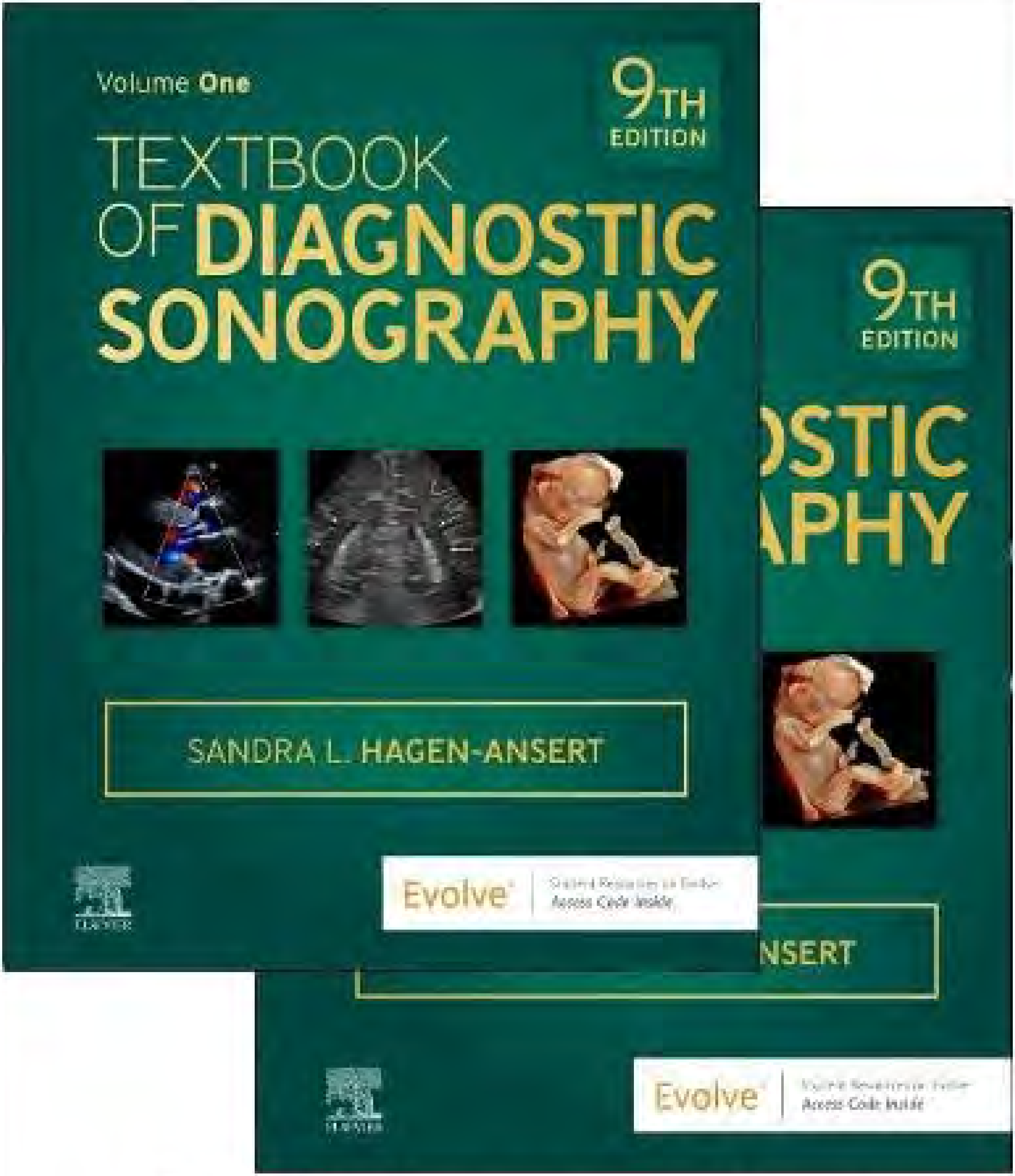
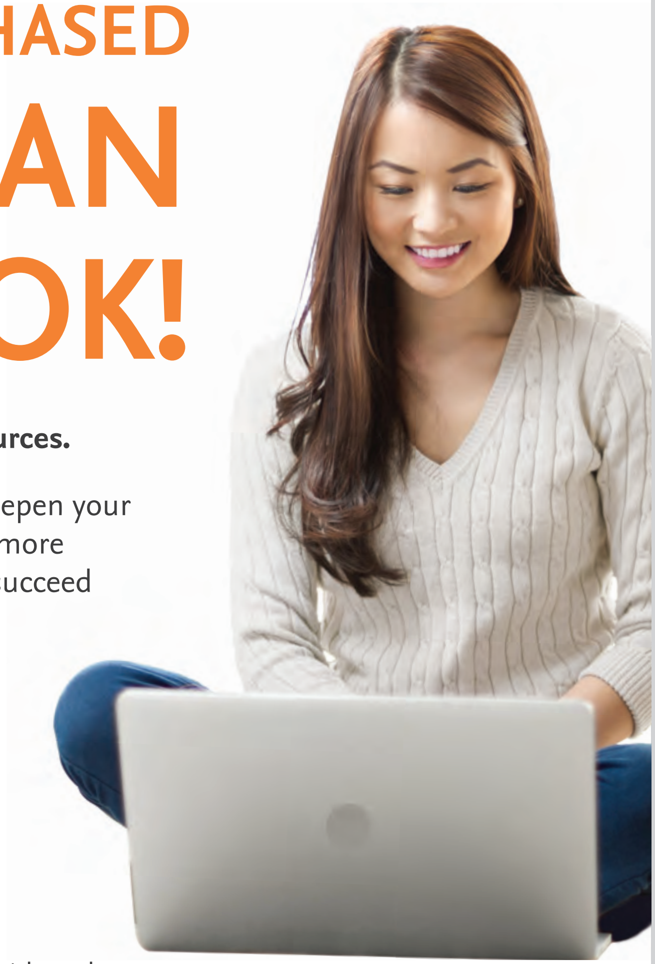

Volume One
9TH EDITION
TEXTBOOK OF DIAGNOSTIC SONOGRAPHY
SANDRA L. HAGEN-ANSERT
Evolve
Access Code Inside
9TH EDITION
Evolve
Access Code Inside

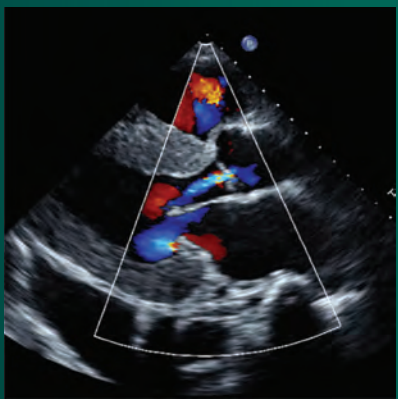
2-Volume Set



TEXTBOOK OF DIAGNOSTIC SONOGRAPHY

9TH EDITION

TEXTBOOK OF DIAGNOSTIC SONOGRAPHY



SANDRA L. HAGEN-ANSERT,
MS, RDMS, RDCS, FASE, FSDMS (RETIRED)
Cardiology Department Manager, Echo Labs
Scripps Clinic & Hospitals—La Jolla, California

ELSEVIER

ELSEVIER
3251 Riverport Lane
St Louis, Missouri 63043

TEXTBOOK OF DIAGNOSTIC SONOGRAPHY, NINTH EDITION

ISBN: 978-0-323-82646-4
Volume 1 ISBN: 978-0-323-82761-4
Volume 2 ISBN: 978-0-323-82762-1

Notices

Knowledge and best practice in this field are constantly changing. As new research and experience broaden our understanding, changes in research methods, professional practices, or medical treatment may become necessary.

Practitioners and researchers must always rely on their own experience and knowledge in evaluating and using any information, methods, compounds, or experiments described herein. In using such information or methods they should be mindful of their own safety and the safety of others, including parties for whom they have a professional responsibility.

With respect to any drug or pharmaceutical products identified, readers are advised to check the most current information provided (i) on procedures featured or (ii) by the manufacturer of each product to be administered, to verify the recommended dose or formula, the method and duration of administration, and contraindications. It is the responsibility of practitioners, relying on their own experience and knowledge of their patients, to make diagnoses, to determine dosages and the best treatment for each individual patient, and to take all appropriate safety precautions.

To the fullest extent of the law, neither the Publisher nor the authors, contributors, or editors, assume any liability for any injury and/or damage to persons or property as a matter of products liability, negligence or otherwise, or from any use or operation of any methods, products, instructions, or ideas contained in the material herein.

Previous editions copyrighted 2018, 2012, 2006, 2001, 1995, 1989, 1983, and 1978.

Executive Content Strategist: Meg Benson
Content Development Manager: Danielle Frazier
Publishing Services Manager: Catherine Jackson
Senior Project Manager/Specialist: Carrie Stetz
Design Direction: Amy Buxton

Printed in India
Last digit is the print number: 9 8 7 6 5 4 3 2 1

To my family,
Art, Aly, Kati, Becca and Eric, Adeline and Osborne,
who mean the world to me

CONTRIBUTORS

Alicia Armour, MA, ACS, RDCS, FASE
Health Center Administrator
Duke Triangle Heart Associates
Duke University Health System
Durham, North Carolina

Joan P. Baker, MSR, RDMS, FSDMS
President, Sound Ergonomics, LLC
Kenmore, Washington

Carolyn T. Coffin, MPH, RDMS, RVT, RDCS
CEO and Consultant
Sound Ergonomics LLC
Kenmore, Washington

M. Robert DeJong, RDMS, RDCS, RVT, FSDMS, FAIUM
Bob DeJong, LLC
Ultrasound Educational Services
Rosedale, Maryland;
Former Radiology Technical Manager–Ultrasound
Russell H. Morgan Department of Radiology and Radiological Science
Johns Hopkins Hospital
Baltimore, Maryland

Kelsey Doyle, MEd, RDMS, RVT
Education and Outreach Coordinator
Center for Perinatal Care
UnityPoint Health-Meriter/University of Wisconsin–Madison
Madison, Wisconsin

John Eisenbrey, PhD
Associate Professor of Radiology
Department of Radiology
Thomas Jefferson University
Philadelphia, Pennsylvania

Kathryn Gill, MS, RDMS, RVT, FSDMS
Sonographer
Program Director
Institute of Ultrasound Diagnostics & Medscan Clinic
Spanish Fort, Alabama

Joy Guthrie, PhD, ACS, RDMS, RDCS, RVT, FSDMS, RCS, RCCS, RVS
Advanced Practice Sonographer
Program Director, Diagnostic Medical Sonography
Researcher, Community Regional Medical Center
Fresno, California

Sandra L. Hagen-Ansert, MS, RDMS, RDCS, FASE, FSDMS (Retired)
Cardiology Department Manager, Echo Labs
Scripps Clinic & Hospitals
La Jolla, California

Talisha M. Hunt, BSRT, RDMS, RDCS, RVT
Lead Sonographer
Assistant Professor of Radiology
Mayo Clinic
Rochester, Minnesota

Mariana Kozirovsky, MS, RDMS, RDCS
Assistant Professor
Long Island University
Brooklyn, New York;
Research Scientist
NYU Grossman School of Medicine
New York, New York

Frederick W. Kremkau, PhD, RACR, RAIMBE, FAIUM, FASA
Professor of Radiologic Sciences
Director, Program for Medical Ultrasound
Center for Experiential and Applied Learning
Wake Forest University School of Medicine
Winston Salem, North Carolina

Dan Lebovic, MD
Professor
Department of Obstetrics and Gynecology
Washington University in St. Louis
St. Louis, Missouri

Daniel Merton, BS, RDMS, FSDMS, FAIUM
Diagnostic Ultrasound Specialist and Principal Project Officer
Health Devices Group
ECRI Institute
Plymouth Meeting, Pennsylvania

Carol Mitchell, PhD, ACS, RDMS, RDCS, RVT, RT(R), FASE, FSDMS
Associate Professor
Department of Medicine
School of Medicine and Public Health
University of Wisconsin–Madison
Madison, Wisconsin

Tanya Nolan, EdD, RDMS, RT(R)(ARRT)
Associate Professor
Director, Diagnostic Medical Sonography
Director, MSRS Innovation and Improvement
School of Radiologic Sciences
Weber State University
Ogden, Utah

Cindy A. Owen, RDMS, RVT, RT, FSDMS
Former Director, Clinical Insights and Development
GE Healthcare, Point of Care Ultrasound
Milwaukee, Wisconsin

Mitzi Roberts, EdD, RDMS, RDCS, FSDMS, RT(R)
Associate Professor
Baptist Health Sciences University;
Clinical Sonographer
Mid-South Maternal-Fetal Medicine
Memphis, Tennessee

Jean Lea Spitz, MPH, RDMS
Executive Director
Perinatal Quality Foundation
Oklahoma City, Oklahoma

Christina Taff, BS, RDMS
Lead Clinical Coordinator
Mid-South Maternal Fetal Medicine
Memphis, Tennessee

Shpetim Telegrafi, MD
Research Professor
Director of Diagnostic Ultrasound
Department of Urology
NYU Grossman School of Medicine
New York, New York

Barbara Trampe, BA, RN, RDMS
Education and Outreach Coordinator
Maternal-Fetal Medicine
University of Wisconsin/UnityPoint Health Meriter
Madison, Wisconsin

Kevin R. Volz, PhD, RVT
Research Lab Manager
Laboratory for Investigative Imaging
Former Instructor/Vascular Technology Clinical Coordinator
School of Health and Rehabilitation Sciences
Division of Radiologic Sciences and Therapy
The Ohio State University College of Medicine
Columbus, Ohio

Kelsi Weakley, MS, RDMS
Clinical Coordinator
Maternal-Fetal Medicine
Regional One Health
Memphis, Tennessee

Kerry Weinberg, PhD, MPA, MA, RDMS, RDCS, RT(T), FSDMS
Associate Professor and Program Director
Diagnostic Medical Sonography
Long Island University
Brooklyn, New York

Michelle Wilson, EdD, RDMS, RDCS, FSDMS
Former Clinical Sonographer and Educator
Kaiser Permanente Medical Center and Kaiser School of Allied Health
Napa, California;
Adjunct Associate Professor
DMS Program
University of Southern Indiana
Evansville, Indiana

Kathryn Zale, MS, RDMS, RVT
Faculty Instructor
Diagnostic Medical Sonography
Pennsylvania College of Health Sciences
Lancaster, Pennsylvania;
Sonographer
Department of Radiology
Children's Hospital of Philadelphia
King of Prussia, Pennsylvania

PREFACE

INTRODUCING THE NINTH EDITION

The ninth edition of *Textbook of Diagnostic Sonography* continues the tradition of excellence that began when the first edition was published in 1978. Like other medical imaging fields, diagnostic sonography has seen dramatic changes and innovations since its first clinical experimental days. Phenomenal strides in transducer design, instrumentation, three-dimensional (3D) and four-dimensional (4D) imaging, image processing, tissue harmonics, elastoraphy, and contrast agents continue to improve image resolution and the diagnostic clinical value of sonography. The ninth edition has kept abreast of advancements in the field by inviting new contributors currently working in different areas of medical sonography throughout the country. The critiques and suggestions from multiple reviewers have helped ensure that this edition includes the most complete and up-to-date information needed to meet the requirements of the modern student of sonography.

Distinctive Approach

This textbook can serve as an in-depth resource both for students of sonography and for practitioners in any number of clinical settings, including hospitals, clinics, and private practices. Care has been taken to cultivate readers' understanding of the patient's total clinical picture even as they study sonographic examination protocol and technique. To this end, each chapter covers the following:

- Key terminology
- Normal anatomy (including cross-sectional anatomy)
- Normal physiology
- Laboratory data and values
- Pathology
- Sonographic evaluation of an organ
- Sonographic findings
- Pitfalls in sonography
- Clinical findings
- Differential considerations
- "Key Pearls"

The full-color art program is of great value to the student of anatomy and pathology for sonography. Detailed line drawings illustrate the anatomic information a sonographer must know to successfully perform specific sonographic examinations. Multiple color photographs of gross pathology help the reader visualize some of the pathology presented, with 3D and color Doppler illustrations included where relevant.

To make important information easy to find, key points are pulled out into numerous boxes; tables throughout the chapters summarize the pathology under discussion and break down the information into Clinical Findings, Sonographic Findings, and Differential Considerations.

Sonographic findings for particular pathologic conditions are always preceded in the text by the following special heading:

Sonographic Findings

This icon makes it very easy for students and practicing sonographers to locate this clinical information quickly.

Study and Review Opportunities

Study and review are also essential to gaining a solid grasp of the concepts and information presented in this textbook. Learning objectives, chapter outlines, "Key Pearls" that summarize the chapter highlights, comprehensive glossaries of key terms, and full references for cited material all help students learn the material in an organized and thorough manner.

Scope and Organization of Topics

The *Textbook of Diagnostic Sonography* is divided into eight parts:

Part I introduces the reader to the foundations of sonography and patient care and includes the following:

- Foundations of sonography, which include the basic principles of ultrasound physics and medical sonography
- Terminology frequently encountered by the sonographer
- Patient care for the sonographer
- Ergonomics and musculoskeletal issues for practitioners
- Anatomic and physiologic relationships within the abdominopelvic cavity
- Comparative sectional anatomy of the abdominopelvic cavity
- Imaging and Doppler artifacts

Part II presents the abdomen in depth. The following topics are discussed:

- Anatomic relationships and physiology
- Abdominal scanning techniques and protocols
- Abdominal applications of ultrasound contrast agents
- Ultrasound-guided interventional techniques
- Emergent abdominal ultrasound procedures
- Sonographic techniques in the transplant patient
- Separate chapters for the vascular system, liver, gallbladder and biliary system, spleen, pancreas, gastrointestinal tract, urinary system, retroperitoneum, peritoneal cavity, and abdominal wall

Part III focuses on the superficial structures of the body, including the breast, thyroid and parathyroid glands, scrotum, and musculoskeletal system.

Part IV is completely updated and explores sonographic examination of the neonate and pediatric patient, including abdomen, adrenal and urinary system, neonatal head, neonatal hip, and neonatal spine.

Part V focuses on the thoracic cavity and includes the following topics:

- Anatomic and physiologic relationships within the thoracic cavity
- Hemodynamics
- Echocardiographic evaluation and techniques
- Introduction to clinical echocardiography
- Fetal echocardiography
- Congenital heart disease

Part VI is composed of four updated chapters on extracranial and intracranial cerebrovascular imaging and peripheral arterial and venous sonographic evaluation.

Part VII is devoted to gynecology and includes the following topics:

- Normal anatomy and physiology of the female pelvis
- Sonographic and Doppler evaluation of the female pelvis
- Separate chapters on the pathologic conditions of the uterus, ovaries, and adnexa
- Updated chapter on the role of sonography in evaluating female infertility

Part VIII takes a thorough look at obstetric sonography. The following topics are discussed:

- The role of sonography in obstetrics
- Clinical ethics for obstetric sonography
- Normal first-trimester findings and first-trimester complications
- Sonography of the second and third trimesters
- Obstetric measurements and gestational age and fetal growth assessment
- Sonography in the high-risk pregnancy
- Prenatal diagnosis of congenital anomalies
- Chapters are devoted to the placenta, umbilical cord, amniotic fluid and fetal membranes, fetal face and neck, neural axis, thorax, anterior abdominal wall, abdomen, urogenital system, and skeleton

New to This Edition

Eight new contributors joined the ninth edition to update and expand existing content, bringing with them a fresh perspective and an impressive knowledge base. They also helped contribute the more than 1000 images new to this edition, including color Doppler, 3D and 4D, and contrast-enhanced images. More than 30 new line drawings complement the new chapters found in the ninth edition.

As the reader proceeds through each chapter, terminology is introduced to lay the foundation for the reader as they study the specific chapters. Information that may seem repetitive to the experienced sonographer is reinforcement for student sonographers as they build their understanding of the many concepts that must be mastered for their clinical experience.

Foundations of Ultrasound (Chapter 1) introduces the reader to the field of sonography, including the role of the sonographer, historical overview of the development of ultrasound, as well as an introduction to basic ultrasound principles and terminology.

Essentials of Patient Care for the Sonographer (Chapter 2) covers all aspects of patient care the sonographer may encounter, including obtaining and understanding vital signs, handling patients on strict bed rest, patients with tubes and oxygen, patient transfer techniques, infection control, isolation techniques, emergency medical situations, assisting patients with special needs, and patient rights.

Ergonomics and Musculoskeletal Issues in Sonography (Chapter 3) outlines the importance of proper technique and positioning throughout the sonographic examination as a way to avoid long-term disability problems that may be acquired with repetitive scanning.

Anatomic and Physiologic Relationships Within the Abdominopelvic Cavity (Chapter 4) introduces the reader to body systems and anatomic relationships, which include membranes and ligaments and potential spaces in the body.

Comparative Sectional Anatomy of the Abdominopelvic Cavity (Chapter 5) is an introduction to sectional anatomy incorporating gross anatomy with comparative ultrasound and computed tomography sectional images. This chapter provides the groundwork for understanding sectional anatomy.

Basic Ultrasound Imaging: Techniques, Terminology, and Tips (Chapter 6) describes scanning techniques, terminology, abdominal ultrasound protocol, and abdominal Doppler technique.

Imaging and Doppler Artifacts (Chapter 7) is an outstanding review of all the artifacts commonly encountered by sonographers. There are numerous examples of the various artifacts and detailed explanations of how these artifacts are produced and how to avoid them.

The abdominal chapters (Chapter 8-19) have all been updated with new images that include ultrasound, CT, and MRI.

Sonographic Techniques in the Transplant Patient (Chapter 20) has been updated to focus on criteria required for organ transplantation, including liver transplant, renal transplant, and pancreatic transplant.

The Breast (Chapter 21) has been updated by a new contributor with new techniques and images.

The Musculoskeletal System (Chapter 24) has been updated by a new contributor with beautiful illustrations and a comprehensive bibliography.

The entire pediatrics section (Chapters 25 to 29) has been fully updated with exquisite new illustrations for each chapter.

Understanding Hemodynamics (Chapter 31) introduces the student to blood flow dynamics, intracardiac pressures and volumes, Doppler basics, and quantification of intracardiac pressures by ultrasound.

Introduction to Clinical Echocardiography: Left-Sided Valvular Heart Disease (Chapter 33) and *Introduction to Clinical Echocardiography: Pericardial Disease, Cardiomyopathies, and Tumors* (Chapter 34) have been included in this edition to provide a basic understanding of significant cardiac findings that may be encountered by the general sonographer or clinician. The fetal echocardiography chapters (Chapters 35 and 36) have been updated to include current protocol and image acquisition.

The entire cerebrovascular section (Chapters 37 to 40) has been updated with new images and current techniques for the sonographer.

Several new contributors have provided their expertise in the obstetrics section (Chapters 47 to 65). *Sonography of the Second and Third Trimesters, Prenatal Diagnosis of Congenital Anomalies, The Placenta, Fetal Face and Neck, Fetal Neural Axis*, and *Fetal Skeleton* chapters have all been updated with new images and references.

Student Resources

Workbook. Available for separate purchase, the *Workbook for the Textbook of Diagnostic Sonography* has also been completely updated. This resource gives the learner ample opportunity to practice and apply the information presented in the textbook.

- Each workbook chapter covers all the material presented in the textbook.
- Each chapter includes exercises on image identification, anatomy identification, key term definitions, and sonographic technique.
- Case studies using images from the textbook invite students to test their skills at identifying key anatomy and pathology and describing and interpreting sonographic findings.
- Students can also test their knowledge with the hundreds of multiple-choice questions found in the four examinations covering different content areas: General Sonography, Pediatric, Cardiovascular Anatomy, and Obstetrics and Gynecology.

Evolve. On the Evolve site, students will find review questions for each chapter.

Instructor Resources

Resources for instructors are also provided on the Evolve site to assist in the preparation of classroom lectures and activities.

- Extensive PowerPoint lectures for each chapter that include illustrations
- Test bank of 1500 multiple-choice questions in Exam View and Word
- Electronic image collection that includes all the images from the textbook both in PowerPoint and in .jpeg format

Evolve Online Course Management. Evolve is an interactive learning environment designed to work in coordination with the *Textbook of Diagnostic Sonography*. Instructors may use Evolve to include an Internet-based course component that reinforces and expands on the concepts delivered in class. Evolve may be used to do all of the following:

- Publish the class syllabus, outlines, and lecture notes
- Set up virtual office hours and email communication
- Share important dates and information on the online class calendar
- Encourage student participation with chat rooms and discussion boards
- Post examinations and manage grade books
- For more information, visit http://www.evolve.elsevier.com/HagenAnsert/diagnostic/ or contact an Elsevier sales representative.

