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VOLUME ONE

超声诊断学

Textbook of Diagnostic Ultrasonography

fifth edition

25 Silver Anniversary Edition

Sandra L. Hagen-Ansert

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VOLUME ONE

Textbook of Diagnostic Ultrasonography

fifth edition

with 2538 illustrations

SANDRA L. HAGEN-ANSERT, M.S., RDMS, RDCS
Ultrasound Consultant and Educational Specialist
Former Program Director and Clinical Sonographer
Baptist College of Health Sciences, Memphis, Tennessee
University of California, San Diego Medical Center, San Diego, California

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CONTRIBUTORS

FRANK CHERVENAK, MD
Professor of Obstetrics and Gynecology
Director of Obstetrics
Director, Maternal-Fetal Medicine
New York Hospital, Cornell Medical Center
New York, New York

DAWN GANGLOFF, BS, RDMS, RT(R)
Staff Sonographer, Ultrasound Department
St. Francis Hospital
Peoria, Illinois

M. ELIZABETH GLENN, MD
Women's Health Center at Baptist East
Memphis, Tennessee

CHARLOTTE HENNINGSEN, MS, RDMS
Program Director, Diagnostic Medical Sonography
Florida College of Health Science
Orlando, Florida

MIRA L. KATZ, PHD, RVT
Research Technologist
Radiology Department
The Children's Hospital of Philadelphia
Philadelphia, Pennsylvania

LAURENCE B. MCCULLOUGH, PHD
Professor of Medicine and Medical Ethics
Center for Medical Ethics and Health Policy
Baylor College of Medicine
Houston, Texas

TRACI PARKER, RDMS
Department of Radiology/Ultrasound
Boulder, Colorado

KERRY WEINBERG, MS, RDMS
Program Director, Diagnostic Medical Sonography
New York University
New York, New York

REVIEWERS

Kevin P. Barry, MEd, RDMS, RDCS, RT(R)
Professor/Department Head
Diagnostic Medical Imaging
New Hampshire Technical Institute
Concord, New Hampshire

Jan D. Bryant, MS, RDMS, RT(R)
Program Director
Diagnostic Medical Sonography Program
El Centro College
Dallas, Texas

Casey Clarke, BSRT, RT(R), RDMS, RDCS
Program Director
Diagnostic Medical Sonography
South Suburban College
South Holland, Illinois

Joan Clasby, BvE, RT, RDMS, RDCS
Director and Professor
Diagnostic Medical Sonographer
Orange Coast College
Costa Mesa, California

Dale E. Collins, MS, RT(R) (M) (QM), RDMS
Instructor
Medical Radiography
State University of New York–HSC–Syracuse
Syracuse, New York

Steven M. Currier, MS, RT, RDMS, RVT
Director
Medical Imaging
Lake Wales Medical Center
Lake Wales, Florida

Janice D. Dolk, MA, RT(R), RDMS
Director
Diagnostic Medical Sonography Program
University of Maryland, Baltimore
Baltimore, Maryland

Janet M. Feldmeier, BSRT, RDMS
Staff Ultrasonographer
Cardinal Glennon Children's Hospital
St. Louis, Missouri

Kathleen Kurshinsky, RT(R)M, RDMS
Clinical Instructor
Chippewa Valley Technical College
Eau Claire, Wisconsin

Thomas F. Walsh, MA, RDMS
Program Director
Middlesex Community College
Bedford, Massachusetts

Kimberlee B. Watts
Director of Sonography
Caldwell Community College & Technical Institute
Hudson, North Carolina

Cheryl L. Zelinsky, BA, RT(R), RDMS
Director
Diagnostic Medical Sonography Program
Oregon Institute of Technology
Klamath Falls, Oregon

FOREWORD

I am pleased to offer a foreword for this prestigious Silver Anniversary Edition of *Textbook of Diagnostic Ultrasonography.*

Continuing growth in the field of sonography certainly has warranted this new edition and Sandra Hagen-Ansert and her colleagues have proved more than equal to the task. New in this edition are chapters on the *foundations of sonography, scanning techniques and protocols, the vascular system, the liver, the genitourinary system, the retroperitoneal cavity, the scrotum, the breast, and the thyroid,* complementing existing chapters on general sonography. Special attention to neonates has resulted in specific chapters on cranial, abdominal, and renal sonography. Obstetric and gynecologic sonography have also been enhanced by revised offerings in normal anatomy and physiology, as well as embryosonology, congenital anomalies, and fetal echocardiography. The vascular chapters have been completely updated to include the latest techniques in vascular imaging. The cardiology section offers introductory material on anatomy and physiology, in addition to the normal echocardiographic protocol and images required to perform a complete examination. A brief overview of pathology the cardiac sonographer may encounter during an echocardiographic procedure is found in the echocardiographic pathology chapter. As with previous editions the quality of the text and illustrations remains very high. The authors are to be commended for their efforts in making a very readable textbook.

