrasound. However, ultrasound is poor in finding secondary extensions.[5]

As stated, the majority of cancer recurrences are detected by a combination of studies and clinical findings. Of those who undergo reoperative surgery between 50-83% had their recurrences discovered by ultrasound alone. This is in comparison to 37-67% found clinically or by CT.[7] Of those detected by a combination of studies 55% underwent a curative reoperation versus 71% of those detected by ultrasound alone who were able to undergo curative reoperation.[7]

In a study of 120 patients by Mascagni et al, all asymptomatic recurrences and 36% of symptomatic recurrences were found by ultrasound alone when other modalities failed. When recurrence was surveiled by exam, endoscopy and ultrasound, 14% were only found by ultrasound.[10]

In a series of 186 patients from the University of Minnesota, there were 23 recurrences. Of these recurrences there were four false positive results. There were three false negative results but these were biopsied under anesthesia due to clinical suspicion resulting effectively in no false negatives.[7]

Summary

Anorectal ultrasound has earned an important role in the study of anorectal disorders. It should be a part of the colorectal surgeons armamentarium. However, like all tests this test should be used in concert with a meticulous history and physical and other radiological modalities. It is then that the pathological processes can be diagnosed and treated with success.

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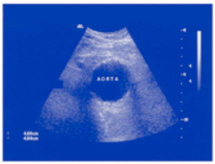

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