ACKNOWLEDGMENTS

I would like to express my gratitude and appreciation to a number of individuals who have served as mentors and guides throughout my years in sonography. It all began with Dr. George Leopold at UCSD Medical Center. His quest for knowledge and his perseverance for excellence have been the mainstay of my career in sonography. I would also like to recognize Drs. Dolores Pretorius, Nancy Budorick, Wanda Miller-Hance, and David Sahn for their encouragement throughout the years at the UCSD Medical Center in both Radiology and Pediatric Cardiology.

I would also like to acknowledge Dr. Barry Goldberg for the opportunity he gave me to develop countless numbers of educational programs in sonography in an independent fashion and for his encouragement to pursue advancement. I would also like to thank Dr. Daniel Yellon for his early-hour anatomy dissection and instruction; Dr. Carson Schneck, for his excellent instruction in gross anatomy and sections of "Geraldine"; and Dr. Jacob Zutuchni, for his enthusiasm for the field of cardiology.

I am grateful to Dr. Harry Rakowski for his continued support in teaching fellows and students while I was at the Toronto General Hospital. Dr. William Zwiebel encouraged me to continue writing and teaching while I was at the University of Wisconsin Medical Center, and I appreciate his knowledge, which found its way into the liver physiology section of this textbook.

My good fortune in learning about and understanding the total patient must be attributed to a very dedicated cardiologist, James Glenn, with whom I had the pleasure of working while I was at MUSC in Charleston, South Carolina. It was through his compassion and knowledge that I grew to appreciate the total patient beyond the transducer, and for this I am grateful.

For their continual support, feedback, and challenges, I would like to thank and recognize all the students I have taught in the various diagnostic medical sonography programs: Episcopal Hospital, Thomas Jefferson University Medical Center, University of Wisconsin-Madison Medical Center, UCSD Medical Center, and Baptist College of Health Science. These students continually work toward the development of quality sonography techniques and protocols and have given back to the sonography community tenfold.

The continual push towards excellence has been encouraged on a daily basis by our Scripps Clinic Medical Director of the Echo Lab, Dr. David Rubenson, and outstanding staff of Scripps Clinic Cardiologists.

The Cardiac Sonographers at Scripps Clinic Anderson Medical Pavillion have been invaluable in their excellent image acquisition. Special thanks to Kristen Billick for her excellent echocardiographic images. The general sonographers at Scripps Clinic have been invaluable in providing the outstanding images for the obstetrics and gynecology chapters.

I would like to thank the very supportive and capable staff at Elsevier who have guided me though yet another edition of this textbook. Danielle Frazier, Carrie Stetz, and the staff at Elsevier are to be commended on their perseverance to make this an outstanding textbook.

I would like to thank my family, Art, Becca, Aly, and Kati, for their patience and understanding, as I thought this edition would never come to an end. My recent retirement and the pandemic lockdown provided an excellent opportunity for total undivided dedication to this edition.

I think that you will find the 9th Edition of the *Textbook of Diagnostic Sonography* reflects the contribution of so many individuals with attention to detail and a dedication to excellence. I hope you will find this educational experience in sonography as rewarding as I have throughout the past 50 years.

Sandra L. Hagen-Ansert,
MS, RDMS, RDCS, FASE, FSDMS (Retired)

CONTENTS

VOLUME ONE

PART VII Gynecology

PART VIII Obstetrics

CHAPTER

1

Foundations of Clinical Sonography

Sandra L. Hagen-Ansert

OBJECTIVES

On completion of this chapter, you should be able to:

- Describe the role of the sonographer and the career path
- Know the historical developments in medical ultrasound
- List the basic principles and terminology of medical ultrasound
- Identify the transducers necessary for specific ultrasound applications
- Explain the multiple display modes on ultrasound instrumentation
- State the Doppler effect

OUTLINE

KEY TERMS

Absorption
Acoustic impedance
Aliasing
Amplitude
Angle of incidence
Angle of reflection
Attenuation
Axial resolution
Azumithal resolution
Color flow Doppler
Compression
Continuous wave Doppler (CW)
Cycle
Decibel (dB)
Depth gain compensation (DGC)
Doppler angle
Doppler shift
Dynamic range
Focal zone
Frame rate
Frequency shift
Gain
Gray scale
Hertz (Hz)
Gate
Intensity
Interface
Kilohertz (kHz)
Laminar
Lateral resolution
Megahertz (MHz)
Nyquist sampling limit
Power
Pulse duration
Pulsed wave (PW) Doppler
Pulse repetition frequency (PRF)
Rarefaction
Real time
Reflection
Refraction
Resistance
Resolution
Scattering
Slice thickness
Spectral analysis
Spectral broadening
Spatial pulse length
Temporal resolution
Time gain compensation (TGC)
Transducer
Turbulent
Velocity
Wave
Wavelength

The primary purpose of this chapter is to introduce the sonographer to the fascinating field of diagnostic medical ultrasound. Historians will tell us that we cannot know where we are going until we know where we have been. Therefore a brief background into the historical development of ultrasound is presented to enable the sonographer to understand the progress that has been made with technology in the medical application of ultrasound. It is important for sonographers to understand their role in the health care field and to have a global concept of anatomic reconstruction. An introduction into the terminology of the basic principles of ultrasound is critical for the student to understand how and why an anatomic image appears as it does on the ultrasound monitor.

The words *diagnostic medical ultrasound, ultrasound*, and *ultrasonography* have all been used to describe the instrumentation used in ultrasound. *Sonography* is the term used to describe a specialized imaging technique to visualize soft tissue structures in the body. The term *echocardiography*, or simple *"echo,"* refers to an ultrasound examination of only the cardiac structures.

A *sonographer* is a member of the allied health profession who has received specialized education in diagnostic medical sonography and has successfully completed the national boards given by the American Registry of Diagnostic Medical Sonography. A *sonologist* is a physician who has received specialized training in ultrasound and has successfully completed the national boards granted by their respective specialty (e.g., radiology, cardiology, obstetrics).

The field of diagnostic medical ultrasound has grown to become a well-respected and valuable addition to diagnostic imaging by providing pertinent clinical information to the physician and to the patient. The applications of ultrasound are extensive; they include, but are not limited to, the following areas:

- General ultrasound (abdominal, renal, retroperitoneal, chest)
- Superficial ultrasound (breast, thyroid, scrotum)
- Neonatal and pediatric ultrasound (abdomen, renal, hips, brain, spine)
- Echocardiography (adult, pediatric, neonatal, fetal)
- Interventional and therapeutic guided ultrasound
- Obstetric and gynecologic ultrasound
- Intraoperative ultrasound
- Musculoskeletal ultrasound
- Ophthalmologic ultrasound
- Point of care ultrasound

Extensive research has verified the safety of ultrasound as a diagnostic procedure. No harmful effects of ultrasound have been demonstrated at power levels used for diagnostic studies when performed by qualified and nationally certified sonographers, under the direction of qualified and board-certified sonologists, using appropriate equipment and techniques.

Diagnostic ultrasound has developed into a valuable imaging technique for many reasons. First is the lack of ionizing radiation for the ultrasound procedure compared with the various other imaging modalities such as computed tomography (CT) or nuclear medicine. The second reason is the portability of the ultrasound equipment. Even the high-end equipment may be moved into the intensive care unit, emergency department, operating room, cardiac catheterization lab, or physician's office. The low-end systems are now so portable they can fit into the physician's lab coat to be used at the bedside as an *initial quick look* evaluation of the patient physical examination.

Ultrasound is unique in other ways as well. The ultrasound image is presented in a real-time cine clip format, which makes it possible to see the image transition from one cardiac structure to another, or from one organ system to another. The flexible multiplanar imaging capability allows the sonographer to "follow" the path of a tortuous vessel, a moving cardiac structure, or a moving fetus to capture the necessary images. Moreover, Doppler techniques allow the qualitative and quantitative evaluation of blood flow hemodynamics within a vessel. Finally, the cost analysis of an ultrasound system is superior compared with other imaging diagnostic systems.

Currently nearly all hospitals and medical clinics have access to some form of ultrasound instrumentation to provide the clinician with an inside look at the soft tissue structures within the body. Ultrasound manufacturers continue their research to improve image acquisition, develop efficient transducer functionality and design, and create software to improve computer assessment of the acquired information. Two-dimensional (2D) ultrasound information can be recreated in a 3D or 4D (real-time) format to provide an "en face" surface rendering of the specific area. Color Doppler, harmonics, tissue characterization, elastography, strain, and spectral analysis have greatly expanded the utility of ultrasound imaging. The development of specialized contrast agents for use with ultrasound has enabled the clinicians to make specific diagnoses with greater precision.

To obtain even more information from the ultrasound image, various medical centers and manufacturers continue their work towards the development of effective contrast agents that may be ingested or administered intravenously into the bloodstream to facilitate the detection and diagnosis of specific pathologies. Early attempts at producing a contrast effect with ultrasound imaging involved administration of aerated saline or carbon dioxide. Currently research is focused on the development of gas microspheres, which are injected into the patient to provide visual contrast during the ultrasound study. Specific applications of ultrasound contrast are found in Chapter 17.

ROLE OF THE SONOGRAPHER

The sonographer is an allied health professional who has received specific training in diagnostic medical sonography (general applications) or cardiovascular technology (cardiac and vascular applications). The sonographer performs ultrasound procedures and gathers diagnostic data under the direct or indirect supervision of a physician. Sonographers are known as "image makers" who have the ability to create images of soft tissue structures and organs inside the body, such as the liver, pancreas, biliary system, kidneys, heart, vascular system, muscular skeletal system, uterus, and fetus. In addition, sonographers can record hemodynamic information with velocity measurements through the use of color Doppler and spectral analysis to determine if a vessel or cardiac valve is patent (open) or restricted.

Sonographers work directly with physicians and patients as a team member in a medical facility. They also interact with nurses and other medical staff as part of the health care team. The sonographer must be able to review the patient's records to assess clinical history and clinical symptoms, interpret laboratory values, and review other pertinent diagnostic examinations. The sonographer is required to understand and operate complex ultrasound instrumentation using the basic principles of ultrasound physics.

To produce the highest-quality sonographic image for interpretation, the sonographer must possess an in-depth understanding of anatomy and pathophysiology and be able to evaluate a patient's problem specific to the examination ordered. Sonographers use their knowledge and skills to provide physicians with clinical information such as the rapid **FAST** scan evaluation of a trauma victim's injury, visualization of detailed fetal anatomy, and measurement and evaluation of fetal growth and progress or even to evaluate the patient for cardiac abnormalities or injury. In addition to technical expertise and knowledge of anatomy and pathophysiology, several other qualities contribute to the sonographer's success (Box 1.1).

What makes the sonographer distinct from the other health care professionals? The sonographer:

- Reviews the clinical chart and speaks directly with patients to identify symptoms that relate directly to the ultrasound examination.
- Explains the procedure to the patient and performs the examination using the protocol established by the department.
- Analyses each image and correlates the information with patient information.
- Uses independent judgment in recognizing the need to make adjustments with the sonographic protocol to answer the clinical question.
- Reviews the previous sonograms and provides an oral or written summary of the technical findings to the physician for the medical diagnosis.
- Alerts the physician if critical findings or new changes are found on the sonographic examination.

Advantages and Disadvantages of a Sonography Career

Advantages. Sonographers with specialized education in ultrasound obtained from a nationally accredited diagnostic medical sonography or cardiovascular technology program have demonstrated their ability to analyze the clinical situation and to produce high-quality sonographic images, thereby earning the respect of other allied health professionals and clinicians. Every day, sonographers are faced with varied human interactions and opportunities to solve problems. These experiences give sonographers an outlet for their creativity by requiring them to come up with innovative ways to meet the challenges of performing quality sonographic examinations on difficult patients. Sonographers must have the creative ability to alter their normal protocol as difficult situations arise (i.e., trauma patient, immobile patient, postoperative surgical patient with multiple bandages). New applications in ultrasound and improvements in instrumentation create a continual challenge for the sonographer. Flexible schedules and variety in examinations and equipment, not to mention patient personalities, make each day interesting and unique. Certified sonographers find that employment opportunities are abundant, schedule flexibility is high, and salaries are attractive.

Disadvantages. Some sonographers find their position to be stressful and demanding, with the constant changes in medical care and decreased staffing causing increased workloads. Hours of continual scanning may lead to tendinitis, arm and shoulder pain, and back strain. (Chapter 3 focuses on ergonomics and musculoskeletal issues in sonography.)

Sonographers may become frustrated when dealing with terminally ill patients, which can lead to fatigue and depression.

Employment. The field of sonography continues to expand. The demand for certified sonographers exceeds the supply nationwide. Sonographers may find employment in the traditional setting of a hospital or medical clinic. Staffing positions within the hospital or medical setting may include the following: Director of Imaging, Technical Director, Manager, Supervisor, Chief Sonographer, Sonographer Educator, Clinical Staff Sonographer, Research Sonographer, or Clinical Instructor. Clinical research opportunities may be found in the major medical centers throughout the country.

BOX 1.1 Qualities of a Sonographer

The sonographer must possess the following qualities and talents:

Intellectual curiosity to keep abreast of developments in the field

Perseverance to obtain high-quality images and the ability to differentiate an artifact from structural anatomy

Ability to conceptualize two-dimensional (2D) images into a 3D format; ability to reconstruct a 2D image into a 3D format to product an "en face" image

Quick and analytical mind to continually analyze image quality while keeping the clinical situation in mind

Technical aptitude to produce diagnostic-quality images

Good physical health because continuous scanning may cause strain on back, shoulder, or arm. Equipment is mobile; thus the sonographer must be able to manipulate equipment weighing greater than 250 pounds. Doppler is audible; thus sonographers must have adequate hearing to interpolate the returning Doppler audible sound

Independence and initiative to analyze the patient, the history, and the clinical findings and tailor the examination to answer the clinical question

Emotional stability to deal with patients in times of crisis; this means the ability to understand the patient's concerns without losing objectivity

Communication skills for interactions with peers, clinicians, and patients; this includes the ability to clearly communicate ultrasound findings to physicians and the ability *not* to disclose or speculate on findings to the patient during the examination

Dedication because a willingness to go beyond the "call of duty" is often required of the sonographer

Sonographers with advanced degrees (e.g., BS, MS, or PhD) may serve as faculty in diagnostic medical sonography programs as Program Director, Department Head, or Dean of Allied Health. Many sonographers have entered the commercial world as Clinical Application Specialists or Director of Education/Continuing Education Director, marketing specialist, product design/engineering, sales, service, or quality control. Other sonographers have become independent business partners in medicine by offering mobile ultrasound services to smaller community hospitals.

Resource Organizations. Specific organizations are devoted to developing standards and guidelines for ultrasound:

- American Institute of Ultrasound in Medicine (AIUM), www.aium.org. This organization represents all facets of ultrasound to include physicians, sonographers, biomedical engineers, scientists, and commercial researchers.
- American Society of Echocardiography (ASE), www.asecho.org. This very active organization represents physicians, sonographers, and scientists involved with cardiovascular applications of sonography.
- Society of Diagnostic Medical Sonography (SDMS), www.sdms.org. This is the principal organization for more than 25,000 sonographers. The website contains information regarding the SDMS position statement on the code of ethics for the profession of diagnostic medical ultrasound; the nondiagnostic use of ultrasound, the scope of practice for the diagnostic ultrasound professional, and diagnostic ultrasound clinical practice standards.
- Society for Vascular Ultrasound (SVU), www.svunet.org. This is the principal organization representing physicians, sonographers, and scientists in vascular sonography.

Certification. The National Certification Examination for Ultrasound is provided by the American Registry for Diagnostic Medical Sonography (ARDMS), www.ardms.org. This is the primary organization offering international credentials for sonographers once their training has been completed.

Joint Review Committee. The national review boards for educational programs in sonography are provided by two groups:

- Joint Review Committee on Education in Diagnostic Medical Sonography (JRC-DMS) (includes general ultrasound, echocardiography, and vascular technology), www.jrcdms.org.
- Joint Review Committee on Education in Cardiovascular Technology (JRC-CVT) (includes noninvasive cardiology (echocardiography), invasive cardiology (cardiac catheterization), and vascular technology), www.jrccvt.org.

HISTORICAL OVERVIEW OF SOUND THEORY AND MEDICAL ULTRASOUND

A complete history of sound theory and the development of medical ultrasound is beyond the scope of this textbook. The following is a brief overview designed to provide readers a sense of the extensive history and exciting developments in this area of study. For a more detailed outline of historical data, the reader is referred to Dr. Joseph Woo's excellent article "A Short History of the Development of Ultrasound in Obstetrics and Gynecology" and other resources listed in the Selected Bibliography at the end of this chapter.

The story of acoustics began with the Greek philosopher **Pythagoras** (6th century BC), whose experiments on the properties of vibrating strings led to the invention of the sonometer, an instrument used to study musical sounds. Several hundred years later, in 1500 AD, **Leonardo da Vinci** (1452–1519) discovered that sound traveled in waves and discovered that the **angle of reflection** is equal to the **angle of incidence. Galileo Galilei** (1564–1642) is said to have started modern studies of acoustics by elevating the study of vibrations to scientific standards. In 1638, he demonstrated that the frequency of sound waves determined the pitch. **Sir Isaac Newton** (1643–1727) studied the speed of sound in air and provided the first analytic determination of the speed of sound. **Robert Boyle** (1627–1691), an Irish natural philosopher, chemist, physicist, and inventor, demonstrated the physical characteristics of air, showing that it is necessary in combustion, respiration, and sound transmission. **Lazzaro Spallanzani** (1729–1799), an Italian biologist and physiologist, essentially discovered echolocation. Spallanzani is famous for extensive experiments on bat navigation, from which he concluded that bats use sound and their ears for navigation in total darkness. **Augustin Fresnel** (1788–1827) was a French physicist who contributed significantly to the establishment of the theory of wave optics, forming the theory of wave diffraction named after him. **Sir Francis Galton** (1822–1911) was an English Victorian scholar, explorer, and inventor. One of his numerous inventions was the Galton whistle used for testing differential hearing ability. This is an ultrasonic whistle, also known as a dog whistle or a silent whistle. **Christian Johann Doppler** (1803–1853) was an Austrian mathematician and physicist. He is most famous for what is now called the "Doppler effect," which is the apparent change in frequency and wavelength of a wave as perceived by an observer moving relative to the wave's source. In 1880, **Paul-Jacques Curie** (1856–1941) and his brother **Pierre Curie** (1859–1906) discovered *piezoelectricity*, whereby physical pressure applied to a crystal resulted in the creation of an electric potential. **John William Strutt (Lord Rayleigh)** (1842–1919) wrote *The Theory of Sound*. The first volume, on the mechanics of a vibrating medium which produces sound, was published in 1877; the second volume on acoustic wave propagation was published the following year. **Paul Langevin** (1872–1946) was a French physicist and is noted for his work on paramagnetism and diamagnetism. He devised the modern interpretation of this phenomenon in terms of spins of electrons within atoms. His most famous work was on the use of ultrasound using Pierre and Jacques Curie's piezoelectric effect. During World War I, he began working on the use of these sounds to detect submarines through echolocation.

Sonar is an acronym for *sound navigation and ranging*. Sonar is a technique that uses sound propagation, usually underwater, to navigate, communicate with, or detect other vessels. Sonar may be used as a means of acoustic location and measurement of the echo characteristics of "targets" in the water. The term *sonar* is also used for the equipment necessary to generate and receive the sound. The acoustic frequencies used in sonar systems vary from very low (infrasonic) to extremely high (ultrasonic). World War II brought sonar equipment to the forefront of military defense, and medical ultrasound was influenced by the advances in sonar instrumentation.

In the 1940s, **Dr. Karl Dussik** (1908–1968) made one of the earliest applications of ultrasound to medical diagnosis when he used two transducers positioned on opposite sides of the head to measure ultrasound transmission profiles (Fig. 1.1). He discovered that tumors and other intracranial lesions could be detected by this technique. **Dr. William Fry**, an electrical engineer whose primary research was in the field of ultrasound, is credited with being the first to introduce the use of computers in diagnostic ultrasound. Around this same time, he and **Dr. Russell Meyers** performed craniotomies and used ultrasound to destroy parts of the basal ganglia in patients with parkinsonism.

Between 1948 and 1950, three investigators, **Drs. Douglass Howry**, a radiologist, **John Wild**, a clinician interested in tissue characterization, and **George Ludwig**, who was interested in reflections from gallstones, each demonstrated independently that when ultrasound waves generated by a piezoelectric crystal transducer are transmitted into the body, ultrasound waves of different acoustic impedances are returned to the transducer.

One of the pioneers in the clinical investigation and development of ultrasound was **Dr. Joseph Holmes** (1902–1982). A nephrologist by training, Dr. Holmes' initial interest in ultrasound involved its ability to detect bubbles in hemodialysis tubing. Holmes began work in ultrasound at the University of Colorado Medical Center in 1950, in collaboration with a group headed by **Douglass Howry**. In 1951, supported by Joseph H. Holmes, Douglass Howry, along with **William Roderic Bliss** and **Gerald J. Posakony**, both engineers, produced the "immersion tank ultrasound system," the first 2D B-mode (or plan position indicator [PPI] mode) linear compound scanner (Fig. 1.2). 2D cross-sectional images, published in 1952, demonstrated that interpretable 2D images of internal organ structures and pathologies could be obtained with ultrasound. The *Pan Scanner*, created by the Holmes, Howry, Posakony, and **Richard Cushman** team in 1957, was a landmark invention in the history of B-mode ultrasonography. With the Pan Scanner, the patient sat on a modified dental chair strapped against a plastic window of a semicircular pan filled with saline solution while the transducer rotated through the solution in a semicircular arc (Fig. 1.3).

In 1954, echocardiographic ultrasound applications were developed in Sweden by Drs. **Hellmuth Hertz** and **Inge Edler**, who first described the M-mode (motion) display (Fig. 1.4).

An early obstetric contact compound scanner was built by **Tom Brown** and **Dr. Ian Donald** (1910–1987) in Scotland in 1957. Dr. Donald went on to discover many fascinating image patterns in the obstetric patient; his work is still referred to today. Meanwhile, in the early 1960s in Philadelphia, **Dr. J Stauffer Lehman** designed a real-time water path obstetric ultrasound system (Fig. 1.5A).

In 1959 the Ultrasonic Institute was formed at the National Acoustic Laboratory in Sydney, Australia. **George Kossoff** and his team, including **Dr. William Garrett** and **David Robinson**, developed diagnostic B-scanners with the use of a water bath to improve resolution of the image

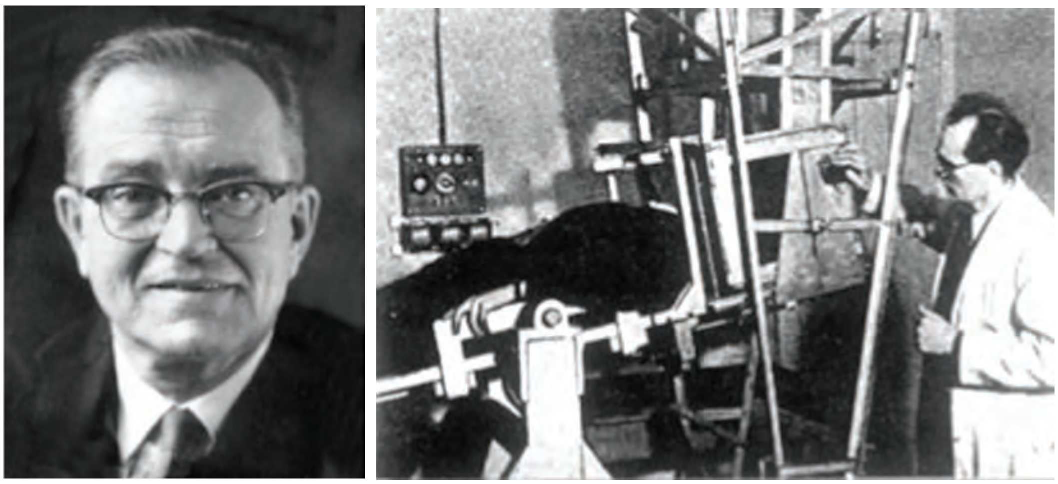


FIG. 1.1 In the 1940s, Dr. Karl Dussik (1908–1968) made one of the earliest applications of ultrasound to medical diagnosis when he used two transducers positioned on opposite sides of the head to measure ultrasound transmission profiles. He discovered that tumors and other intracranial lesions could be detected by this technique.