The focus of this text has always been on the sonographer actually performing studies. Those who assume this role have a unique relationship with physicians responsible for interpreting sonographic studies. Real-time sonography provides the sonographer with vast amounts of information, most of which is discarded. Final images reaching the physician are a distillation of this information. In a very real sense the sonographer performs diagnosis during the study. Nowhere else in medicine does this relationship exist. Perhaps the closest analogy is in gastrointestinal fluoroscopy, in which spot films are made of real-time images, often sacrificing functional information. Technologists perform these studies in virtually no institutions. Yet curiously, in these same institutions, sonographers daily churn out complex studies of the heart, abdomen, and pelvis–in my view a far more complex task.

This unique role as a physician's assistant clearly deserves recognition. It requires high-quality instruction, of which this book is an excellent example. It also requires outstanding and dedicated individuals, of which the book's principal author is an excellent example. She and her co-authors are to be congratulated on their success in advancing our knowledge in this discipline.

It is hard to overestimate the number of individuals who have benefited from previous editions of this text. Although this text was initially conceived for sonographers, I frequently see it used by sonologists as well. It is my belief that this usage typifies the close relationship between these groups, which is essential for top-quality sonography. In this edition, Sandra Hagen-Ansert and her colleagues have once again shown us that through prodigious effort it is still possible to produce a text benefiting all who labor in this vineyard.

George R. Leopold, MD

PREFACE

A LOOK BACK

Medicine has always been a fascinating field to me. I was introduced to it by Dr. Charles Henkelmann in 1963, who provided me with the opportunity to learn radiography. Although x-ray technology was interesting, it did not provide the opportunity to evaluate patient history or to follow through interesting cases, which seemed to be the most intriguing aspect of medicine and my primary concern.

Shortly after I finished my radiographic training in 1968, I was assigned to the radiation therapy department, where I was introduced to a very quiet, young, dedicated radiologist, whom I would later grow to admire and respect as one of the foremost authorities in diagnostic ultrasound. Convincing George Leopold that he needed another hand to assist him was difficult in the beginning, and it was through the efforts of his resident, Dan MacDonald, that I was able to learn what has eventually developed into a challenging and exciting new medical modality.

Using high-frequency sound waves, diagnostic ultrasound provides a unique method for visualization of soft tissue anatomic structures. Identifying such structures and correlating the results with clinical symptoms and patient data offers an ongoing challenge to the sonographer. The state of the art demands expertise in scanning techniques and maneuvers to demonstrate the internal structures; without quality scans, limited diagnostic sonographic information can be provided to the physician.

Our initial experience in ultrasound took us through the era of A-mode techniques, identifying aortic aneurysms through pulsatile reflections, trying to separate splenic reflections from upper-pole left renal masses, and, in general, attempting to echo every patient with a probable abdominal or pelvic mass. Of course, the one-dimensional A-mode techniques were difficult for me to conceptualize, let alone trust. However, with repeated successes and experience gained from mistakes, I began to believe in this method. The conviction that Dr. Leopold had about this technique was a strong indicator of its success in our laboratory.

In 1969, when our first two-dimensional ultrasound unit arrived in the laboratory, the "skeptics" started to believe a little more in this modality. I must admit that those early images looked like weather maps to me for several months. The repeated times I asked, "What is that?" were enough to try anyone's patience.

I can recall when Siemens installed our real-time unit and we saw our first obstetric case. It was such a thrill for us to see the fetus move, wave his hand, and show us fetal heart pulsations!

We scouted the clinics and various departments in the hospital for interesting cases to scan. With our success rate surpassing our failures, the case load increased, so that soon we were involved in all aspects of ultrasound. There was not enough material for us to read to see the new developments. It was for this reason that excitement in clinical research soared, attracting young physicians throughout the country to develop techniques in diagnostic ultrasound.

Because Dr. Leopold was so intensely interested in ultrasound, it became the diagnostic method of choice for our patients. It was not long before conferences were incomplete without the mention of the technique. Later, local medical meetings and eventually national meetings grew to include discussion of this new modality. A number of visitors were attracted to our laboratory to learn the technique, and thus we became swamped with a continual flow of new physicians, some eager to work with ultrasound and others skeptical at first but believers in the end.

In 1970, the beginning of education progressed slowly, with many laboratories offering a one-on-one teaching experience. Commercial companies thought the only way to push the field was to develop their own national training programs, and thus several of the leading manufacturers were the first to put a dedicated effort into the development of ultrasound.