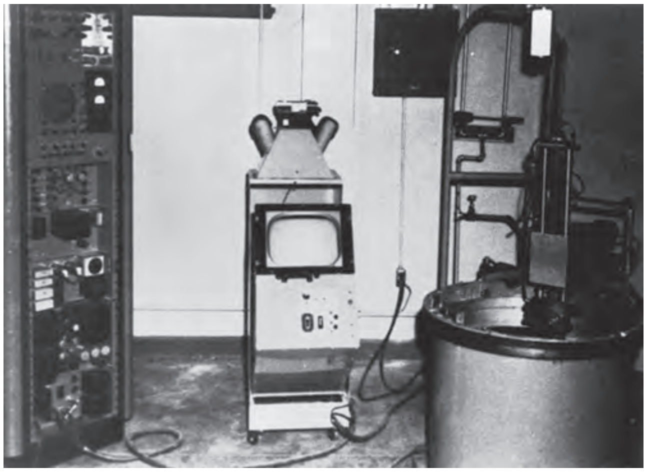


FIG. 1.2 Douglass Howry, along with William Roderic Bliss and Gerald J. Posakony, both engineers, produced the "immersion tank ultrasound system," the first two-dimensional B-mode (or plan position indicator mode) linear compound scanner.

FIG. 1.3 The *Pan Scanner*, put together by the Holmes, Howry, Posakony, and Richard Cushman team in 1957, was a landmark invention in the history of B-mode ultrasonography. With the Pan Scanner, the patient sat on a modified dental chair strapped against a plastic window of a semicircular pan filled with saline solution while the transducer rotated through the solution in a semicircular arc.

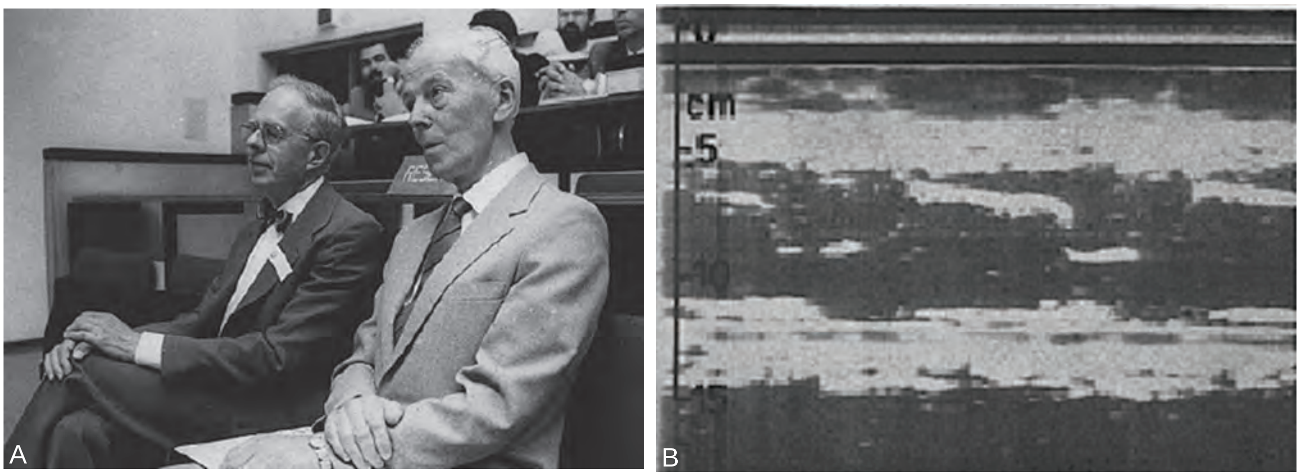


FIG. 1.4 (A) In 1954, echocardiographic ultrasound applications were developed in Sweden by Drs. Hellmuth Hertz and Inge Edler, who first described the M-mode (motion) display. (B) M-mode display of mitral stenosis.

(Figs. 1.5 and 1.6). This group was also responsible for introducing gray-scale imaging in 1972. Kossoff and his colleagues were pioneers in the development of large-aperture, multitransducer technology in which the transducers were automatically programmed to operate independently or as a whole to provide high-quality images without operator intervention, as was required with the contact static scanner that had been developed in 1962 at the University of Colorado.

The advent of real-time scanners changed the face of ultrasound scanning. The first real-time scanner (initially known as a fast B-scanner) was developed by **Walter Krause** and **Richard Soldner**. It was manufactured as the Vidoscan by Siemens Medical Systems of Germany in 1965. The Vidoscan used three rotating transducers housed in front of a parabolic mirror in a water coupling system and produced 15 images per second. The image was made up of 120 lines with basic gray scale. The use of fixed-focus, large-face transducers produced a narrow beam to ensure good resolution and a good image. Fetal life and motions could be demonstrated clearly. In 1973 **James Griffith** and **Walter Henry** at the National Institutes of Health produced a mechanical oscillating real-time scanning device that could produce clear 30-degree sector real-time cardiac images with good resolution. The phased-array scanning mechanism was first described by **Jan Somer** at the University of Limberg in the Netherlands and was in use from 1968, several years before the appearance of linear-array systems.

Medical applications of ultrasonic Doppler techniques were first implemented by **Shigeo Satomura** and **Yasuhara Nimura**

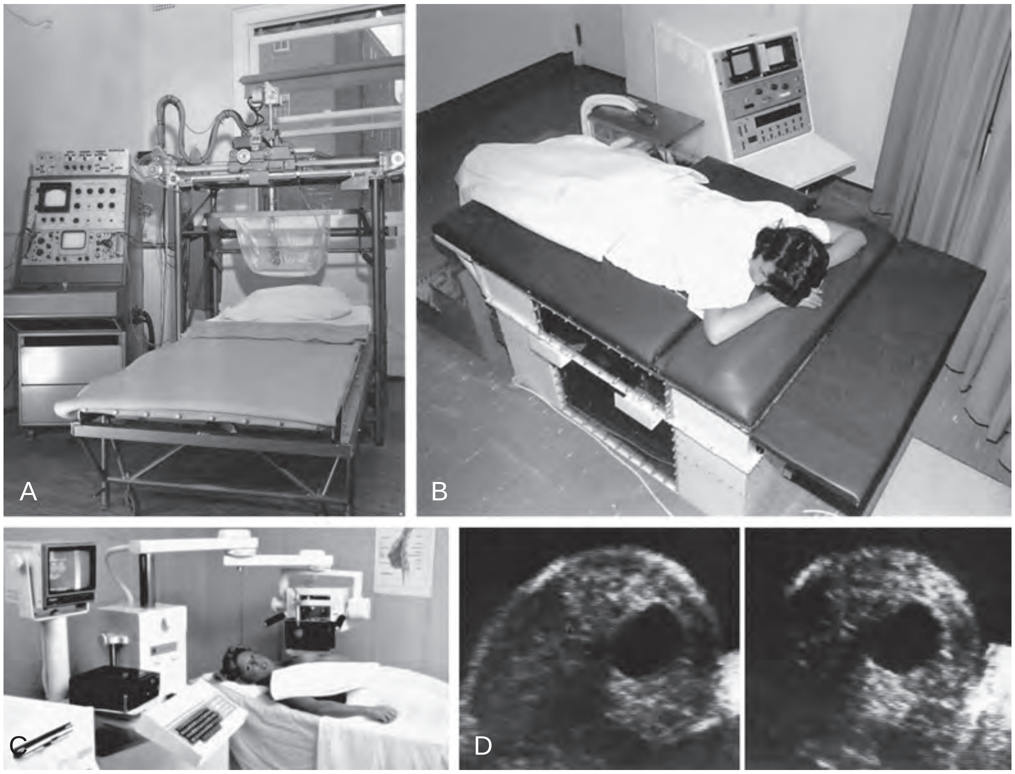


FIG. 1.5 (A) Dr. J. Stauffer Lehman designed a real-time water bath obstetric ultrasound system in Philadelphia. The weight of the water path compressed the mother's inferior vena cava and caused her to become lightheaded. (B–C) Further developments of the water path system show the patient prone with the breast suspended in water or the patient supine with the water path compressing the breast. (D) Images of a breast cyst imaged with the breast suspended.

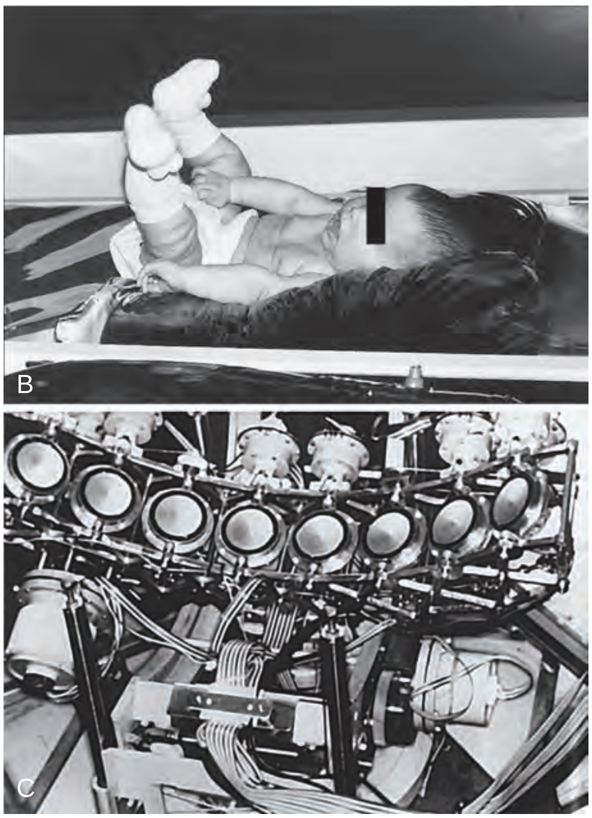


FIG. 1.6 In 1959 the Ultrasonic Institute was formed at the National Acoustic Laboratory in Sydney, Australia. George Kossoff (A) and his team developed diagnostic B-scanners with the use of a water bath (B) to improve resolution of the image. (C) This group was also responsible for introducing gray-scale imaging in 1972. Kossoff and his colleagues were pioneers in the development of large-aperture, multitransducer technology in which the transducers were automatically programmed to operate independently or as a whole to provide high-quality images without operator intervention.

at the Institute of Scientific and Industrial Research in Osaka, Japan, in 1955 for the study of cardiac valve motion and pulsations of peripheral blood vessels. This team pioneered transcutaneous Doppler flow measurements in 1959. In 1966 **Kato** and **T. Izumi** pioneered the directional flowmeter using the local oscillation method whereby flow directions were detected and displayed. This was a breakthrough in Doppler instrumentation because reverse flow in blood vessels could now be documented. In the United States, **Robert Rushmer** and his team did groundbreaking work in Doppler instrumentation, beginning in 1958. They pioneered transcutaneous continuous wave (CW) flow measurements and spectral analysis in 1963. **Donald Baker**, a member of Rushmer's team, introduced a pulsed-Doppler system in 1970 (Fig. 1.7). In 1974 Baker, along with **John Reid**, **Frank Barber**, and others, developed the first duplex pulsed-Doppler scanner, which allowed 2D scale imaging to be used to guide placement of the ultrasound beam for Doppler signal acquisition. In 1985 a work entitled "Real-Time Two-Dimensional Blood Flow Imaging Using an Autocorrelation Technique" by **Chihiro Kasai, Koroku Namekawa**, and **Ryozo Omoto** was published in English. The autocorrelation technique described in this publication could be applied to estimating blood velocity and turbulence in color flow imaging. The autocorrelation technique is a method for estimating the dominating frequency in a complex signal, as well as its variance. The algorithm is both computationally faster and significantly more accurate compared with the Fourier transform because the resolution is not limited by the number of samples used. This provided the rapid means of frequency estimation to be performed in real time that is still used currently.

In 1987 The Center for Emerging Cardiovascular Technologies at **Duke University** started a project to develop a real-time volumetric scanner for cardiac imaging. In 1991 they produced a matrix array scanner that could image cardiac structures in real time and in 3D. By the second half of the 1990s, many other centers throughout the world were working on laboratory and clinical research into 3D ultrasound (3DU). Currently, 3DU has developed into a clinically effective diagnostic imaging technique.

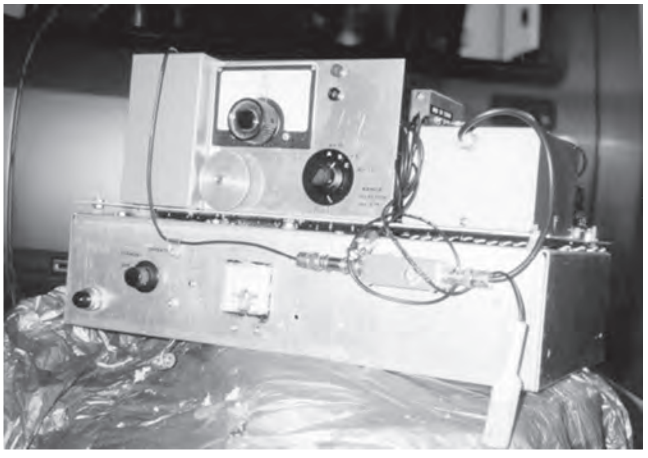


FIG. 1.7 Donald Baker, a member of Rushmer's team, introduced a pulsed-Doppler system in 1966.

INTRODUCTION TO BASIC ULTRASOUND PRINCIPLES

To produce high-quality images that are free of artifacts, the sonographer must have a firm understanding of the basic principles of ultrasound. This section introduces the basic principles of acoustics, measurement units, instrumentation, real-time sonography, 3DU, harmonic imaging, and optimization of gray-scale and Doppler ultrasound to reinforce the sonographer's understanding of scanning techniques. The student sonographer needs to understand a new language and terminology with ultrasound physics. This serves as a brief overview of the material that would be covered in depth in a dedicated ultrasound physics textbook.

Acoustics

Acoustics is the branch of physics that deals with sound and sound waves. It is the study of generating, propagating, and receiving sound waves. Within the field of acoustics, *ultrasound* is defined as sound frequencies that are beyond (ultra-) the range of normal human hearing. Most human hearing ranges between 20 **hertz (Hz)** and 20 **kilohertz (kHz)** (Fig. 1.8). Thus ultrasound refers to sound frequencies greater than 20 kHz.

Sound is the result of mechanical energy that produces alternating **compression** and **rarefaction** of the conducting medium as it travels as a wave (Fig. 1.9). (A **wave** is a propagation of energy that moves back and forth or vibrates at a steady rate.) Diagnostic ultrasound uses short sound pulses at frequencies of 1 to 20 million **cycles**/sec (**megahertz [MHz]**) that are transmitted into the body to examine soft tissue anatomic structures (Table 1.1). In medical ultrasound, the piezoelectric vibrating source within the transducer is a ceramic element that vibrates in response to an electrical signal. The vibrating motion of the ceramic element in the transducer causes the particles in the surrounding tissue to vibrate. In this way the ultrasound transducer converts electrical energy into mechanical energy as the sonographic imaging is produced. As the sound beam is directed into the body by the transducer at various angles to the organs, reflection, absorption, and scatter cause the returning signal to be weaker than the initial impulse. Over a short period of time, multiple anatomic images are acquired in a real-time format.

The **velocity** of propagation is constant for a given tissue and is not affected by the frequency or wavelength of the pulse. In soft tissues, the assumed average propagation velocity is 1540 m/sec (Table 1.2). It is the stiffness and the density of a medium that determine how fast sound waves will travel through the structure. The more closely packed the molecules, the faster is the speed of sound.

The velocity of sound differs greatly among air, bone, and soft tissue, although the velocity of sound varies by only a little

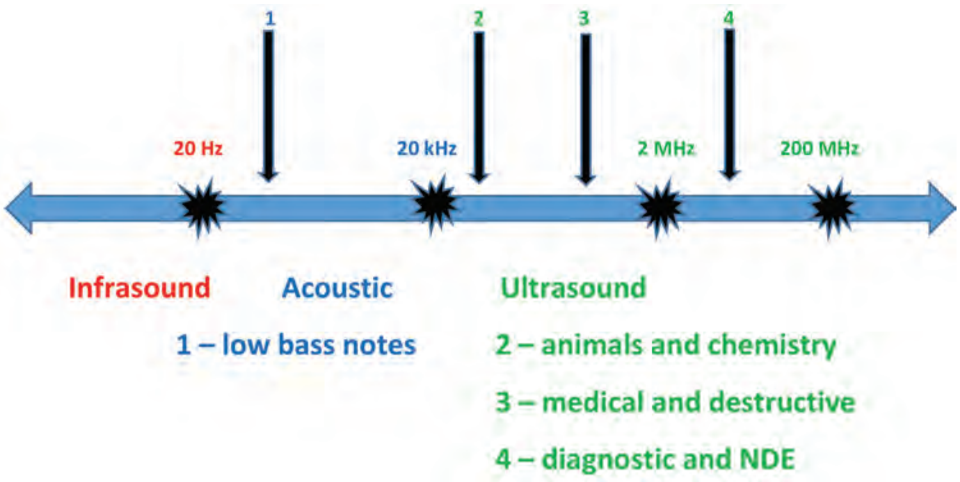


FIG. 1.8 Acoustics is the branch of physics that deals with sound and sound waves. Within the field of acoustics, ultrasound is defined as sound frequencies that are beyond (ultra-) the range of normal human hearing. Most human hearing ranges between 20 hertz (Hz) and 20 kilohertz (kHz). Thus ultrasound refers to sound frequencies greater than 20 kHz.

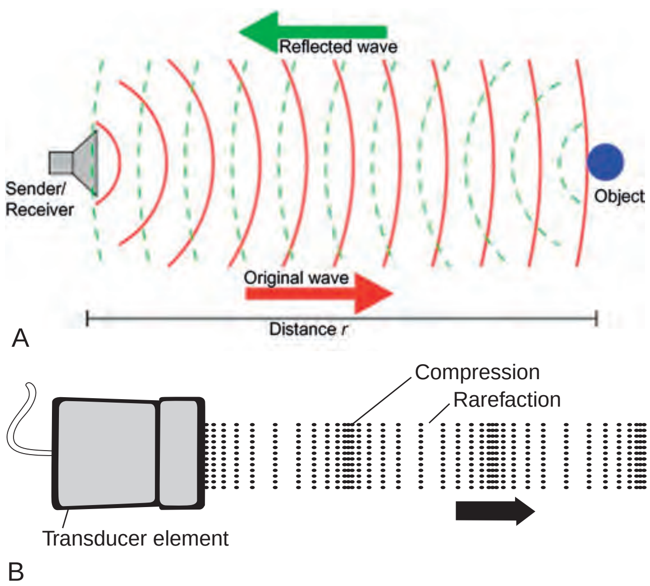


FIG. 1.9 (A) Ultrasound waves are created by a vibrating crystal within a ceramic probe. Waves travel through the tissue and are partly reflected at each tissue interface. (B) As the transducer element vibrates, waves undergo compression and expansion, or rarefaction, by which the molecules are pulled apart.

from one soft tissue to another. Sound waves travel slowly through gas (air), at intermediate speed through liquids, and quickly through solids (metal). Air-filled structures, such as the lungs and stomach, or gas-filled structures, such as the bowel, impede the sound transmission, and sound is attenuated through most bony structures. Small differences among fat, blood, and organ tissues that are seen on an ultrasound image may be better delineated with higher-frequency transducers that improve resolution but lose the depth penetration.

Measurement of Sound. The decibel (dB) unit is used to measure the intensity (strength), amplitude, and power of an ultrasound wave. Decibels allow the sonographer to compare

TABLE 1.1 Applications of Sound Frequency Ranges

Frequency Range	Manner of Production	Application
Infrasound		
0–25 Hz	Electromagnetic vibrators	Vibration analysis of structures
Audible		
20 Hz–20 kHz	Electromagnetic vibrators, musical instruments	Communications, signaling
Ultrasound		
20–100 kHz	Air whistles, electric devices	Biology, sonar
100 kHz–1 MHz	Electric devices	Flaw detection, biology
1–20 MHz	Electric devices	Diagnostic ultrasound

Hz, Hertz; *kHz*, kilohertz; *MHz*, megahertz.

TABLE 1.2 Characteristic Acoustic Impedance and Velocity of Ultrasound

Material	Acoustic Impedance (g/cm/sec × 10)	Velocity
Air	0.0001	331
Fat	1.38	1450
Water	1.50	1430
Blood	1.61	1570
Kidney	1.62	1560
Liver	1.65	1550
Muscle	1.70	1580
Skull	7.80	4080

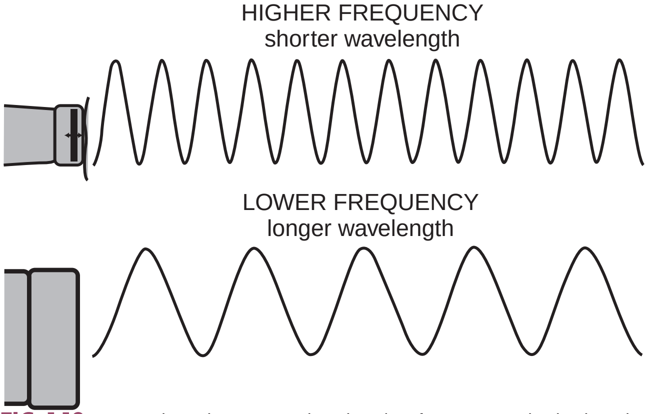


FIG. 1.10 Wavelength is inversely related to frequency. The higher the frequency, the shorter is the wavelength and the less is the depth of penetration. The longer wavelength has a lower frequency and a greater depth of penetration.

the intensity or **amplitude** of two signals. **Power** refers to the rate at which energy is transmitted. Power is the rate of energy flow over the entire beam of sound and is often measured in watts (W) or milliwatts (mW). **Intensity** is defined as power per unit area. It is the rate of energy flow across a defined area of the beam and can be measured in watts per square meter (W/m^2) or milliwatts per square centimeter. Power and intensity are directly related: If you double the power, the intensity also doubles.

Frequency. Sound is characterized according to its frequency (Fig. 1.10). Frequency may be explained by the following analogy: If a stick were moved into and out of a pond at a steady rate, the entire surface of the water would be covered with waves radiating from the stick. If the number of vibrations made in each second were counted, the frequency of vibration could be determined. In ultrasound, **frequency** describes the number of oscillations per second performed by the particles of the medium in which the wave is propagating:

1 oscillation/sec = 1 cycle/sec = 1 **hertz (1 Hz)**
1000 oscillations/sec = 1 kilocycle/sec = 1 **kilohertz (1 kHz)**
1,000,000 oscillations/sec = 1 megacycle/sec = 1 **megahertz (1 MHz)**

The sonographer should be familiar with the units of measurement commonly used in ultrasound (Table 1.3).

Propagation of Sound Through Tissue. Once sound pulses are transmitted into a body, they can be reflected, scattered, refracted, or absorbed. **Reflection** occurs whenever the pulse encounters an **interface** between tissues with different acoustic impedances (Fig. 1.11). **Acoustic impedance** is the measure of a material's **resistance** to the propagation of sound. The strength of the reflection depends on the difference in acoustic impedance between the tissues, as well as the size of the interface, its surface characteristics, and its orientation with respect to the transmitted sound pulse. The greater the acoustic mismatch, the greater is the backscatter or reflection (Fig. 1.12). Large, smooth interfaces are called *specular reflectors*. If specular reflectors are aligned perpendicular to the direction of the transmitted pulse, they reflect sound directly back to the active crystal elements in the transducer and produce a strong signal. Specular reflectors that are not oriented perpendicular to the sound produce a weaker signal. **Scattering** refers to the redirection of sound in multiple directions. This produces a weak signal and occurs when the pulse encounters a small acoustic interface or a large interface that is rough (Fig. 1.13). **Refraction** is a change in the direction of sound that occurs when sound encounters an interface between two tissues that transmit sound at different speeds. Because the sound frequency remains constant, the **wavelength** changes to accommodate differences in the speed of sound in the two tissues. The result of this change in wavelength is a redirection of the sound pulse as it passes through the interface. **Absorption** describes the loss of sound energy secondary to its conversion to thermal energy. This is greater in soft tissues than in fluid and greater in bone than in soft tissues. Absorption is a major cause of acoustic shadowing.

Piezoelectric Crystals. The piezoelectric effect is a method by which ultrasound is generated. An ultrasound transducer, consisting of an array of piezoelectric crystals, is used to

TABLE 1.3 Units Commonly Used in Ultrasound

Quantity	Unit	Abbreviation
Amplifier gain	Decibels	dB
Area	Meters squared	m^2
Attenuation	Decibels	dB
Attenuation coefficient	Decibels per centimeter	dB/cm
Frequency	Hertz (cycles per second)	Hz
Intensity	Watts per square meter	W/m^2
Length	Meter	m
Period	Microseconds	μsec
Power	Watts	W
Pressure amplitude	Pascals	Pa
Relative power	Decibels	dB
Speed	Meters per second	m/sec
Time	Seconds	sec
Volume	Meters cubed	m^3

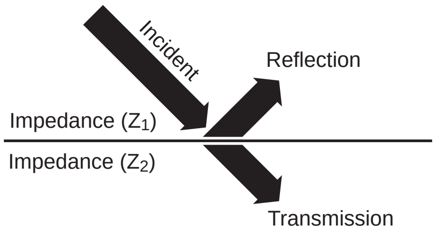


FIG. 1.11 Reflection occurs when a sound wave strikes an interface between two objects with different acoustic impedances, causing some of the energy to be transmitted across the interface and some of it to be reflected.

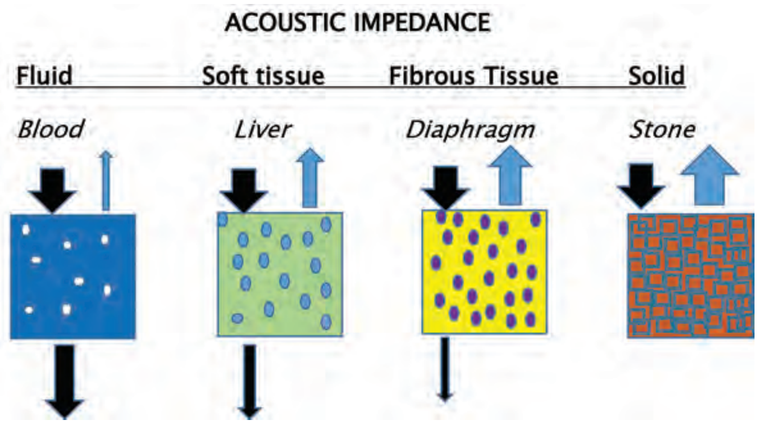


FIG. 1.12 Acoustic impedance is the measure of a material's resistance to the propagation of sound. The strength of the reflection depends on the difference in acoustic impedance between the tissues, as well as the size of the interface, its surface characteristics, and its orientation with respect to the transmitted sound pulse. The greater the acoustic mismatch, the greater is the backscatter or reflection.

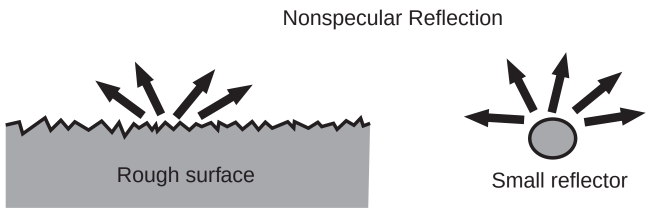


FIG. 1.13 Scattering. Nonspecular reflectors reflect, or scatter, the sound wave in many directions.

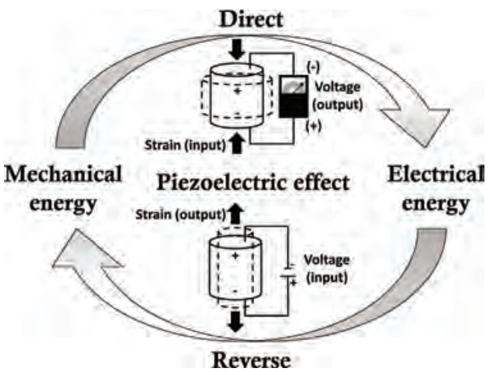


FIG. 1.14 Piezoelectric effect. When a ceramic crystal is electronically stimulated, it deforms and vibrates to produce the sound pulses used in diagnostic sonography. If the organ or structure is exposed to an electric shock, it will begin to vibrate and transmit a sound wave back to the crystal.

generate and detect (or receive) ultrasound waves (Fig. 1.14). An ultrasound transducer converts electrical energy to a mechanical vibration and vice versa. Because ultrasound is a mechanical wave in a longitudinal direction, it is transmitted in a straight line and it can be focused. These waves obey laws of reflection and refraction.

Pulse duration is the time that a piezoelectric element vibrates after electrical stimulation. Each pulse consists of a band of frequencies referred to as *bandwidth*. The center frequency produced by a transducer is the resonant frequency of

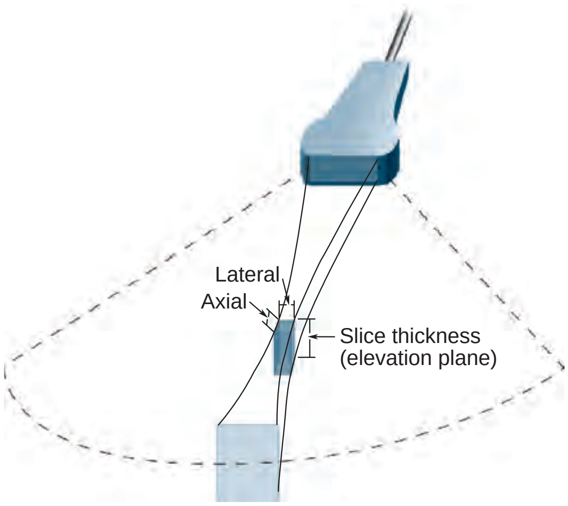


FIG. 1.15 Axial resolution refers to the ability to resolve objects within the imaging plane that are located at different depths along the direction of the sound pulse. Lateral resolution refers to the ability to resolve objects within the imaging plane that are located side by side at the same depth from the transducer. Azimuthal (elevation) resolution refers to the ability to resolve objects that are the same distance from the transducer but are located perpendicular to the plane of imaging.

the crystal element and depends on the thickness of the crystal. The echoes that return to the transducer distort the crystal elements and generate an electric pulse that is processed into an image. The higher-amplitude echoes produce a greater crystal deformation and generate a larger electronic voltage, which is displayed as a brighter pixel. These 2D images are known as *B-mode*, or brightness mode, images.

Image Resolution. Resolution is the ability of an imaging process to distinguish adjacent structures in an object and is an important measure of image quality. The resolution of the ultrasound image is determined by the size and configuration of the transmitted sound pulse. Resolution is always considered in three dimensions: axial, lateral, and azimuthal (elevation). **Axial resolution** (Fig. 1.15) refers to the ability to resolve objects within the imaging plane that are located at different depths along the direction of the sound pulse. This depends on the direction of the sound pulse, which, in turn, depends on the wavelength. Because wavelength is inversely proportional to frequency, the higher-frequency probes produce shorter pulses and better axial resolution but with less penetration. These probes are best for superficial structures such as thyroid, breast, and scrotum. **Lateral resolution** (see Fig. 1.15) refers to the ability to resolve objects within the imaging plane that are located side by side at the same depth from the transducer. Lateral resolution can be varied by adjusting the **focal zone** of the transducer, which is the point at which the beam is the narrowest. **Azimuthal** (elevation) **resolution** (see Fig. 1.15) refers to the ability to resolve objects that are the same distance from the transducer but are located perpendicular to the plane of imaging. Azimuthal resolution is also related to the thickness of the tomographic slice. **Slice thickness** is usually determined by the shape of the crystal elements or the characteristics of fixed acoustic lenses.

Attenuation. **Attenuation** is the sum of acoustic energy loss resulting from absorption, scattering, and reflection. It refers to the reduction in intensity and amplitude of a sound wave as it travels through a medium as some of the energy is absorbed, reflected, or scattered (Fig. 1.16A). Thus, as the sound beam travels through the body, the beam becomes progressively weaker. In human soft tissue, sound is attenuated at the rate of 0.5 dB/cm per million hertz. If air or bone is coupled with soft tissue, more energy will be attenuated. Attenuation through a solid calcium interface, such as a gallstone, will produce a posterior shadow to the ultrasound beam with sharp borders on the ultrasound image (see Fig. 1.16B).

With the exception of air-tissue and bone interfaces, the differences in acoustic impedance in biologic tissues are so slight that only a small component of the ultrasound beam is reflected at each interface. The lung and bowel have a detrimental effect on the ultrasound beam, causing poor transmission of sound. Therefore anatomy beyond these two areas cannot be imaged because of air interference. Bone conducts sound at a much faster speed (4080 m/sec) than soft tissue. Recall the normal transmission of sound through soft tissue travels at 1540 m/sec. Much of the sound beam is absorbed or scattered as it travels through the body, undergoing progressive attenuation. The sound is reflected according to the acoustic impedance, which is related to tissue density. Most of the sound is passed into tissues deeper in the body and is reflected at other interfaces. Because acoustic impedance is the product of the velocity of sound in a medium and the density of that medium, acoustic impedance increases if the density or propagation speed increases.

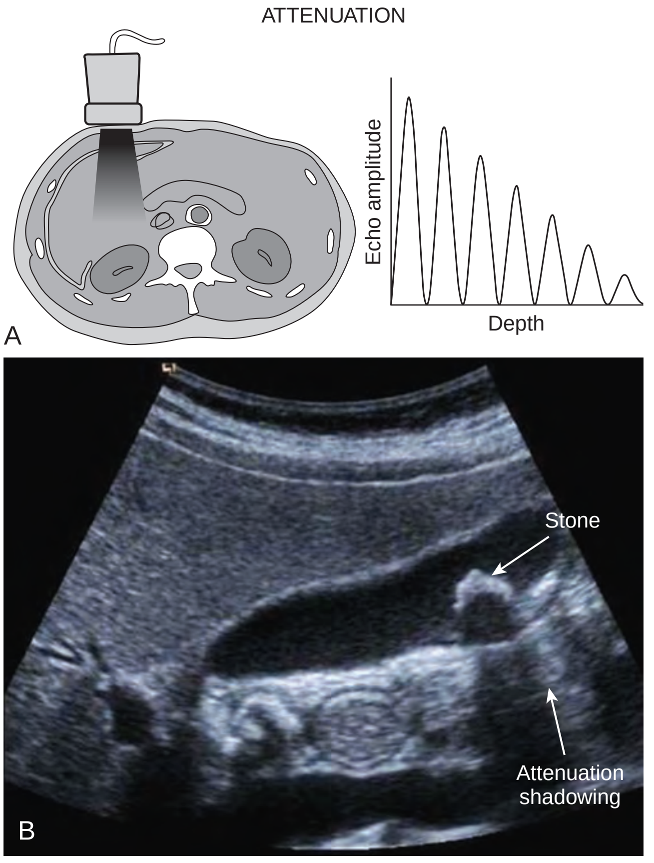


FIG. 1.16 (A) Attenuation. As the sound travels through the abdomen, it becomes attenuated, as some of it is reflected, scattered, and absorbed. (B) Large gallstone causing attenuation (shadowing) beyond the calcified stone.

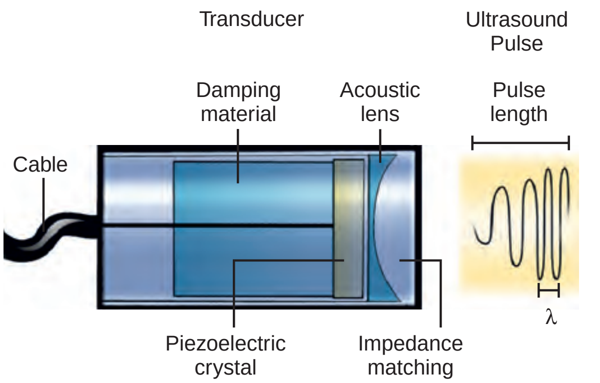


FIG. 1.17 A transducer is a device that converts energy from one form to another. Most of the transducers used currently are not a single element but rather a combination of elements that form an array. The transducer array scan head contains multiple small piezoelectric elements, each with its own electrical circuitry. These elements are very small in diameter, which greatly reduces beam divergence. A reduction in beam divergence leads to beam steering and focusing. The focus of the array transducers occurs on reception and on transmission.

Transducer Selection in a Clinical Imaging Practice

Many different types of ultrasound probes are available for the sonographer to become familiar with and understand which probe is best for a specific application. The probes are available in different frequencies with different physical dimensions, footprints, and shapes to provide specific image formats.

A **transducer** is a device that converts energy from one form to another. Fig. 1.17 illustrates the single-element transducer design. Most of the transducers used currently are not a single element but rather a combination of elements that form an array. The transducer array scan head contains multiple small piezoelectric elements, each with its own electrical circuitry. These elements are very small in diameter, which greatly reduces beam divergence. A reduction in beam divergence leads to beam steering and focusing. The focus of the array transducers occurs on reception and on transmission (Fig. 1.18). The focusing is done dynamically during reception. Shortly after pulse transmission, the received focus is set close to the transducer. As time elapses and the echoes from the distant targets return, the focal distance is gradually lengthened. Some instruments have multiple transmit focal zones to allow better control of the resolution of the beam at certain depths of field in the image.

Very high-frequency (7 to 15 MHz) linear array probes are generally used for smaller structures (carotids, leg veins, thyroid, scrotum, breast, musculoskeletal, and peripheral vascular structures) that are superficial in nature and therefore do not require depth of view (Fig. 1.19). The footprint of the linear array may be small with small element sizes. The fine detail of the breast and thyroid uses very high frequencies (14 MHz), whereas the imaging of the peripheral vascular structures remains lower at 3 to 11 MHz.

The abdomen is usually scanned with a curved or convex array and/or a sector array; the frequency will depend on the size of the patient. Most abdominal probes are multifrequency (broadband) probes, allowing the sonographer to select the low frequency for technically difficult patients. The key factors for the selection of the convex array include the footprint, the field of view (FOV), and the radius of the curvature. The footprint describes the contact area of the area imaged and may be displayed as a rectangle, circle, or ellipse. The radius of curvature and FOV are related to the image extent and coverage. For 3D imaging in the abdomen, the fully electronic convex 2D arrays are used with two FOVs given for the orthogonal scan directions. The phased array sector probe is also available to image specific areas in the abdomen. The small footprint of the sector probe is also useful to scan in between the intercostal spaces in the abdomen.

Obstetric and gynecologic scans are usually performed with a multifocused linear or mechanically scanned convex array transducer. Matrix or fully populated 2D arrays are also available to image the fetus in real time. The endocavity probe is used to scan intercavity areas in the pelvis. The end-fire arrays are located at the end of the probe and are convex or curved arrays with wide FOVs. In addition, phased arrays in an endo-array package may be used. The frequencies are usually 5 MHz and higher.

Neonatal and pediatric probes have smaller footprints than those used for the adult. The higher frequencies (7 MHz) are used because the FOV is much less than the adult. The arrays useful in this population include the static and, for 3D,

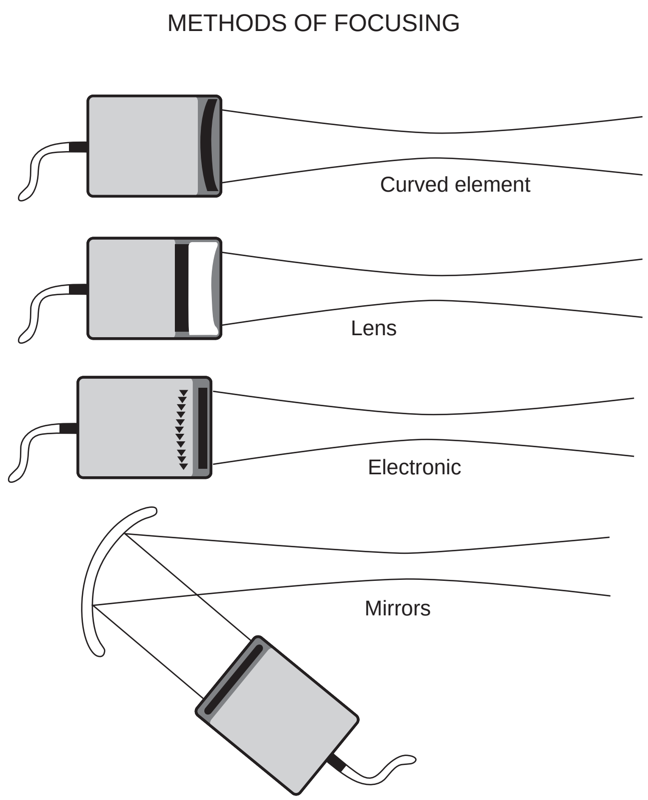


FIG. 1.18 Focusing effectively narrows the ultrasound beam. Multiple methods may be used to achieve this effect.

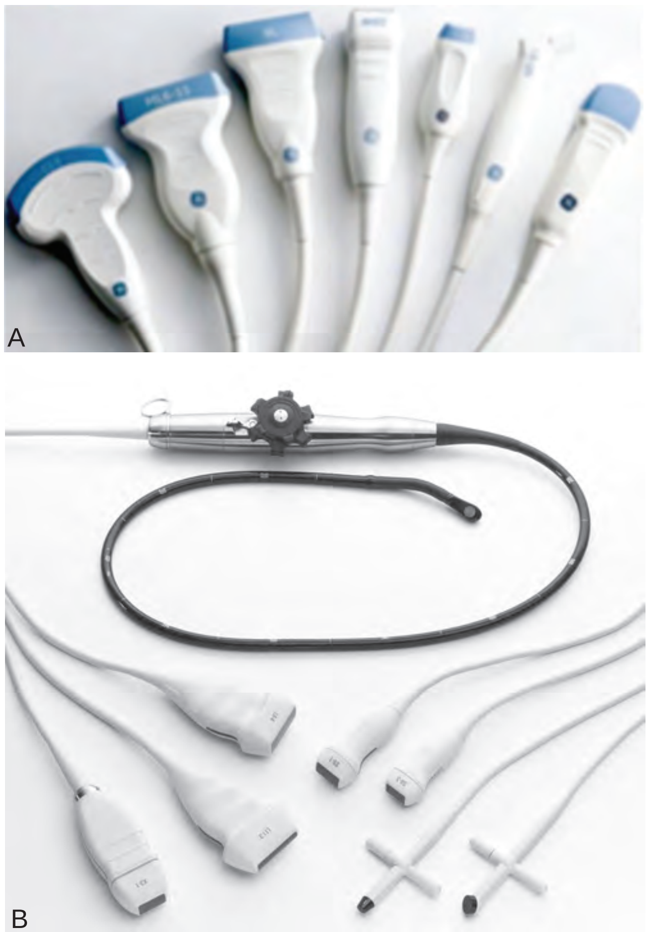


FIG. 1.19 (A) The type of transducer selected for a particular examination depends on several factors: the type of examination, size of the patient, and amount of fatty or muscular tissue present. (B) Transducers vary in size from the small Pedof transducer to the larger diameter transducers.

the mechanically swept linear array and convex probe. The cardiac images use a higher frequency phased array for 2D and 3D imaging.

The transesophageal studies are obtained with the specialized smaller transesophageal probe, which is inserted into the patient's esophagus to image detailed anatomy of the cardiac structures. This phased array or matrix probe uses high frequencies (5 MHz) and are implemented with manipulators and motors to adjust the orientation of the transducer by the physician. These probes are available in both adult and pediatric sizes.

A smaller intracardiac phased array probe with very high frequencies (20 MHz) may be used during specialized cardiac catheterization procedures to image the coronary arteries. Other surgical intracavity probes may be used during laparoscopic surgery to image vessels or specific areas in the abdomen.

An echocardiographic examination is performed with a multifocused broadband fully populated 2D or matrix arrays containing thousands of elements. This allows the sonographer to produce real-time (4D) depiction of pyramidal volumes, visualization of arbitrary cut planes, and 4D cardiac imaging and color flow mapping.

Multielement Transducer. These transducers contain groups of small crystal elements arranged in a sequential fashion (Fig. 1.20). The transmitted sound pulses are created by the summation of multiple pulses from many different elements. The timing and sequence of activation are altered to steer the transmitted pulses in different directions while focusing at multiple levels.

Sector Phased-Array Transducer. With this transducer, every element in the array participates in the formation of each transmitted pulse. The sound beams are steered at varying angles from one side of the transducer to the other to produce a sector format (Fig. 1.21). The transducer is smaller and is better able to scan in between ribs (especially useful in echocardiography). The transducer permits a large, deep FOV. The limitations of this transducer are a reduced near field focus and a small superficial FOV.

Linear-Array Transducer. The linear-array transducer activates a limited group of adjacent elements to generate each pulse. The pulses travel in the same direction (parallel) and are oriented perpendicular to the transducer surface, resulting in a rectangular image. The pulses may also be steered to produce a trapezoidal image (see Fig. 1.21). This transducer provides high resolution in the near field. The transducer is quite large and cumbersome for accessing all areas and is used more often in obstetric ultrasound.

Curved-Array Transducer. The curved-array transducer uses the linear-array transducer with the surface of the transducer re-formed into a curved convex shape to produce a moderately sized sector-shaped image with a convex apex. This

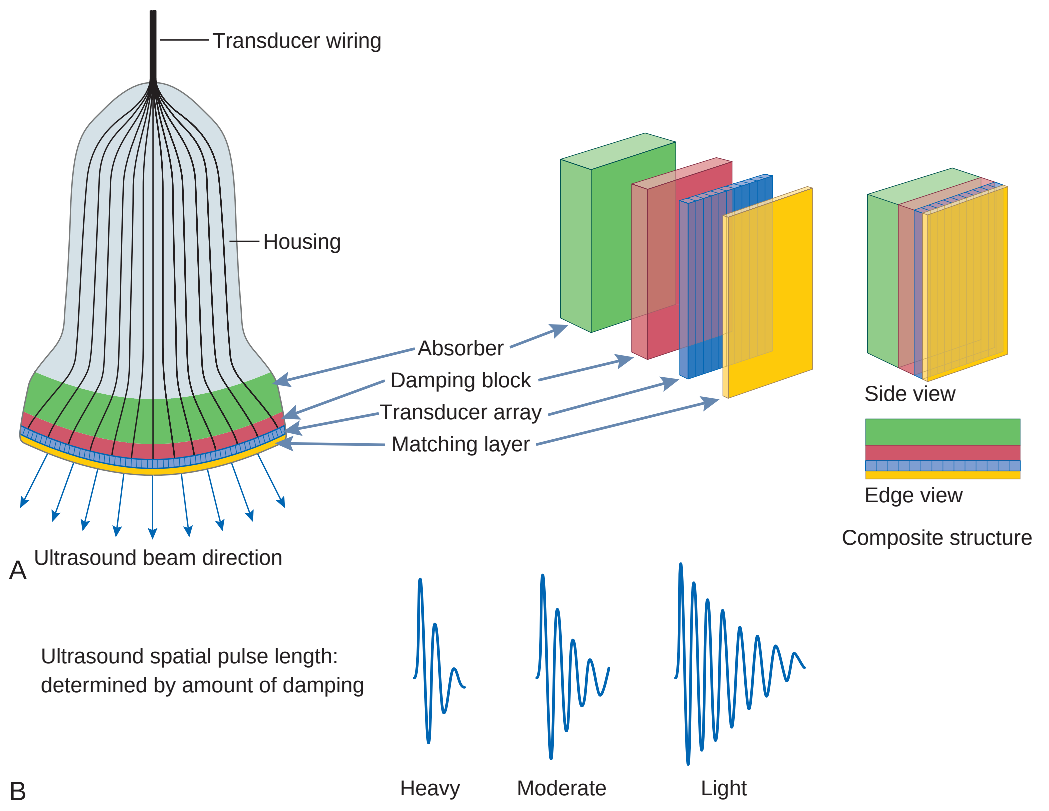


FIG. 1.20 (A) The multielement transducer contains groups of small crystal elements arranged in a sequential fashion. The transmitted sound pulses are created by the summation of multiple pulses from many different elements. (B) The timing and sequence of activation are altered to steer the transmitted pulses in different directions while focusing at multiple levels.

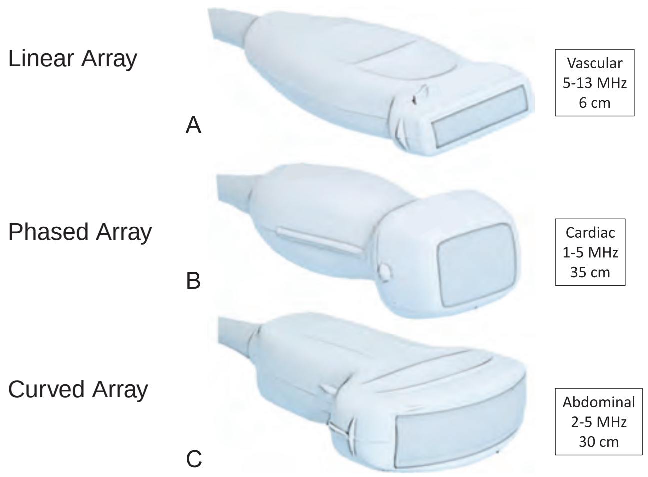


FIG. 1.21 (A) The linear-array transducer activates a limited group of adjacent elements to generate each pulse. The pulses travel in the same direction (parallel) and are oriented perpendicular to the transducer surface, resulting in a rectangular image. The pulses may also be steered to produce a trapezoidal image. (B) With the sector phased array transducer, every element in the array participates in the formation of each transmitted pulse. The sound beams are steered at varying angles from one side of the transducer to the other to produce a sector format (Fig. 1.21). The transducer is smaller and is better able to scan in between ribs (especially useful in echocardiography). The transducer permits a large, deep field of view. (C) The curved-array transducer uses the linear-array transducer with the surface of the transducer re-formed into a curved convex shape to produce a moderately sized sector-shaped image with a convex apex. This allows for a wider far field of view, with slightly reduced resolution. This type of probe can be formatted into many different applications with varying frequencies for use in the abdomen and in obstetrical ultrasound.

allows for a wider far FOV, with slightly reduced resolution. This type of probe can be formatted into many different applications with varying frequencies for use in the abdomen and in obstetrical ultrasound (see Fig. 1.21).

Intraluminal Transducer. These transducers are very small and can be placed into different body lumens that are close to the organ of interest. Much higher frequencies are used with high resolution. Elimination of the body adipose tissue greatly enhances image quality. The drawback of a high-frequency transducer is a limited depth of field. These transducers have been labeled as transvaginal and endorectal when used to image the female organs and rectum, respectively (Fig. 1.22A). Cardiologists have used the transesophageal probe to produce exquisite views of the cardiac valvular apparatus (Fig. 1.22B). Interventional physicians have used the tiny intracardiac echocardiography (ICE) probes that fit onto the end of a catheter in order to see intracoronary and intravascular detail.

Pulse-Echo Display Modes

A-Mode (Amplitude Modulation). A-mode, or amplitude modulation, produces a 1D image that displays the amplitude strength of the returning echo signals along the vertical axis and the time (distance) along the horizontal axis. The amplitude display represents the time or distance it takes the beam

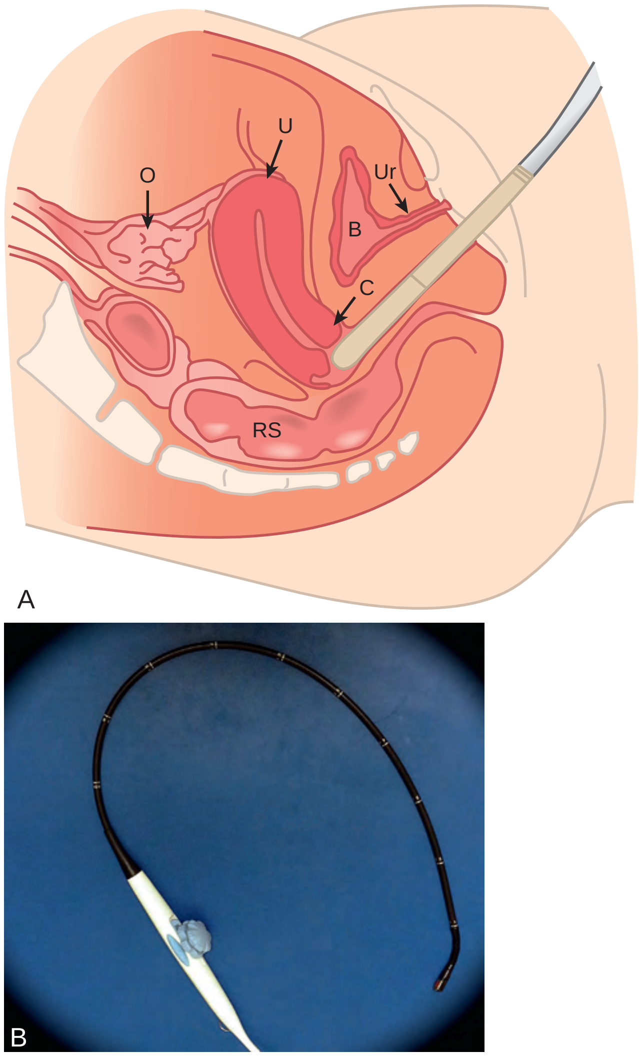


FIG. 1.22 Intraluminal transducer. These transducers are very small and can be placed into different body lumens that are close to the organ of interest. Much higher frequencies are used with high resolution. Elimination of the body adipose tissue greatly enhances image quality. The drawback of a high-frequency transducer is a limited depth of field. A transvaginal probe (A) is used for the pelvis and a transesophageal probe (B) is used for a cardiac procedure.

to strike an interface and return the signal to the transducer. The greater the reflection at the interface, the taller the amplitude spike will appear (Fig. 1.23).

B-Mode (Brightness Modulation). The B-mode, or brightness modulation, method displays the intensity (amplitude) of an echo by varying the brightness of a dot to correspond to echo strength. **Gray scale** is an imaging technique that assigns to each level of amplitude a particular shade of gray to visualize the different echo amplitudes. The B-mode is the basis for all real-time imaging in ultrasound (Fig. 1.24). In B-mode imaging, the ultrasound beam is sent in various directions into the region of interest to be scanned. Each beam interrogates the reflectors along a different line. The echo data picked up along the beam line are displayed in a B-mode format. The B-mode display "tracks" the ultrasound beam line as it scans the region, "sketching out" the 2D image of the body. As many as 200 beam lines may be used to construct each image.

M-Mode (Motion Mode). The M-mode, or motion mode, displays time along the horizontal axis and depth along the vertical axis to depict movement, especially in cardiac structures (Fig. 1.25). M-mode is used to record a graphic representation of wall motion, cardiac valvular motion, posterior cardiac wall motion, or fetal heart rhythm.

Real-time. **Real-time** or **"cine"** imaging provides a dynamic presentation of multiple image frames per second over selected areas of the body. The **frame rate** is dependent on the frequency and depth of the transducer and depth selection. Typical frame rates are 30 frames/sec or less. The principal barrier to higher scanning speeds is the speed of sound in tissue, dictating the time required to acquire echo data for each beam line. All of ultrasound imaging now is acquired with real-time acquisition. These images may be stored in a cine loop or single frame image. The **temporal resolution** refers to the ability of the system to accurately depict motion.

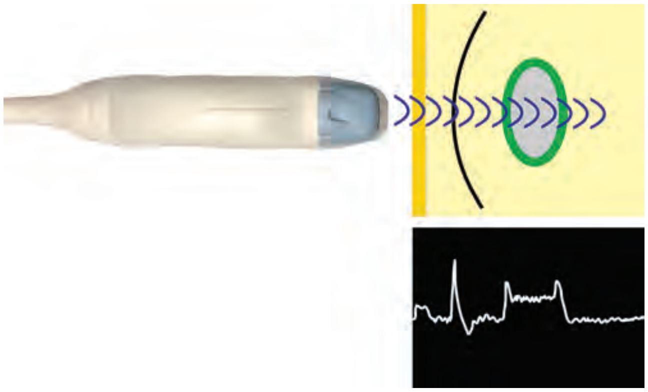


FIG 1.23 A-mode, or amplitude modulation, produces a one-dimensional image that displays the amplitude strength of the returning echo signals along the vertical axis and the time (distance) along the horizontal axis. The amplitude display represents the time or distance it takes the beam to strike an interface and return the signal to the transducer. The greater the reflection at the interface, the taller the amplitude spike will appear.

Harmonic Imaging

Sound waves contain many component frequencies. Harmonics are those components whose frequencies are integral multiples of the lowest frequency (the "fundamental" or "first harmonic"). Harmonic imaging involves transmitting at frequency f and receiving at frequency $2f$, the second harmonic. Because of the finite bandwidth constraints of transducers, the transducer insonates at half of its nominal frequency (e.g., 3 MHz for a 6-MHz transducer) in harmonic mode and then receives at its nominal frequency (6 MHz in this example). The harmonic beams generated during pulse propagation are narrower and have lower side-lobe artifacts than the fundamental beam. The strength of the harmonics generated depends on the amplitude of the incoming beam. Therefore the image-degrading portions of the fundamental beam (i.e., scattered echoes, reverberations, and slice-thickness side lobes) are much weaker than the on-axis portions of the beam and generate weaker harmonics (Fig. 1.26).

Harmonic formation increases with depth, with few harmonics being generated within the near field of the body wall. Therefore filtering out the fundamental frequency and creating an image from the echoes of the second harmonic should

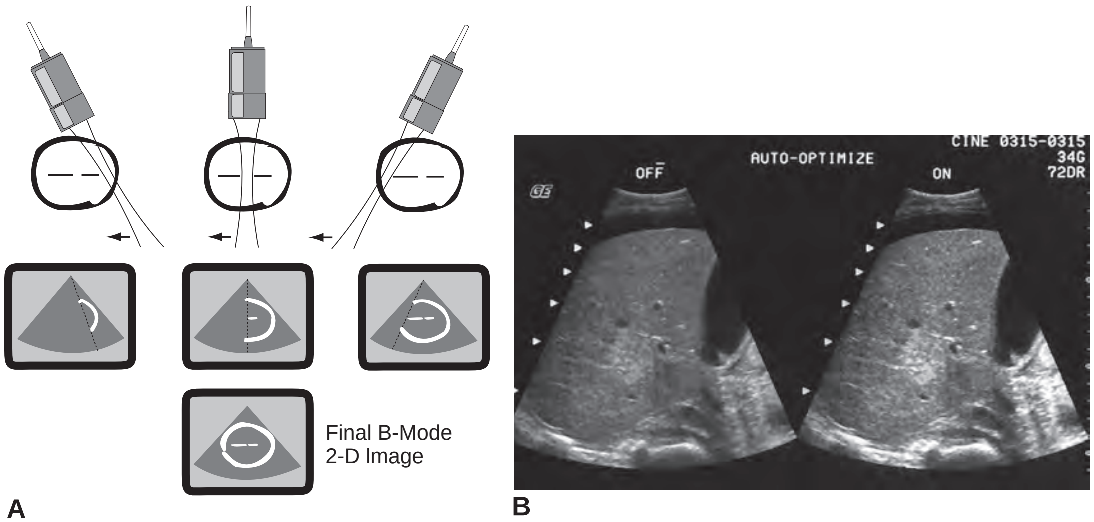


FIG 1.24 (A) Acquisition of multiple image planes over a period of time is made to produce a B-mode image. (B) B-mode image of the liver with a hemangioma in the center of the right lobe. The auto-optimize control is used in the right-hand display to show improved focus.

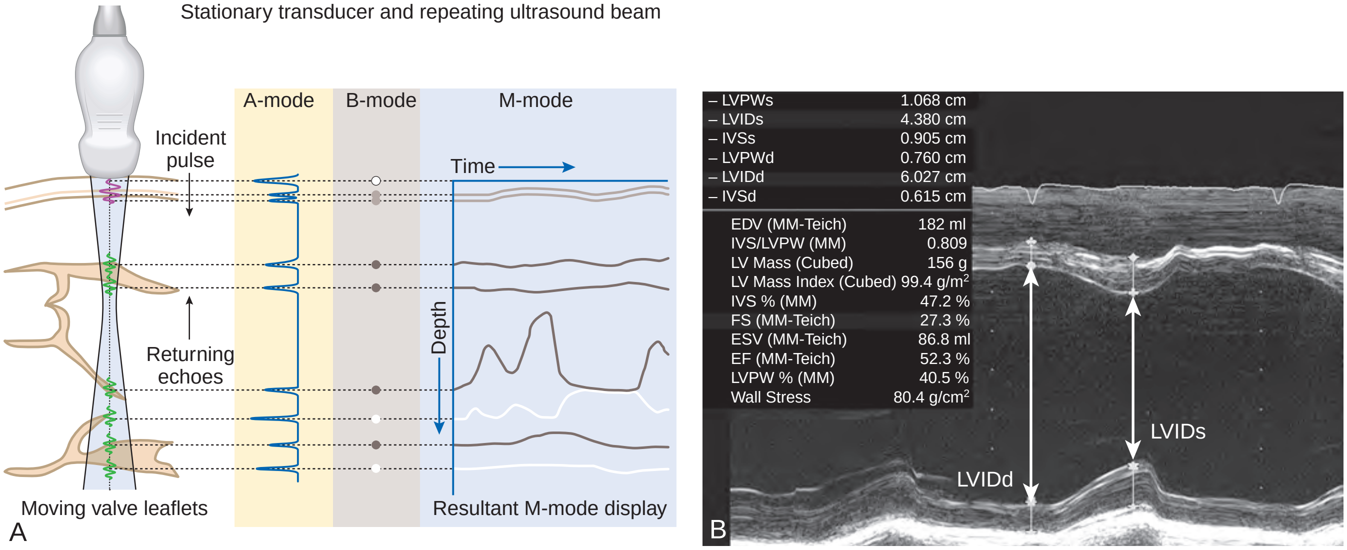


FIG. 1.25 (A) The M-mode, or motion mode, displays time along the horizontal axis and depth along the vertical axis to depict movement, especially in cardiac structures. M-mode is used to record a graphic representation of wall motion, cardiac valvular motion, posterior cardiac wall motion, or fetal heart rhythm. The diagram displays A-mode, B-mode, and M-mode. (B) The M-mode image is taken of the left ventricle. *LV*, Left ventricle; *PW*, posterior wall; *S*, septum.

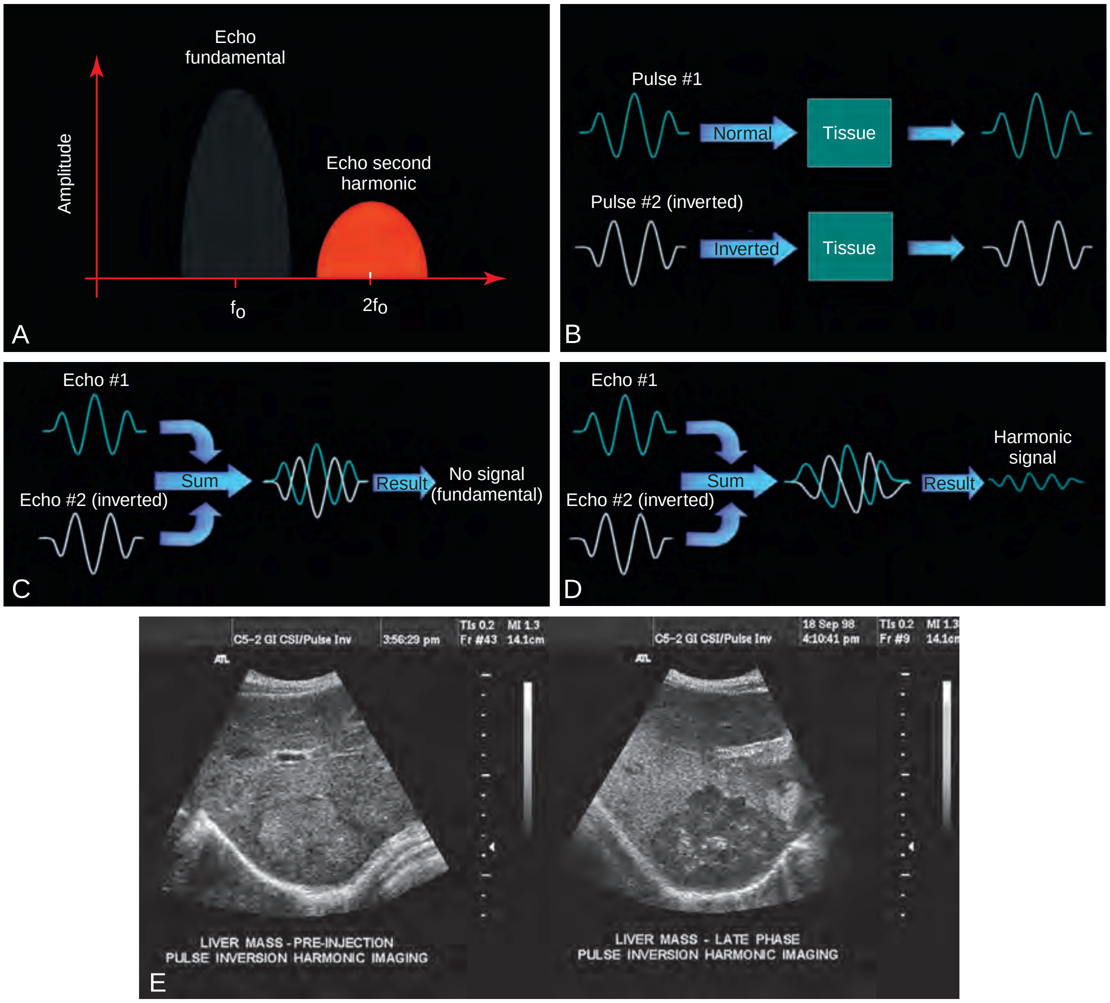


FIG 1.26 (A–D) Harmonic formation increases with depth, with few harmonics being generated within the near field of the body wall. Therefore filtering out the fundamental frequency and creating an image from the echoes of the second harmonic should result in an image that is relatively free of the noise formed during the passage of sound through the distorting layers of the body wall. (E) The liver mass is better visualized with harmonic imaging.

result in an image that is relatively free of the noise formed during the passage of sound through the distorting layers of the body wall.

Three-Dimensional and Four-Dimensional Ultrasound

Conventional ultrasound offers a 2D visualization of anatomic structures with the flexibility of visualizing images from different orientations or "windows" in real-time. The sonographer acquires these 2D images in at least two different scanning planes and then forms a 3D image in his or her head. Technical developments in technology now allow ultrasound images to be acquired on their *x*, *y*, and *z* axes, manually realigned, and then reconstructed into a 3D "en face" format. This technique has been useful in reconstructing the fetal face, ankle, and extremities in the second- and third-trimester fetus (Fig. 1.27A). The use of 3D reconstruction in echocardiography has provided improved information to the clinician and surgeon in diagnosing valvular heart problems and in accurate intracardiac device placement (Fig. 1.27B).

With improvements in resolution and accuracy, 3DU has continued to develop. Data for the 3DU are acquired as a stack of parallel cross-sectional images with the use of

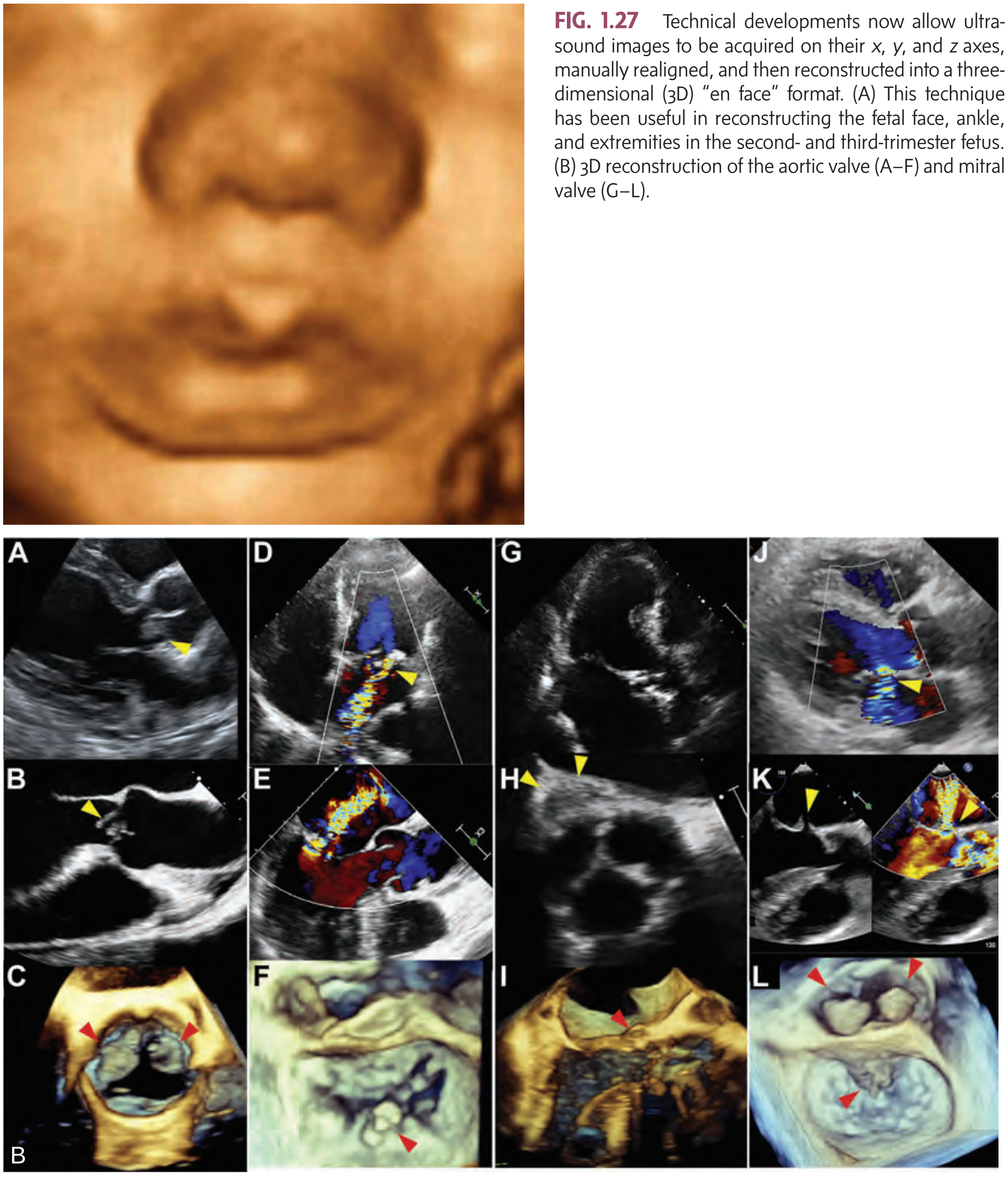


FIG. 1.27 Technical developments now allow ultrasound images to be acquired on their *x*, *y*, and *z* axes, manually realigned, and then reconstructed into a three-dimensional (3D) "en face" format. (A) This technique has been useful in reconstructing the fetal face, ankle, and extremities in the second- and third-trimester fetus. (B) 3D reconstruction of the aortic valve (A–F) and mitral valve (G–L).

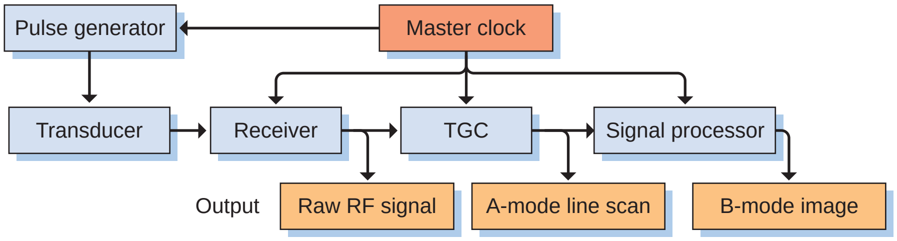


FIG. 1.28 The critical component of the pulse-echo instrument is the B-mode (two-dimensional) imager. The beam former includes the electronic transmitter and the receiver. The transmitter supplies electrical signals to the transducer for producing the sound beam. The transducer may be connected to the transmitter and receiver through a beam-former system. Echoes picked up by the transducer are applied to the receiver. At this point, the echoes are amplified and processed into a suitable format for display. An image memory (scan converter) retains data for viewing or storage on digital media.

a conventional ultrasound system or as a volume with the use of an electronic array probe. These images can be reconstructed in a variety of formats to produce the desired image. In addition, 4DU is the real-time motion of the 3DU image.

System Controls for Image Optimization

Pulse-Echo Instrumentation. The critical component of the pulse-echo instrument is the B-mode (2D) imager. The beam former includes the electronic transmitter and the receiver. The transmitter supplies electrical signals to the transducer for producing the sound beam. The transducer may be connected to the transmitter and receiver through a beam-former system. Echoes picked up by the transducer are applied to the receiver. At this point, the echoes are amplified and processed into a suitable format for display. An image memory (scan converter) retains data for viewing or storage on digital media (Fig. 1.28).

Power Output. The power output determines the strength of the pulse that is transmitted into the body. The returning echoes are stronger when the transmitted pulse is stronger, and thus the image is "brighter." The power output is displayed as a dB or as a percentage of maximum.

Gain. Once the sound wave strikes the body, sound attenuation occurs with each layer the beam transverses, causing an interface in the deep tissues to produce a weaker reflection and less distortion of the crystal than a similar interface in the near tissues. To compensate for this attenuation of sound in the deeper tissues, the sound is "electronically amplified" after the sound returns to the transducer. The receiver **gain** allows the sonographer to amplify or boost the echo signals. It may be compared with the volume control on a radio—as one increases the volume, the sound becomes louder. The acoustic exposure to the patient is not changed when the receiver gain is increased. If the gain is set too high, artifactual low level "echo noise" will be displayed throughout the image. Fluid or normal vascular structures should be anechoic (without echoes); if the gain is set too high, low level artifactual echoes will be noted in these structures.

Recall the discussion of how the signal is absorbed, reflected, and attenuated as the beam traverses the body. The depth of the interface is determined by the amount of time it takes for the transmitted sound pulse to return to the transducer. The **time gain compensation (TGC)** control, sometimes referred to as **depth gain compensation (DGC)**, allows the sonographer to manually amplify the receiver gain gradually at specific depths (Fig. 1.29). Thus the echoes well seen in the near field may be reduced in amplitude, while the echoes in the far field may be amplified or increased with changing the TGC controls. The TGC control will be continually

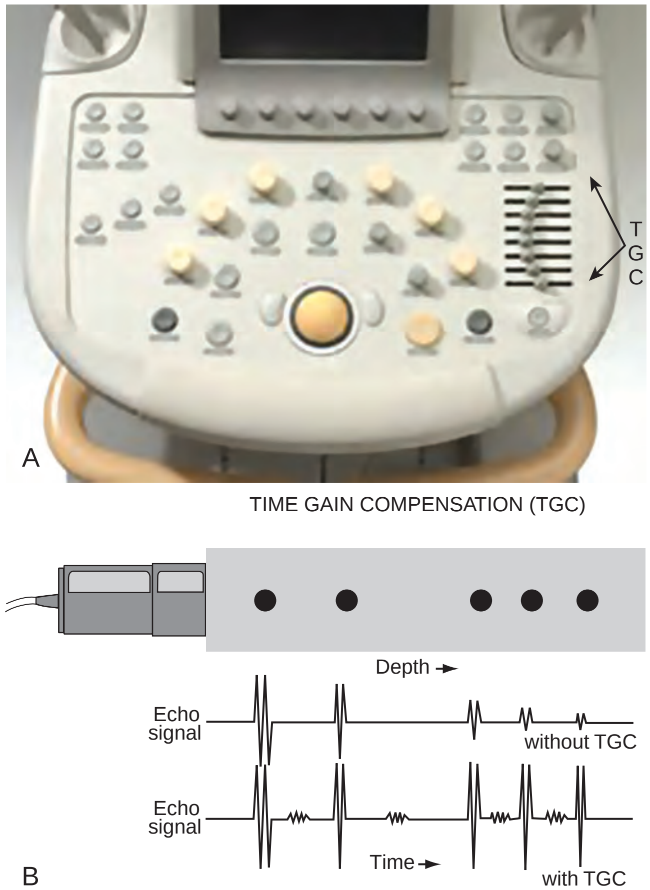


FIG. 1.29 (A) Ultrasound control panel that shows the time gain compensation (TGC) controls along the right side of the panel. (B) The TGC allows the sonographer to amplify the receiver gain gradually at specific depths to adjust for attenuation.

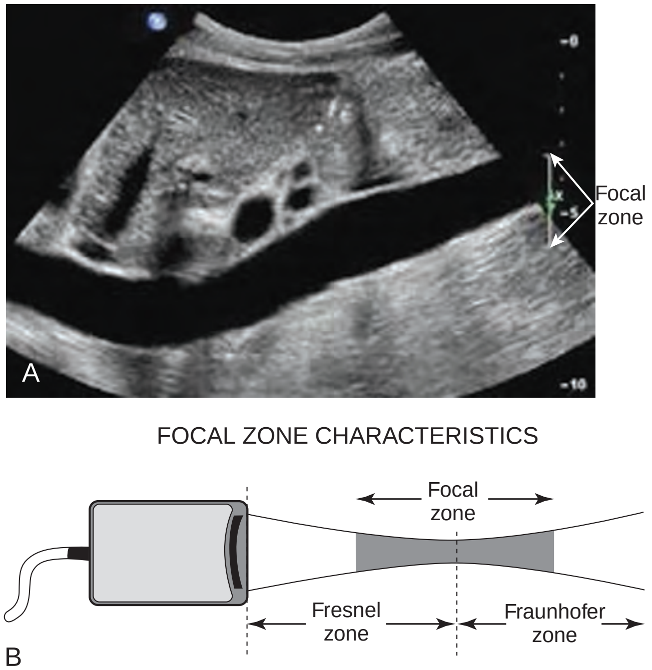


FIG. 1.30 (A) The focal zone *(arrows)* should be placed at the area of interest, which in this case is the inferior vena cava. (B) The near field (Fresnel zone) is the area closest to the transducer. The far field (Fraunhofer zone) is farthest from the transducer.

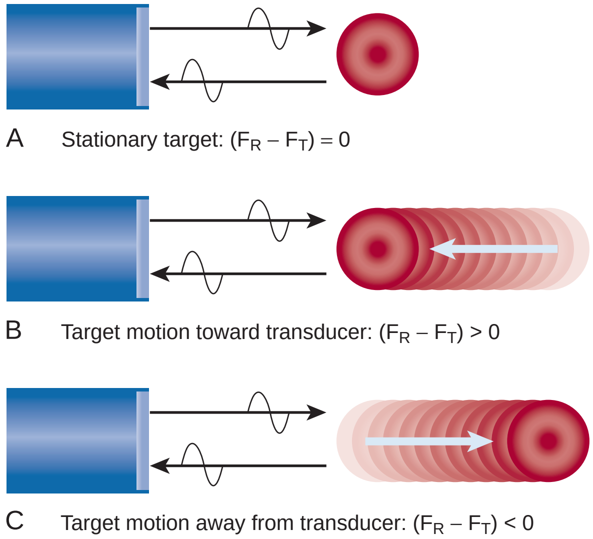


FIG. 1.31 (A–C) The Doppler effect is the apparent change in frequency of sound or light waves emitted by a source as it moves away from or toward an observer. Sound that reflects off a moving object undergoes a change in frequency. Objects moving toward the transducer reflect sound at a higher frequency than that of the incident pulse, and objects moving away reflect sound at a lower frequency. The difference between the transmitted and the received frequency is called the Doppler frequency shift.

adjusted during the sonographic examination to highlight or display various signals within the body. In the abdomen, the liver is a great organ to set the TGC controls because the organ should be homogeneous from the near field (close to the transducer) to the far field (furthest from the transducer).

Focal Zone. The focal zone control allows the transducer to focus the transmitted sound at different depths (Fig. 1.30). It is usually indicated on the side of the image as single or multiple arrowheads and may be adjusted in depth to focus on specific areas of interest. As multilevel focusing is used, a decrease in the frame rate will occur.

Field of View. This control allows the sonographer to adjust the depth and width of the image. The larger or deeper FOV will directly cause the frame rate to decrease. Depth is displayed as centimeters on the side of the image. Width adjusts the horizontal axis of the image and may be used to reduce side-lobe artifacts.

Reject. The reject control eliminates both electronic noise and low-level echoes from the display. This control is important to understand; as the sonographer attempts to "clean up" the image artifacts, one must be careful not to eliminate important low-level information that may be significant in the clinical diagnosis.

Dynamic Range. The **dynamic range** of a device is the range of input signal levels that produce noticeable changes in the output of the device. The dynamic range capabilities vary among different ultrasound machines. The sonographer usually notes the low dynamic range as one of high contrast (echocardiography and peripheral vascular), whereas the high dynamic range shows more shades of gray and lower contrast (abdominal and obstetric).

Doppler Ultrasound

Two basic modes of transducer operation are used in medical diagnostic applications: continuous wave (CW) and pulsed wave (PW). Real-time 2D instrumentation uses only the pulse-echo amplitude of the returning echo to generate gray-scale information, whereas Doppler instrumentation uses both continuous and pulsed wave operations.

Doppler Effect. The Doppler effect is the apparent change in frequency of sound or light waves emitted by a source as it moves away from or toward an observer (Fig. 1.31). Sound that reflects off a moving object undergoes a change in frequency. Objects moving toward the transducer reflect sound at a higher frequency than that of the incident pulse, and objects moving away reflect sound at a lower frequency. The difference between the transmitted and the received frequency is called the Doppler **frequency shift**. This Doppler effect is applied when the motion of laminar or turbulent flow is detected within a vascular structure. When the source moves toward the listener, the perceived frequency is higher than the emitted frequency, thus creating a higher-pitched sound. If the sound moves away from the listener, the perceived frequency is lower than the transmitted frequency, and the sound will have a lower pitch.

In the medical application of the Doppler principle, the frequency of the reflected sound wave is the same as the frequency transmitted only if the reflector is stationary. If the red blood cell (RBC) moves along the line of the ultrasound beam (parallel to flow), the Doppler shift is directly proportional to the velocity of the RBC. If the RBC moves away from the transducer in the plane of the beam, the fall in frequency is directly proportional to the velocity and direction of RBC movement (Fig. 1.32). The frequency of the echo will be higher than the transmitted frequency if the reflector is moving toward the transducer, and lower if the reflector is moving away.

Doppler Shift. The difference between the receiving echo frequency and the frequency of the transmitted beam is called the **Doppler shift**. This change in the frequency of a reflected wave is caused by relative motion between the reflector and the transducer's beam. In general, the Doppler shift is only a small fraction of the transmitted ultrasound frequency.

The Doppler shift frequency is proportional to the velocity of the moving reflector or blood cell. The frequency at which a transducer transmits ultrasound influences the frequency of the Doppler shift. The higher the original, or transmitted, frequency, the greater is the shift in frequency for a given reflector velocity. The returning frequency increases if the RBC is moving toward the transducer and decreases if the blood cell is moving away from the transducer. The Doppler effect produces a shift that is the reflected frequency minus the transmitted frequency. When interrogating the same blood vessel with transducers of different frequencies, the higher-frequency transducer will generate a larger Doppler shift frequency.

The angle that the reflector path makes with the ultrasound beam is called the **Doppler angle**. As the Doppler angle increases from 0 to 90 degrees, the detected Doppler frequency shift decreases. At 90 degrees, the Doppler shift is zero, regardless of flow velocity. The frequency of the Doppler shift is proportional to the cosine of the Doppler angle. The beam should be parallel to flow to obtain the maximum velocity. *The closer the Doppler angle is to zero, the more accurate is the flow velocity* (see Fig. 1.32). If the angle of the beam to the reflector exceeds 60 degrees, velocities will no longer be accurate.

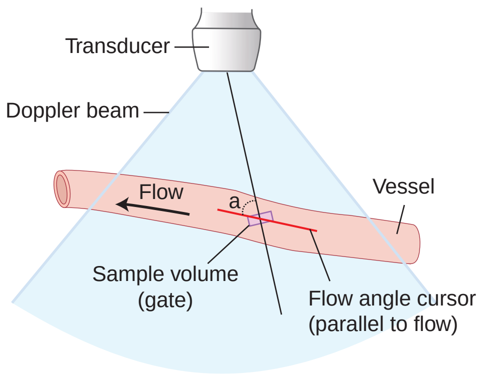
Spectral Analysis. Blood flow through a vessel may be laminar or turbulent (Fig. 1.33). **Laminar** flow is the normal pattern of vessel flow, which occurs at different velocities, because flow in the center of the vessel is faster than it is at the edges. When the range of velocities increases significantly, the flow pattern becomes turbulent. The audio of the Doppler signal enables the sonographer to distinguish laminar flow from turbulent flow patterns. **Turbulent** flow is the abnormal pattern of vessel flow that occurs when there is a narrowing in the vessel that causes a high velocity flow profile. The process of **spectral analysis** allows the instrumentation to break down the complex multifrequency Doppler signal into individual frequency components.

The spectral display shows the distribution of Doppler frequencies versus time (Fig. 1.34). This is displayed as velocity on the vertical axis and time on the horizontal axis. Flow toward the transducer is displayed above the baseline, and flow away from the transducer is displayed below the baseline.

When the area of the vessel that is examined contains RBCs moving at similar velocities, they will be represented on the spectral display by a narrow band. This area under the band is called the "window." As flow becomes more turbulent or disturbed, the velocity increases, producing **spectral broadening** on the display. A very stenotic (high-flow velocity) lesion would cause the window to become completely filled in.

Continuous Wave Doppler. **Continuous wave (CW) Doppler** uses two piezoelectric elements: one for sending and one for receiving. The sound is transmitted continuously rather than in short pulses. CW is used to record the higher-velocity flow patterns, usually greater than 2 m/sec, and is especially useful in cardiology (Fig. 1.35). Unlike PW Doppler, CW cannot pinpoint exactly where along the beam axis flow is occurring because it samples all of the flow along its path. In the example of a five-chamber view of the heart, a sample volume placed in the left ventricular outflow tract will sample all the flow along that "line" to include the flows in the outflow tract and in the ascending aorta.

Pulsed Wave Doppler. **Pulsed wave (PW) Doppler** is used for lower-velocity flow and has one crystal that pulses to transmit the signal while also listening or receiving the returning signal (see Fig. 1.35). The PW Doppler uses brief bursts of sound like those used in echo imaging. These bursts are usually of a longer duration and produce well-defined frequencies. The sonographer may set the **gate** or Doppler window to a specific area of interest in the vascular structure so interrogated. This



Doppler equation

$$V = \frac{f\,c}{2F\cos(a)}$$

V = blood velocity (cm/sec)
f = frequency change (kHz)
c = velocity of sounds (cm/sec)
F = frequency of initial beam (kHz)
a = angle between soundbeam and direction of flow

FIG 1.32 In the medical application of the Doppler principle, the frequency of the reflected sound wave is the same as the frequency transmitted only if the reflector is stationary. If the red blood cell (RBC) moves along the line of the ultrasound beam (parallel to flow), the Doppler shift is directly proportional to the velocity of the RBC. If the RBC moves away from the transducer in the plane of the beam, the fall in frequency is directly proportional to the velocity and direction of RBC movement.

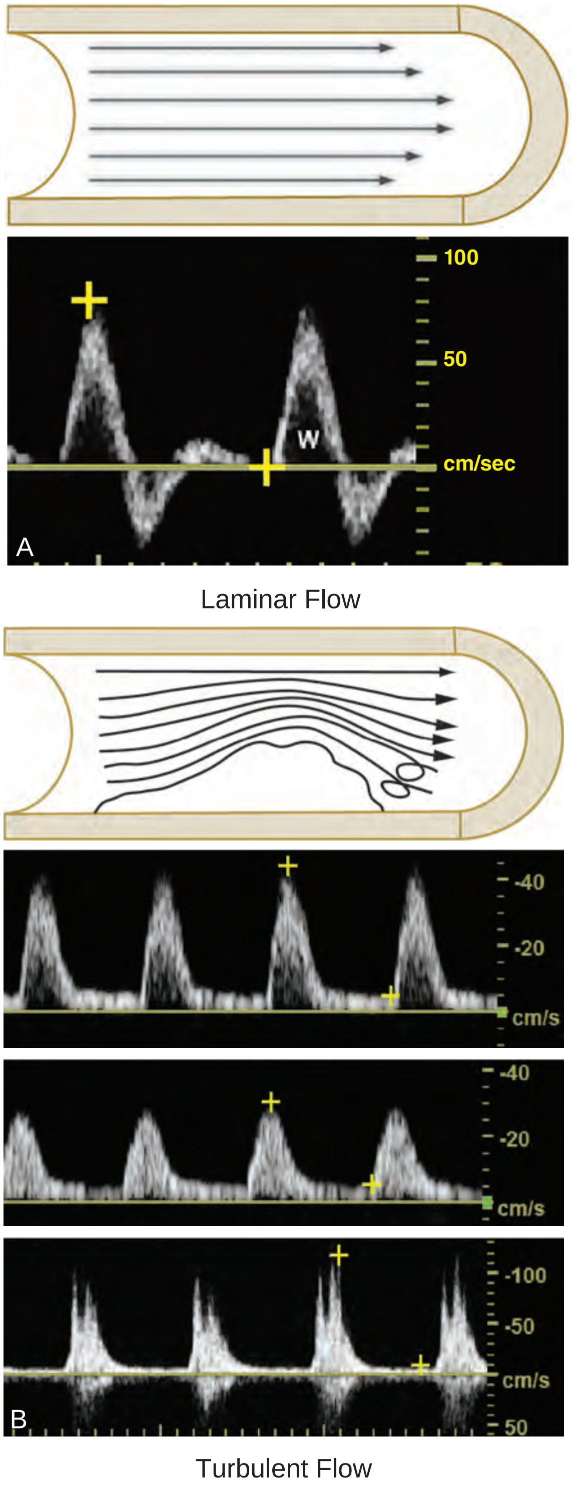


FIG. 1.33 Blood flow through a vessel may be laminar or turbulent. (A) Laminar flow is the normal pattern of vessel flow, which occurs at different velocities, as flow in the center of the vessel is faster than it is at the edges. When the range of velocities increases significantly, the flow pattern becomes turbulent. The audio of the Doppler signal enables the sonographer to distinguish laminar flow from turbulent flow patterns. (B) Turbulent flow is the abnormal pattern of vessel flow that occurs when there is a narrowing in the vessel that causes a high velocity flow profile.

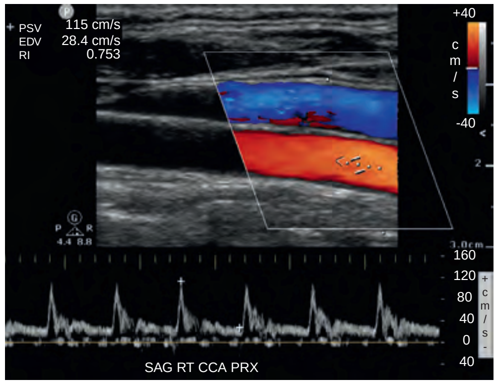


FIG. 1.34 The spectral display shows the distribution of Doppler frequencies versus time. This is displayed as velocity on the vertical axis and time on the horizontal axis. Flow toward the transducer is displayed above the baseline, and flow away from the transducer is displayed below the baseline.

means that a specific area of interest may be examined at the point the gate or sample volume is placed. For example, in a longitudinal view of the abdominal aorta, the sample volume may be placed directly in the middle of the aortic flow, and recordings only from that particular area "within the gate or window" will be measured (see Fig. 1.34).

With pulsed Doppler, for accurate detection of Doppler frequencies to occur, the Doppler signal must be sampled at least twice for each cycle in the wave. This phenomenon is known as the **Nyquist sampling limit**. When the Nyquist limit is exceeded, an artifact called aliasing occurs. **Aliasing** presents on the spectral display as an apparent reversal of flow direction and a "wrapping around" of the Doppler spectral waveform. Therefore the highest velocity may not be accurately demonstrated when aliasing occurs; this usually happens when the flows are greater than 2 m/sec. One can avoid aliasing by changing the Doppler signal from PW to CW to record the higher velocities accurately.

Color Doppler. Color Doppler is sensitive to Doppler signals throughout an adjustable portion of the area of interest. A real-time image is displayed with both gray scale and **color flow** in the vascular structures. Color Doppler is able to analyze the phase information, frequency, and amplitude of returning echoes.

Velocities are quantified by allocating a pixel to flow toward the transducer and flow away from the transducer. Each velocity frequency change is allocated a color. Color maps may be adjusted to obtain different color assignments for the velocity levels; signals from moving RBCs are assigned a color (red or blue) based on the direction of the phase shift (i.e., the direction of blood flow toward or away from the transducer) (Fig. 1.36). Flow velocity is indicated by color brightness: The higher the velocity, the brighter is the color. Aliasing also occurs in color flow imaging when Doppler frequencies exceed the Nyquist limit, just as in spectral Doppler. This appears as a wrap-around of the displayed color. The velocity scale pulse repetition frequency (PRF) may

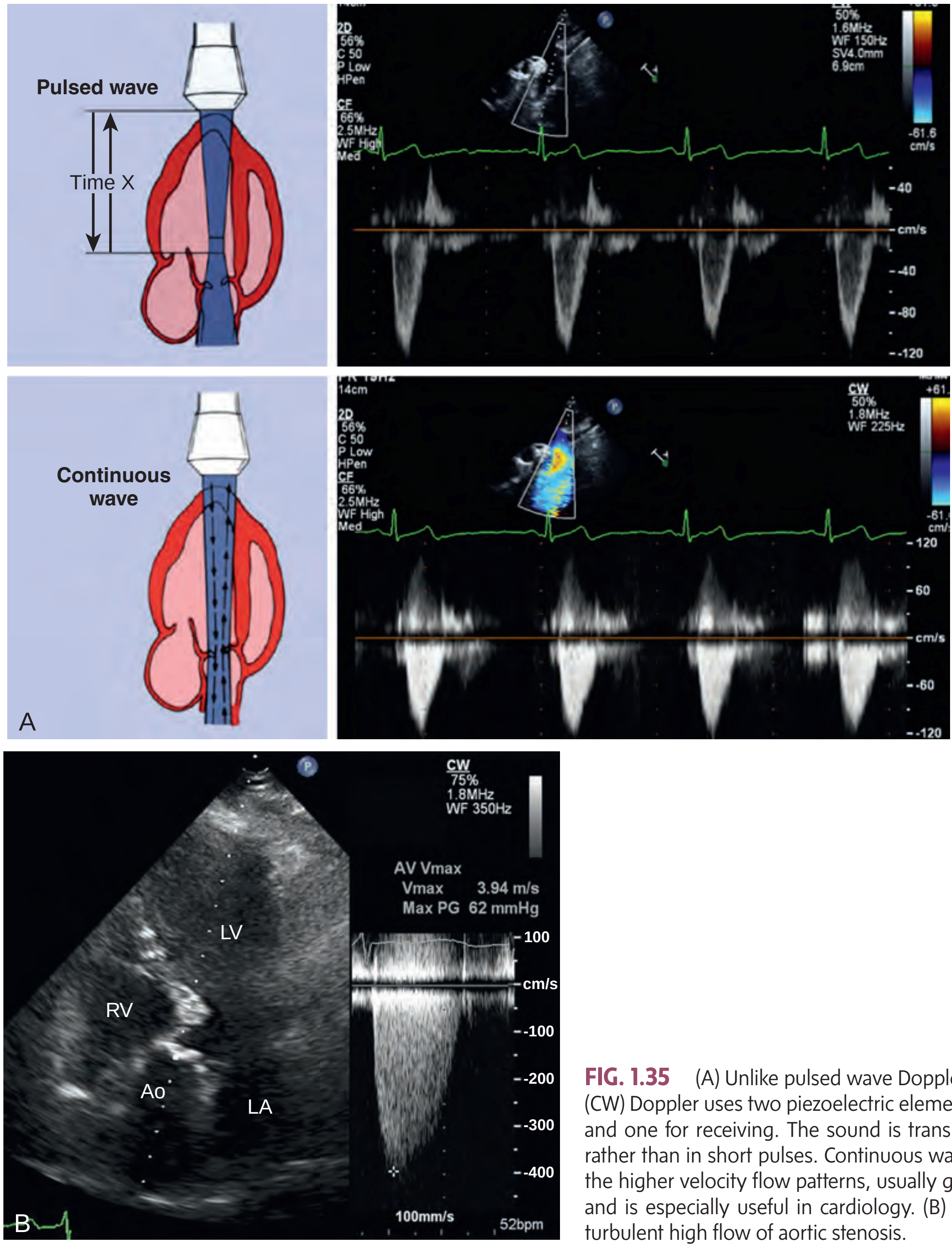


FIG. 1.35 (A) Unlike pulsed wave Doppler, continuous wave (CW) Doppler uses two piezoelectric elements: one for sending and one for receiving. The sound is transmitted continuously rather than in short pulses. Continuous wave is used to record the higher velocity flow patterns, usually greater than 2 m/sec, and is especially useful in cardiology. (B) CW example of the turbulent high flow of aortic stenosis.

be adjusted to avoid aliasing. Color arising from sources other than moving blood is referred to as flash artifact or ghosting.

Power Doppler. Power Doppler estimates the power or strength of the Doppler signal rather than the mean frequency shift. Although the Doppler detection sequence used in power Doppler is the same as that used in frequency-based color Doppler, once the Doppler shift has been detected, the frequency components are ignored in lieu of the total energy of the Doppler signal. The color and hue relate to the moving blood volume rather than to the direction or the velocity of flow (Fig. 1.37).

This principle provides power Doppler several advantages over color Doppler imaging. In power Doppler, low-level noise is assigned as a homogeneous color background, even when the gain is increased. With color Doppler, the higher gains produce noise in the signal that obscures the image. The Doppler angle is not affected in power Doppler; with color Doppler the angle is critical in determining the exact flow velocity. The downside of power Doppler is that it provides no information about the direction or velocity of blood flow, and it is susceptible to flash artifact (zones of intense color that results from motion of soft tissues and motion of the transducer).

Doppler Optimization.

Transducer Frequency. The Doppler frequency shift is proportional to the transmitted frequency. Therefore

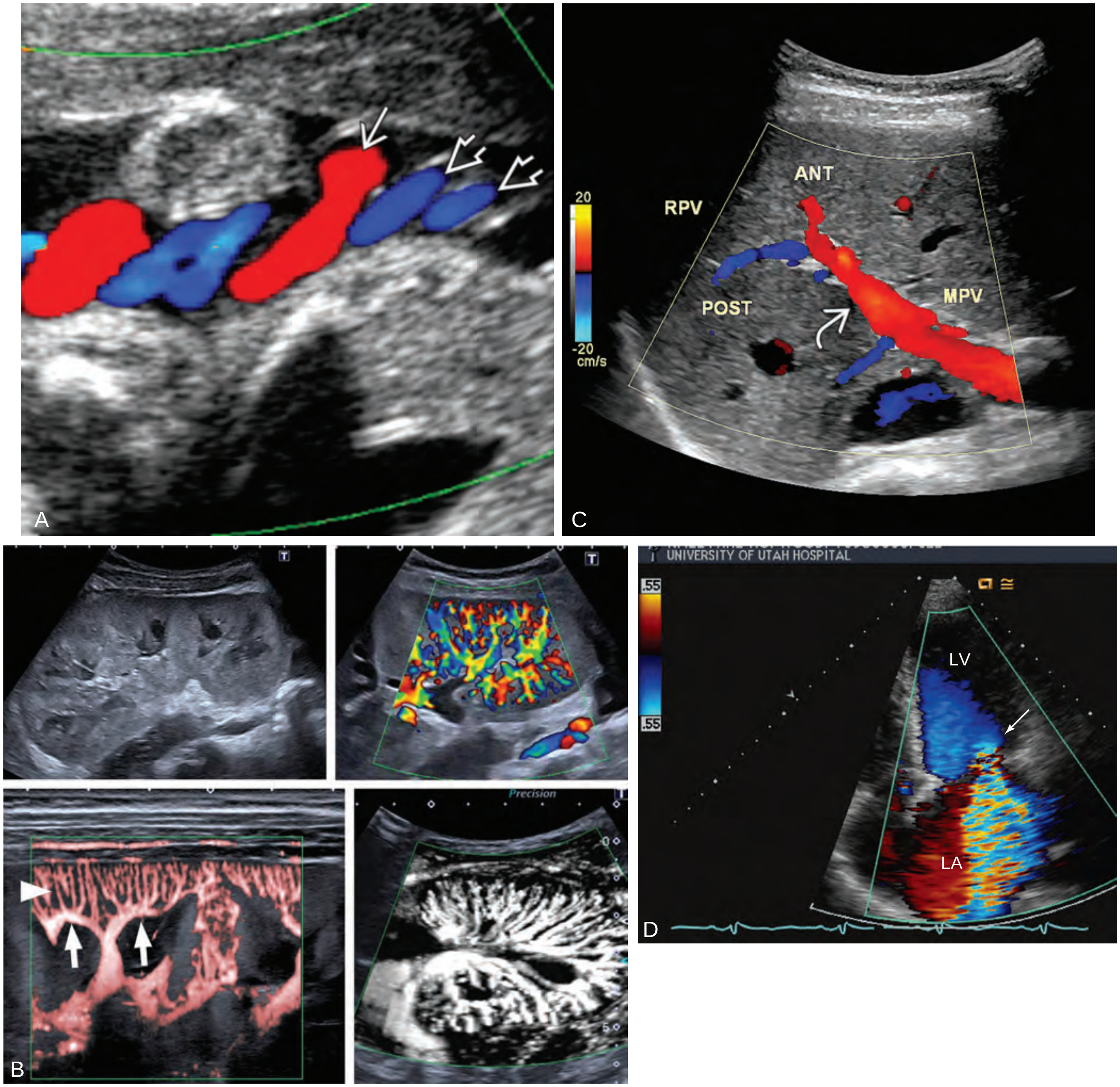


FIG. 1.36 Color Doppler is sensitive to Doppler signals throughout an adjustable portion of the area of interest. A real-time image is displayed with both gray scale and color flow in the vascular structures. Color Doppler is able to analyze the phase information, frequency, and amplitude of returning echoes. (A) Normal three-vessel umbilical cord. (B) Normal renal vasculature. (C) Normal portal vein flow. (D) Abnormal flow from the mitral regurgitation into the left atrial cavity.

higher-frequency transducers cause a higher Doppler frequency shift that is easier to detect. Higher-frequency probes also result in stronger reflections from RBCs. Remember that the higher-frequency probes are not sensitive to deeper structures; therefore multiple probes may be necessary, depending upon the type of ultrasound examination.

Gain. Doppler gain is the receiver end amplification of the Doppler signal. This can be applied to either the waveform itself or to the color Doppler image. The Doppler gain is usually increased to the maximum limit where "noise" scatter is seen in the background. The gain is then slowly decreased until that noise disappears. The Doppler gain is independent of the gray scale gain.

Scale. Scale allows the sonographer to expand or reduce the range of depth of the returning signal.

Baseline. The baseline may be moved up or down to image the maximal velocity of the returning signal.

Power. Power refers to the strength of the transmitted ultrasound pulse. The stronger pulse will produce stronger reflections that are more easily detected. Power will affect both gray-scale and Doppler images. Increasing the power may be helpful in the deeper structures, but increasing power

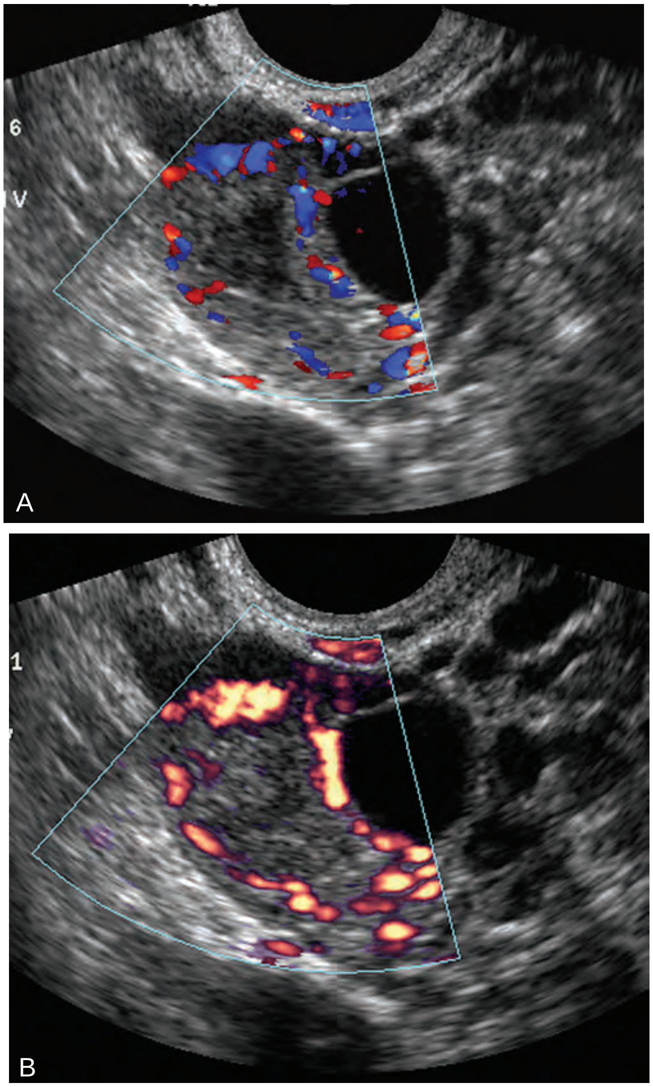


FIG. 1.37 Color Doppler (A) and power Doppler (B). Power Doppler estimates the power or strength of the Doppler signal rather than the mean frequency shift. Although the Doppler detection sequence used in power Doppler is the same as that used in frequency-based color Doppler, once the Doppler shift has been detected, the frequency components are ignored in lieu of the total energy of the Doppler signal. The color and hue relate to the moving blood volume rather than to the direction or the velocity of flow.

increases patient exposure and may cause increased artifacts. For these reasons, power controls generally are not modified as frequently by the sonographer as the other controls.

Pulse Repetition Frequency. The **pulse repetition frequency (PRF)** refers to the number of sound pulses transmitted per second. A high PRF results in a high Doppler scale (to record higher velocities, i.e., aortic stenosis), whereas a lower PRF results in a lower Doppler scale (to record lower velocities, i.e., venous return or low-flow states). The PRF is adjusted for the higher flows to eliminate aliasing.

Wall Filter. The wall filter allows the sonographer to eliminate artifactual or unwanted signals arising from pulsating vessel walls or moving soft tissues. This filter allows frequency shifts above a certain level to be displayed while lower-frequency shifts are not displayed.

Key Pearls

- Ultrasound refers to instrumentation; sonography refers to the imaging technique; echocardiography refers to cardiac imaging.
- A sonographer is a member of the allied heath profession who has received specialized education in diagnostic medical sonography and has successfully completed the national boards given by the American Registry of Diagnostic Medical Sonography.
- A sonologist is a physician who has received specialized training in ultrasound and has successfully completed the national boards granted by their respective specialty.
- Diagnostic ultrasound is portable and economical and does not use radiation.
- Diagnostic ultrasound uses short sound pulses at frequencies of 1–20 million cycles/sec that are transmitted into the body to examine soft tissue anatomic structures.
- Velocity of propagation is constant for a given tissue and not affected by the frequency or wavelength of the pulse.
- Sound waves travel slowly through gas, at intermediate speed through liquids, and quickly through solids.
- The decibel unit is used to measure the intensity, amplitude, and power of an ultrasound wave.
- Power is measured in watts or milliwatts.
- Frequency describes the number of oscillations per second performed by the particles of the medium in which the wave is propagating.
- Once sound pulses are transmitted into a body, they can be reflected, scattered, refracted, or absorbed.
- Acoustic impedance is the measure of a material's resistance to the propagation of sound.
- Resolution is the ability of an imaging process to distinguish adjacent structures in an object and is an important measure of image quality (axial, lateral, and azimuthal resolution).
- Attenuation is the sum of acoustic energy loss resulting from absorption, scattering, and reflection.
- Transducers are selected for a particular examination. (multielement, phased array, sector array, linear-array, curved-array, intraluminal)
- Pulsed echo display modes include A-mode, M-mode, B-mode, real-time, harmonics, and three and four dimensional.
- Systems controls for image optimization: power output, gain, time gain compensation, focal zone, field of view, reject, dynamic range.
- Doppler effect is the apparent change in frequency of sound or light waves emitted by a source as it moves away from or toward an observer.
- The difference between the receiving echo frequency and the frequency of the transmitted beam is called the Doppler shift.
- Doppler may be measured using either continuous wave or pulsed wave analysis.
- Color Doppler is able to analyze the phase information, frequency, and amplitude of returning echoes.
- Power Doppler estimates the power or strength of the Doppler signal rather than the mean frequency shift.
- Doppler optimization is controlled by transducer frequency, gain, scale, baseline, power, pulse repetition frequency, wall filter.

BIBLIOGRAPHY

American College of Radiology: ACR-SPR-SRU practice guideline for performing and interpreting diagnostic ultrasound examinations. Revised 2017. www.acr.org.

Baker DW, Watkins D: A phase coherent pulse doppler system for cardio-vascular measurement. In Proceedings of the 20th Annual Conference of Engineering Medicine Biologists 1967;27:2.

Bom N, Lance CT, Honkoop J, Hugenholtz PG. Ultrasonic viewer for cross-sectional analyses of moving cardiac structures. *BioMed Eng*. 1971;6:500.

Curie JP. Développement par pression de l'électricite polaire dans les cristaux hémièdres à faces inclinées. *CR Acad Sci (Paris)*. 1880;91:294.

Donald I. Clinical applications of ultrasonic techniques in obstetrical and gynaecological diagnosis. *Br J Obstet Gynaecol*. 1962;69:1036.

Dussik KT. On the possibility of using ultrasound waves as a diagnostic aid. *Neurol Psychiat*. 1942;174:153–168.

Edler I, Hertz CH. The use of ultrasonic reflectoscope for the continuous recording of the movements of heart walls. *K Fysiogr Sallsk Lund Forh*. 1954;24:40.

Firestone FA. The supersonic reflectoscope, an instrument of inspecting the interior of solid parts by means of sound waves. *J Acoust Soc Am*. 1945;17:287–299.

Griffith JM, Herny WL. A sector scanner for real-time two-dimensional echocardiography. *Circulation*. 1974;49:1147.

Holmes JH, Howry DH, Posakony GJ, Cushman CR. The ultrasonic visualization of soft tissue structures in the human body. *Trans Am Clin Climatol Assoc*. 1954;66:208–223.

Howry DH. Development of an ultrasonic diagnostic instrument. *Am J Phys Med*. 1958;37:234.

Kossoff G, Carpenter D, Robinson D, Garrett WJ: A new multi-transducer water coupling echoscope. In Proceedings of the 2nd European Congress on Ultrasonics in Medicine, May 12-16, 1975, Munich, Germany.

Langévin MP. Les ondes ultrasonores. *Rev Gen Elect*. 1928;23:626.

Ludwig GD, Bolt RH, Hueter TF, Ballantine HT. Factors influencing the use of ultrasound as a diagnostic aid. *Trans Am Neurol Assoc*. 1950;51:225–228.

Nelson TR, Downey DD, Pretorius DH, et al. *Three-dimensional ultrasound. Philadelphia.* : Lippincott Williams & Wilkins; 1999.

Omoto R, Namekawa K, Kasai C. A prototype device incorporating a new technology for visualizing intracardiac flow. *Jpn Circ J*. 1983;47:191.

Reid JM, Spencer MP. Ultrasonic Doppler technique for imaging blood vessels. *Science*. 1972;176:1235–1236.

Robinette WB. Ultrasound contrast agents: an overview. *J Diagn Med Sonogr*. 1997;13:29S.

Szabo TL, Lewin PA. Ultrasound Transducer Selection in Clinical Imaging Practice. *J Ultrasound Med*. 2013;32:573–582.

von Ramm OT, Thurstone FL. Cardiac imaging using a phased array system (I. System design). *Circulation*. 1976;53:258–262.

Wild JJ, French LA, Neal D. Detection of cerebral tumours by ultrasonic pulses. *Cancer*. 1950;4:705.

Woo JSK: A short history of the development of ultrasound in obstetrics and gynecology. www.ob-ultrasound.net/history.html.

Zagzebski J, Parks J: Ultrasound physics and instrumentation, advanced ultrasound seminars, 1997.

CHAPTER

2

Essentials of Patient Care for the Sonographer

M. Robert De Jong

OBJECTIVES

On completion of this chapter, the reader should be able to:

- Discuss nonscanning aspects of being a sonographer
- Define patient-centered care
- Describe patient transfer techniques
- Demonstrate proper placement of a blood pressure cuff on the arm
- Discuss the importance of proper disinfection of the transducer and ultrasound equipment
- Discuss Spaulding's classification system and how it relates to ultrasound
- List various types of patient isolation

OUTLINE

KEY TERMS

Arrhythmia
Body mechanics
Bradycardia
Consent
Cyanosis
Dyspnea
Heimlich maneuver
Nasal cannula
Nosocomial infections
Oximetry
Oxygen therapy
Patient-centered care
Pulse
Refusal
Respiration
Standard precautions
Tachycardia
Urinary catheters
Vital signs
White coat hypertension

INTRODUCTION

Sonography is a profession that is more than just creating diagnostic images. A sonographer will have a patient under their care while they are performing the exam and will need to know some basic patient care skills as well as understand how to keep the patient, as well as themselves, safe. Understanding and mastering these nonscanning skills will make you a well-rounded sonographer. The goal of this chapter is to provide you with the knowledge needed to provide care and a safe environment for patients under your care.

A SONOGRAPHER'S COMMITMENTS

A good sonographer understands their commitments to their patient, the sonologist, their employer, their coworkers, to the sonography profession, and to themselves. What exactly are these commitments? Our patients expect us to have the skills and knowledge to produce a diagnostic sonographic exam, to keep them safe while in our care, and to be understanding of their needs.

The sonologist is the interpreting physician of the sonographic study. There are a variety of sonologists but the most common physicians that a sonographer will work with are radiologists, cardiologists, vascular surgeons, and obstetricians. Sonography is a very unique imaging modality as it involves trust between the sonographer and the sonologist. Breaking this trust (by too often missing pathology or frequently trying to cover up your mistakes) can take a long time to repair before the sonologist gains confidence in your studies. The commitment of the sonographer to the sonologist is to produce diagnostic studies, to be trustworthy, and to have good interpersonal and communication skills.

The commitment to the employer will enable the sonographer to be seen as a valuable employee. Such commitments include punctuality, protecting and respecting the work environment, adhering to policies and guidelines, being a positive representative of the institution to the outside world, and taking care of the patient.

The commitments to your coworkers are important to promote a healthy work environment. This includes maintaining good work habits, following and adhering to both the policies and guidelines of the ultrasound department, supporting each other during difficult times as well as celebrating the good times, and being respectful to one another.

As a sonographer, there is a need to educate our patients about the profession of sonography, to follow the SDMS Sonographer Code of Ethics, to support the ultrasound community and its professional organizations with our membership, and to attain national registration in the field of ultrasound in which you are practicing.

We should have the desire to help all people; to use our skills and knowledge to obtain the best diagnostic exam on every patient; to be a good team player; to constantly advance our knowledge of anatomy, physiology, and pathology; to utilize ergonomics; and to maintain good physical and mental health. A positive attitude brings with it a sense of pride in your work.

Patient-Centered Care

Florence Nightingale advocated focusing on the patient, rather than on the disease, as a way to recognize the patient's basic needs by improving hygiene practices. By distinguishing patient care from medicine, Nightingale established the value of nurses and created the earliest patient advocates.

Patient-centered care ensures that the patient and/or their family is involved in all clinical decisions for their care and treatment. To a sonographer this means being respectful if the patient refuses the exam, or part of the exam, such as the endovaginal aspect of a pelvic sonogram, or wants the exam terminated early. As a sonographer, you should not force the patient to do anything they are uncomfortable with; however, it would be appropriate to ask the question "Why?" Ask the patient why they are refusing the exam or want the exam stopped early. You may discover their fears or concerns, which may help you understand their **refusal**. You may be able to address their concerns, and they will consent to the exam or to finish the exam. For example, the patient may say that they do not want the ultrasound as they just had a CT scan, that they feel like a "guinea pig" and the hospital is just trying to make money off of them. Discussing the differences between these two imaging modalities may be enough to relieve their concerns and allow you to perform the exam.

Due to the ultrasound imaging from the entertainment industry, many patients believe that a physician will be performing their exam and may get upset when you tell them that you will be taking care of them. This situation should lead to a conversation about the roles and misconceptions of sonography, sonographers, and sonologists. Allowing the patient to voice their concerns and to ask you questions shows that you respect them. Be sure that you address their concerns and answer their questions and not brush them off.

The most important facet of being a sonographer is seeing the patient as a person, not as an appointment or a type of study. We need to treat the patient with respect, empathy, and compassion. You must put aside personal feelings and prejudices and be considerate of many factors such as patient's age, sex, gender identification, sexual orientation, race, religious beliefs, ethnicity, language spoken, occupation, disabilities, and socioeconomic status. Good patient care is more than your sonography skills and includes open communication with the patients, which will allow them to express their concerns, fears, and frustrations.

The patient-centered approach encourages sonographers to relate to patients as people with needs, who are to be respected and cared for in a mature and dignified manner. They should be listened to and their concerns not dismissed. A common phrase a sonographer may hear is, "But it hurts here. Aren't you going to look there?" The knee-jerk reaction is to say, "I can only scan the area ordered by the physician" instead of explaining things such as referred pain or the limitations of ultrasound. A good solution is to place the transducer over the area of pain and take a few images labeled as "area of pain." This makes the patient feel heard and their concerns addressed. I remember being called in to do a right upper quadrant sonogram on a patient with an indication of right-sided pain. The patient asked if I could scan where she felt the pain. I put the transducer there and found a 20 cm complex ovarian mass despite a normal pelvic exam a few days earlier. I called the emergency department physician and told them of my findings and if they would order a pelvic ultrasound, to which they agreed. The surgeon came to see me the next day and told me that I had saved her life as the mass was ready to rupture any moment and would have spread the cancer throughout her body. You can imagine how I felt especially when the patient and her husband came and thanked me for saving her life when she was being discharged. (A few tears of joy were shed by all.) This is one of many joys of being a sonographer, and I will never forget that patient. Just think of the consequences if I had refused to put the transducer where she had pain.

Sonographers must remember that the patients' needs come first, despite how it will affect you personally. You cannot let the patient know how upset and frustrated you are for having to stay over to do their exam. This frustration may manifest itself as being curt with the patient or maybe even treating them a little rough. Never take your frustrations out on the patient. After all, the patient did not ask to have a swollen leg at 5 PM on a Friday. You are working in a profession in which you may need to put yourself second to the needs of the patient. Remember, they are the reason that we have a job.

You have chosen a profession that is challenging in many ways. It will test you technically, physically, mentally, and even emotionally. As a student or staff sonographer, you will need to focus on many things at once as you are scanning including your knowledge of anatomy, physiology, pathology, imaging protocols, and techniques. You may be faced with pressures from physicians, time restraints, challenging personalities, or even your own personal issues. What is important is to provide caring attention to your patient who is not focused on the same things as you. They are worried about what you are going to do to them, will it hurt, and what the results are going to be. As a sonographer, you need to constantly provide a level of care similar to that which you would want provided to you or a loved one. You have to challenge yourself to make every patient experience one in which your patient can sense that you really care. You can do this through the practice of compassion, sympathy, and empathy.

Empathy is the ability to understand and share the feelings of another usually as a result of you having experienced similar circumstances. Sympathy refers to your ability to feel sorry about their situation even though you have not had a similar experience. In health care, empathy or sympathy toward your patient will enable you to understand what they need from you as you perform their exam. For example, maybe you had a urinary tract infection (UTI) in the past, and you remember how cold you were from the fever caused by the UTI. This might cause you to get the patient a blanket without them asking for one. This may surprise the patient at your thoughtfulness. This is an example of empathy as you have experienced something similar. By contrast, if you had never had a UTI, you would show sympathy to the patient by asking if them if they would like a blanket.

Compassion is when we are moved by someone's pain or suffering and are motivated to help them. Compassion for your patient is what drives you to do something for them. Maybe your patient has had other tests that have not diagnosed why they are in pain. This may motivate you to go that extra mile to try to find the cause of their pain, if it can be seen with ultrasound. You can show compassion by asking the patient if they need to talk when you sense that they are upset. Even if they do not want to talk, the patient will sense your compassion for them.

Explain the Ultrasound Exam. There is so much misinformation out there about sonography thanks to the entertainment industry. Some patients will assume that a doctor will perform their exam and are surprised and maybe even concerned to discover that you will be performing the sonogram. This is an educational moment to correct any misconceptions that the patient might have. Ask them if they have ever had an ultrasound before. If not, you can help patients understand how ultrasound works by saying something like, "I will be using soundwaves to create images of your uterus and ovaries," followed by a variation on the following explanation, "I will be exposing your stomach area and will be putting some gel on your skin to help the soundbeam get into your body. There is no radiation, and it should be painless. If you feel any pain, please let me know." Let them know if they will need to be in different positions: "I will start you out on your back and will also have you turn up on your side facing away from me." Do not forget to tell them that they will need to hold their breath if needed. I used to say, "Sometimes I get involved scanning and may forget to tell you to breathe. When you need to breathe, please go ahead and breathe." Always give an idea on how long they will be with you: "The ultrasound should take about 30 minutes. I then need to have the images checked by the radiologist before you leave to make sure that they don't want any additional images. The whole process takes about 40 minutes from start to finish." At the end of the exam explain that their physician will be the one giving them the results. Give them an estimation of the typical time it takes the physician to obtain the results. In this electronic world physicians typically have their patients' ultrasound results in 8 to 24 hours. Before you start, it is important to ask the patient if they have any questions. You have your spiel that you usually tell patients, but every patient is different, and you may need to address any specific questions that that patient may have.

Patient Consent and Refusal. **Consent** means giving permission to have something done, in this case an ultrasound study. Hopefully, the patient's physician has already informed the patient that they need to have an ultrasound exam, the reason why, and that the patient has verbally consented to their physician to have the test. If the patient is awake, alert, and legally responsible for their own health decisions, you will obtain their permission to perform the ultrasound exam through verbal communication. This is called *verbal consent* and typically is not documented. This is the case for any ultrasound whether it is external or internal, although some places may require a written consent for a transvaginal study. Transvaginal ultrasounds will always require the consent of the patient or the person that is legally responsible for their health care decisions, when the patient is unable to give consent or when the patient is a minor. When another person gives consent on behalf of the patient it may need to be in the form of a *written consent*, or the name of the person documented in the patient's medical records. If it is a medical emergency the physician taking care of the patient may give consent, based on hospital policy which may require two doctors to give consent. This would need to be documented as per hospital policy. As a staff sonographer you will need to know and follow these policies. For a written consent it is appropriate for the sonographer to witness the signature on the consent form. If you are asked to witness a consent when you did not see the patient sign it, show the patient the consent form and ask them to verify that that is their signature before you sign.

Consent is mandatory when the patient is having any invasive procedure such as a biopsy or fluid tap. The consent needs to list the benefits, potential complications, and alternative options to the procedure which might include doing nothing. The patient or a person legally responsible for the patient must sign the consent form, which will become part of the patient's permanent record. The consent must be witnessed and signed (which can be the sonographer as previously discussed) (Fig. 2.1). A student typically is not allowed to witness the consent since they are not an employee of the hospital. Some hospitals are transitioning into electronic consents with everyone signing on an electronic signature capture pad which will transfer everything into the patient's electronic medical record.

As discussed, an ultrasound should not be performed if the patient refuses the exam or asks you to stop. If you cannot persuade the patient to finish their exam, then the reading physician or the ordering physician should talk to the patient and address their concerns. If the patient agrees, you may finish the exam; if not, the exam will be terminated. Whatever the reason, you should remain respectful to the patient and not be rude or condescending to them.

Patient Privacy. Performing an ultrasound study will involve exposure of part of the patient's body, and you should assume everyone is modest. In fact, you may come across some cultures or religions where people cannot expose their skin in public, especially to someone they perceive as the opposite sex. The sonographer must honor if a patient specifically requests a male or female to perform their study. Before beginning each ultrasound examination, be sure to close the door and pull any curtains for the patient's privacy. Inform the patient that you are going to be lifting their shirt or gown, uncovering only the parts of the body that are necessary to perform the exam. You will want to explain to the patient why you are tucking a towel into their pants or shirt to protect their clothes from the gel. Sometimes the patient will put the gown on with the opening in the front. This can make it difficult to keep their breasts covered so place a towel, sheet, or another gown across their chest explaining that you want to keep their chest covered.

Always allow the patient privacy when they are changing their clothes. Knock on the door before entering, crack it just a little and ask if they are finished changing before entering. Do not assume that they are finished changing and barge into the room.

If you need to go into a room where a patient is being scanned, for example, looking for a certain transducer, always knock on the door and ask for permission to enter. Be respectful when entering the room, maintaining the privacy of the patient. Just imagine the patient's embarrassment if the door is flung open while they are having a vaginal, scrotal, or breast ultrasound, and have now been exposed to "the world."

Another aspect of privacy is to not discuss the patient's information in public places such as an elevator or in the hallway. Do not ask questions about their medical history where others can easily overhear you. Not only can this make the patient uncomfortable but it is also a violation of their protected health information. Your place of employment or ultrasound program will train you about the Health Insurance Portability and Accountability Act (HIPAA) of 1996, which established national standards for protection of patient medical information (or as it is commonly called, PHI). You must comply with the regulations involved with this act and be aware of ways that patient information can be compromised, especially in social media. A student may be excited when they see pathology or perform a good exam or a sonographer when they have unusual findings. However, writing about your patient on your social media account even though their name is not mentioned can be considered a violation of HIPAA. People have lost their jobs talking about patients on their social media accounts.

Who Can Be in the Room? Some patients may want a friend or family member with them for support and at other times

1. INDICATIONS FOR THE OPERATION OR OTHER PROCEDURE ARE:
   Mass/lesion, fluid, oher:____

2. MAJOR RISKS AND PROBABILITY OF SUCCESS OF THE OPERATION OR OTHER PROCEDURE (including such items as failure to obtain the desired result, discomfort, injury, additional therapy and death):
   - **Pain**
   - **Vasovagal reaction/allergic reaction**
   - **Bleeding/inadvertent injury to other organs**
   - **Inadequate specimen**
   - **Other:**________________

3. DISCUSSIONS OF ALTERNATIVES TO THE PROPOSED OPERATION OR OTHER PROCEDURE **including risks, benefits and side effects as well as possible outcome of not receiving the procedure:**
   - **Do nothing**
   - **Biopsy without imaging guidance**
   - **Surgery**

4. IN INSTANCES WHERE A DISCUSSION OF THE ABOVE IS DEEMED UNWISE MEDICAL PRACTICE, THERE SHOULD BE DOCUMENTED A STATEMENT TO THIS EFFECT BELOW, STATING THE REASON FOR THIS DECISION. (This space may also be used for explanatory diagrams.)

Signature of Patient *Signature of Witness*

Signature of Physician/Health Care Provider Securing Consent

IF PATIENT IS UNABLE TO SIGN OR IS A MINOR, COMPLETE THE FOLLOWING:

Patient is a minor (__ years of age) or is unable to sign because: ____________________

Signature of Parent, Surrogate, Health Care Agent or Legal Guardian *Signature of Witness*

*******TIME OUT VERIFICATION***** – Please document the names of the participants below:**

Surgeon/Physician/Licensed Health Care Provider *Nurse* *Anesthesiologist/CRNA*

DATE________________ **TIME**____________**AM/PM**

FIG. 2.1 Sample basic consent form that also includes the time out documentation.

they may want privacy during their exam. The preference of the patient, whether an inpatient or outpatient, must always be considered. In a patient's hospital room, if the patient would like visitors or family members to stay with them, you should try to honor this request. Depending on the situation, you will communicate that it is either fine for them to stay, or that it is preferred that they wait somewhere else and the reason why. At times you may get more cooperation if you allow their visitors to stay.

When performing a portable ultrasound, the nurse is another person that may be in the room. The nurse in the room can also help make your job easier by providing you with information about the patient, helping to position the patient, providing comfort to the patient during the exam, and communicating as needed with the patient and their visitors. There may be times that the nurse or other hospital staff will have to interrupt the ultrasound to address a patient care issue, such as giving important meds. Usually, you can manage to work around each other but if not, you should step away from the bed until they have finished.

When a patient comes to the ultrasound department you have a little more control over who comes into the room with the patient. Consider their wishes on deciding if the visitor should wait outside. If the patient is a minor, in most cases you will have the parent come into the ultrasound room with you. A teenager may be uncomfortable having their parent in the room for an ultrasound, especially if it is a breast, pelvic, or testicular exam. A good solution is to ask the patient if they prefer to have their parent with them or to wait outside. This may be a difficult conversation with the parent explaining the reason why they should wait outside. If they are going to stay, try and position the parent so that they cannot see their child.

There may be times when you need to leave a patient alone in a room. This can be a concern for a very ill patient or someone with a risk of falling. If you need to leave the patient alone in a room, be sure to lower the bed height, raise the bedrails, and leave your patient with a call button (Fig. 2.2). If necessary, find someone to sit with your patient until you return or move them into a place where they can be observed. If a family member is waiting outside, invite them in to stay with the patient. Remember patient safety first.

Certain types of ultrasound exams may require a chaperone. A chaperone is an employee that is present during a sensitive clinical exam or procedure in which a patient may feel uncomfortable. A chaperone also protects the sonographer from being falsely accused of inappropriate behavior by the patient. A chaperone is required for a vaginal ultrasound, even if the sonographer is female since a variety of sonographers have been successfully sued. This is a serious subject, and you need to know the policy of the institution and question if they do not require a chaperone for a female sonographer performing an endovaginal exam. The legal department can be a good resource as usually there is a blanket policy that involves any employee, including doctors, who is performing any type of vaginal exam. Having a chaperone protects not only the patient's concerns, but legally protects the sonographer from any false accusations of sexually molesting or abusing the patient. The name of the chaperone is documented in the patient's medical record. If a patient ever makes a legal claim that a sonographer acted unprofessionally, the documented chaperone will serve as a witness. Sometimes you may want a chaperone to protect you if you feel threatened or perceive unwanted advances from the patient. For example, a patient may keep exposing their penis, which has an erection, to the sonographer while they are scanning their scrotum, despite multiple attempts to keep the penis covered. If you feel threatened, you need to have another person in the room. You never want to put yourself at risk, either physically, emotionally, or legally.

FIG. 2.2 (A) A simple call button. Pressing the button will cause an alarm to go off. This is usually the type of call bell found in an ultrasound department. (B) A call button that can also control the television in a patient's room. Pressing the red button on top with the nurse icon will notify someone that the patient needs help, causing a light to flash and an audible signal. The cancel button is typically in the patient's room, requiring a staff visit when it is pressed.

Efficiency in Patient Care. Timing of the ultrasound is a very important aspect of patient care. When speaking to the nurse before the exam, you will want to ask if it is a good time to perform the ultrasound. The patient may have other tests ordered that may have priority over the ultrasound, such as an endoscopy. At times you will need to work with the nurse to find the best time to get the ultrasound done, especially if it is a portable exam. Communication and planning with the nurse are crucial for efficiency and good patient care.

A patient should be off of their unit for a limited amount of time in order to receive the best care. They will typically have other tests that need to be performed, need to be available to see doctors, and will have visitors. This will require being prepared for the patient's arrival by having the room ready, inputting their identification information into the ultrasound unit, and investigating the pertinent patient history before they arrive to the department. Working efficiently will help your patients have good experiences.

Unfortunately, there will be times when the patient will need to wait. Emergent situations will happen that will need to be addressed immediately, causing patients to wait. Here communication is vital. The patient should be informed as to the reason for the wait and the expected amount of time that they will have to wait. Inpatients should be given the option to return to their unit to be called later and outpatients the chance to reschedule, especially if the wait time may exceed 30 minutes. Patients should be offered any comfort that you can provide while they wait. Any further delays will also need to be communicated to the patient. For safety, do not leave an inpatient alone for an extended period of time. They should be where other employees can watch or help them as needed. Leaving a patient alone increases the risk of the patient trying to get out of their wheelchair or off of their stretcher causing them to fall, pull out their IV, or even wander off. Critically ill patients should never be left alone. What if they code and no one is around to call the code and start cardiopulmonary resuscitation (CPR)? It is important that all safety measures are being used when a patient has to wait, which includes but is not limited to having the brakes applied, side rails up, and that they have a call button. Failure to do so may cause the patient to harm themselves and for you to be disciplined.

BASIC PATIENT CARE

Vital Signs

Vital signs are a group of measurements that give an idea of the body's life-sustaining functions. They are used to help assess the general physical health of a person and to potentially alert the possibility of a disease process. The four most common vital signs that are taken are pulse rate, respiratory rate, body temperature, and blood pressure. The readings of the vital signs will vary with the age, sex, weight of the patient, and their overall health. The normal range for vital signs is constantly being evaluated, and these values may change. The reader is encouraged to be familiar with current normal values.

Sonographers do not routinely assess the vital signs of a patient unless performing specific ultrasound studies, such as an ankle-brachial index (ABI) or assessing for a subclavian steal. Vital signs are always part of a complete echocardiogram procedure. It is possible to be asked to help in an emergency situation, so learning how to properly take a pulse, count respirations, or to properly put on a blood pressure cuff can be helpful for the care of the patient. Automatic blood pressure pumps may have a pulse oximeter attached and the sonographer may have to place the sensor on the patient's finger so that the oxygen levels can be determined as well.

Pulse. The **pulse** is used to measure the heart rate, or the number of times the heart beats per minute. When the heart pumps, blood is forced into the arteries during contraction of the left ventricle. The amount of force that is created when the blood hits the arterial walls will produce an advancing pressure wave that causes the arterial walls to expand. This expansion produces the feeling of a pulse. The pulse can be felt in the wrists (radial artery), the neck (carotid artery), the inside of the elbow (brachial artery), the ankles (posterior tibial artery), the top of the foot (dorsalis pedis), behind the knee (popliteal artery), and in the groin (femoral artery). The place where the pulse is measured is named after the artery that is palpated, with the radial and carotid arteries being the most common places to assess the patient's pulse.

The pulse offers an easy and effective way to measure heart rate and is recorded as beats per minute. The beat of the pulse should be evaluated for rate, rhythm, and regularity, as well as for strength. Normal adult pulse rates should be between 60 and 100 beats/min with a regular rhythm. However, there are some normal variations. For example, rates in children, women, and the elderly are slightly higher, whereas rates in athletes are slightly lower.

A normal pulse will have strong palpitations, whereas a weak pulse will feel faint. No discernible pulse is suggestive of arterial occlusion. An irregular pulse and therefore heartbeat is termed an **arrhythmia** or dysrhythmia. Among the most common arrhythmias are tachycardia and bradycardia.

Tachycardia is defined as a heart rate of more than 100 beats/min. This finding may only be temporary, caused by exertion or nervousness, or it may be secondary to disease.

A heart rate of fewer than 60 beats/min is **bradycardia** and may arise from disease in the heart's electrical conduction system or with the sinoatrial node. These patients may have a sinus node dysfunction or heart block. Remember that athletes can have heart rates less than 60 beats/min, which would be normal for them.

When taking a pulse, first explain the procedure to the patient and then have them place their arm straight palm side up. The radial artery can be located by placing the index and middle fingers at the base of the wrist on the thumb side. Never use your thumb to take the patient's pulse, as the strong pulse within your own thumb may be confused with that of the patient's. Using your finger, gently feel for the radial artery on the inner side of the wrist (Fig. 2.3). If no abnormalities are detected, the pulse should be counted for 30 seconds and multiplied by 2. If irregularities are noted, the pulse should be counted for a full minute. Record the pulse rate and anything you notice about the pulse, such as its being weak, strong, or missing beats. If an irregularity is detected, determine whether it occurs in a pattern or is random. If the radial pulse is difficult to palpate, try the carotid artery. To find the carotid artery, place your fingers just below the angle of the patient's mandible (Fig. 2.4).

In the vascular lab the vascular sonographer may assess the pulses at the ankles to evaluate the legs for arterial disease. As part of a lower extremity arterial evaluation the pulse rate is typically not measured but the quality and strength of the pulse is assessed using a number from 0 to 2 with a normal strong pulse written as 2^+, a weak pulse that is barely felt as a 1, and no pulse as a 0.

FIG. 2.3 Properly taking a radial pulse.

FIG. 2.4 Properly taking a carotid pulse.

FIG. 2.5 A patient getting a blood pressure measurement with an automatic device. Notice how the patient's arm is resting on the holder to keep it at the proper height, the level of the heart, with the palm up. Both feet are flat on the floor. This unit also measures the patient's pulse simultaneously. The thermometer is stored in its holder on the back of the unit. The wire holder holds the various sized cuffs.

Blood Pressure. One of the most important and common vital signs assessed is blood pressure. Blood pressure is the pressure or force exerted by circulating blood against the walls of the arteries. Blood pressure is expressed as two numbers. The first number is the systolic measurement, when the pressure is at its highest when the heart beats, and the second number is the diastolic measurement, when the pressure is at its lowest as the heart relaxes between beats. Blood pressure is written as follows, 120/80, and would be expressed verbally as 120 over 80. Although these numbers appear to be a fraction, they are not nor are these numbers a ratio. Blood pressure is measured in millimeters of mercury (mm Hg).

The blood pressure is typically obtained from the brachial artery in the arm. Blood pressure may be taken manually or with an automatic unit. Typically, the automatic units will also measure the pulse, and some will have accessories such as a pulse oximeter and a thermometer. These units can obtain multiple readings to get an average blood pressure, which is a more accurate measurement as our blood pressure can fluctuate.

Cuff placement and patient position are the same whether the blood pressure is being obtained manually or automatically. In a perfect world the patient should rest for five minutes before their blood pressure is taken, and they should not have a full bladder as this can cause a falsely elevated reading. The patient should sit in a chair with their back supported, feet flat on the floor and with their arm supported so that the cuff is at the level of the heart. The hand should not be clenched (Fig. 2.5). The bottom edge of the cuff should be one to two inches above the elbow and should encircle the patient's upper arm with about 80% of the cuff (Fig. 2.6). If the cuff is too small it will give a higher reading, and if it too large it will produce a lower reading. Before beginning, verify that the patient has not crossed their legs as this will increase the blood pressure. The patient should be instructed not to talk while their pressure is being taken. To obtain a manual blood pressure follow the steps in Box 2.1.

The manual measurement of blood pressure is performed with a sphygmomanometer, blood pressure cuff, and a stethoscope. The blood pressure cuff consists of an air pump, a pressure gauge, and a rubber cuff (Fig. 2.7).

Blood pressure readings can be affected by a variety of factors, including cardiac disease, nervousness about seeing the doctor (called **white coat hypertension**), obesity, smoking, stress, drinking alcohol or caffeine 30 minutes before the reading, being cold or chilly, and some medications and herbal supplements. The reader is encouraged to do a search on medications and herbs that affect the blood pressure. If the first blood pressure reading is higher than normal, a second reading should be taken after 2 to 3 minutes allowing the patient time to relax.

The vascular sonographer may use a manual system for taking brachial and ankle pressures required to determine the ABI. To measure the ABI, the systolic readings are obtained using Doppler, as opposed to a stethoscope. The cuff is placed above the ankle for the ankle readings and above the elbow for the brachial reading. A reading is obtained from both arms and ankles using the brachial, dorsalis pedis, and posterior tibial arteries. Find the artery with the continuous wave Doppler transducer. Inflate the cuff until the Doppler signal is no longer heard. When the signal returns take note of the reading as this is the systolic number. Repeat for the other arteries. Note that the Doppler signal will always be present, so a diastolic reading cannot be obtained.

Pulse Oximetry. Oximetry is a convenient, noninvasive method of monitoring blood oxygen levels. This information is useful to

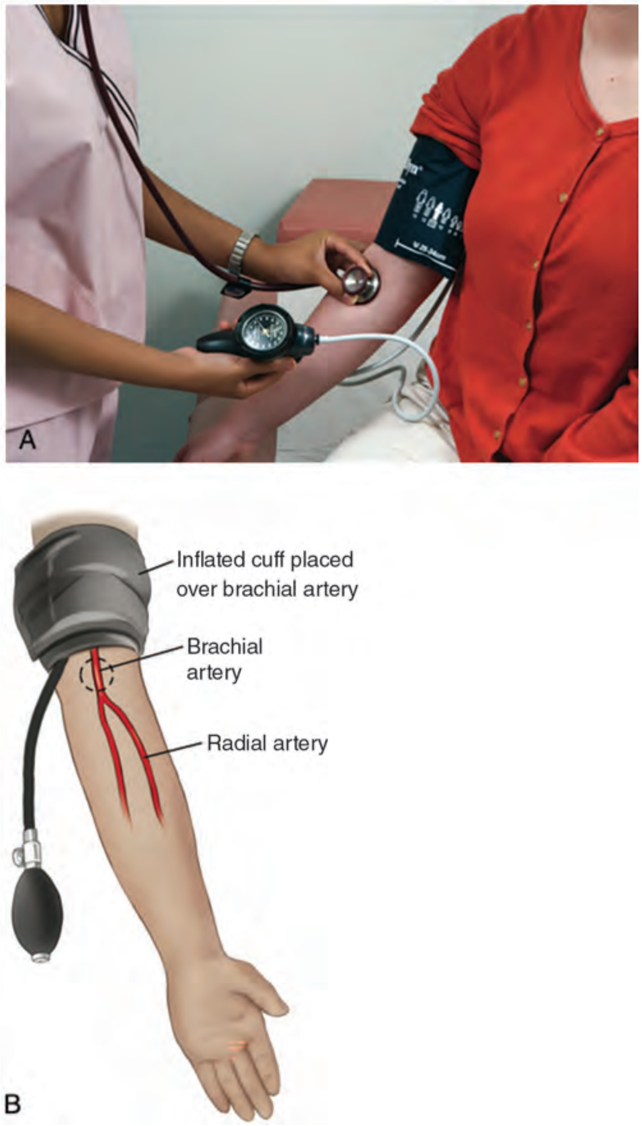


FIG. 2.6 (A) Taking a blood pressure with a manual device. (B) Proper cuff size and placement.

FIG. 2.7 Manual blood pressure device in a patient's room showing the pump, display, and hose to connect to the cuff.

BOX 2.1	**Taking a Manual Blood Pressure**

- Have the patient sit with their arm supported and with the arm at the level of the chest or heart.
- The bottom edge of the cuff should be one to two inches above the elbow and should encircle the patient's upper arm with about 80% of the cuff.
- Squeeze the pump to rapidly inflate the cuff to about 200 mm Hg, or until no sound is heard with the stethoscope over the brachial artery.
- Loosen the valve slowly, about 5 mm Hg/sec, to let out air while listening for the sound of the return of the heartbeat. When it returns check the measurement on the manometer as this is the systolic reading.
- Continue deflating the cuff slowly until you can no longer hear the heartbeat. This last audible sound is the diastolic reading.
- Record both readings as a fraction (e.g., 136/88).

determine whether the heart, lungs, and blood are working synchronously to deliver oxygen to various parts of the body. A low blood oxygen reading can be a sign of an illness or injury.

The test is performed by using an oximeter, a specially designed photoelectric device, which measures the difference between levels of the red pigment hemoglobin, which carries oxygen in the blood. The most commonly used oximeters are called pulse oximeters because they respond to the pulsations of the capillaries in the area to be tested. One end of the device is attached like a clothespin to the end of the patient's index finger (Fig. 2.8). The other end of the oximeter is attached to a monitor so that the patient's oxygen level can be seen at all times.

The amount of oxygen in the blood is given as a percentage. A normal reading for a person breathing room air is in the high 90 s. A reading of 90% or less will trigger visual and audible alarms, requiring immediate action. Asking the patient to take in a couple of deep breaths will help raise the oxygen levels. If the levels keep falling, the patient will be given oxygen to help maintain good levels. The oximeter acts as an indicator that something is interfering with the oxygenation of blood levels and that further investigation is required. It does not diagnose what is interfering with the patient's oxygen levels.

A patient that is having a lung or chest biopsy under ultrasound guidance will have their pulse ox monitored as a sudden drop can be a sign that the lung has been punctured.

Respiration. **Respiration**, or breathing, is the process of inhaling and exhaling air. Its primary function is to obtain oxygen for use by the body's cells and to eliminate carbon dioxide. Normal breathing is quiet, effortless, and has a regular rhythm. In an adult at rest, respiration occurs at a rate of