It was through the combined efforts of our laboratory and commercial interests that I became interested in furthering ultrasound education. Seminars, weekly sessions, local and national meetings, and consultations became a vital part of the growth of ultrasound.

Thus, as ultrasound grew in popularity, more intensified training was desperately needed to maintain the initial quality that the pioneers strived for. Through working with one of the commercial ultrasound companies conducting national short-term training programs, I became acquainted with Barry Goldberg and his enthusiasm for quality education in ultrasound. His organizational efforts and pioneer spirit led me to the east coast to further develop more intensive educational programs in ultrasound. The challenge grew of establishing new programs and continuing education in diagnostic medical sonography in the years to follow as we ventured across the United States and Canada.

INTRODUCING THE NEW FIFTH EDITION

Welcome to the Silver Anniversary Edition of the *Textbook of Diagnostic Ultrasonography.* This fifth edition continues the tradition of excellence begun when the first edition was published in the 1970s. Of course, the textbook has been vastly updated and reorganized over the years. The field of diagnostic ultrasound has changed so dramatically in the past 40 years that the approach to many procedures has been altered significantly. Phenomenal strides in transducer design, instrumentation, and color flow Doppler have provided increased resolution in the ultrasound image. The introduction of contrast media is becoming more clinically accepted to image the gastrointestinal tract, the female reproductive system, and the multiple vascular pathways in the body. Three-dimensional imaging has provided additional information on the fetus to help the clinician obtain a clearer definition of fine detail.

The primary goal of this textbook continues: to provide an in depth resource for students studying sonography, as well as practitioners in hospitals, clinics, and private radiology, cardiology, and obstetric settings. This new, fifth edition strives to keep up with this fast-moving field, giving students and practitioners not only complete, but also up-to-date information in sonography.

ORGANIZATION

Textbook of Diagnostic Ultrasonography remains divided into two volumes to compensate for its expanded coverage and to make the book more convenient and easier to use. The content has been completely reorganized to provide better flow for the reader. The first volume covers general ultrasound applications, that is, abdominal and retroperitoneal cavities, superficial structures, and pediatrics. Also included in this volume are four chapters on cerebrovascular and peripheral vascular Doppler imaging, as well as two chapters focusing on an introduction to echocardiography with an overview of cardiac pathology. The second volume has been reorganized to primarily focus on obstetrics and gynecology.

Each chapter begins with a list of key terms and definitions to aid the reader. Sonographic concepts continue to be presented in a logical and consistent manner in each chapter. To help the student and the sonographer understand the patient's total clinical picture before the sonographic examination, discussions on anatomy, physiology, laboratory data, clinical signs and symptoms, pathology, and sonographic findings are found within each specific chapter. References cited in the text are listed at the end of each chapter. In addition, review questions are included at the end of each chapter to help the reader measure comprehension of the material.

ILLUSTRATIONS AND VISUALS

The reader will notice colorful illustrations throughout and color within the layout of the chapters. Focus charts highlight important areas throughout both volumes.

To keep up with the continually changing field of ultrasound, hundreds of new images have been incorporated, including many new color Doppler images. *Out of more than 3000 images, approximately 70% are new.* In addition, the multitude of anatomic illustrations have been completely redrawn in color to demonstrate many of the relevant landmarks the sonographer should look for when performing an ultrasound examination.

Ultrasound findings for particular pathologies and conditions are now preceded by the following special head:

Ultrasound findings.

This makes location of these sections easier for both the student and the practicing sonographer.

NEW TO THE FIFTH EDITION

This edition has been completely revised and expanded to offer a comprehensive textbook for the student in general ultrasound. The peripheral vascular chapters are appropriate for the student to understand vascular applications within a general ultrasound department. New chapters have been added on the foundations of sonography; the breast, thyroid, and scrotum and prostate; renal and retroperitoneal areas; high-risk pregnancy; congenital anomalies; fetal head and neural tube defects; and ethics and legal issues in obstetric ultrasound.

Particularly noteworthy is the section on obstetrics and gynecology, which has been completely updated from the excellent work of Kara Mayden Argo and her collegues in the fourth edition, with several excellent new contributors. The pediatric ultrasound section written by Suzanne Devine and her colleagues from Children's Hospital in Chicago in the last edition has been updated as well. The cerebrovascular and peripheral vascular chapters have been completely revised by Mira Katz. Dr. Elizabeth Glenn has extensively rewritten the chapter on the breast from the focus of a sonographer working within a women's health center.

It is my hope that this textbook will not only introduce the reader to the field of ultrasound, but also go a step beyond to what I have found to be a very stimulating and challenging experience in diagnostic patient care.

Sandra Hagen-Ansert

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Very special recognition goes to my patient and understanding family, Art, Rebecca, Alyssa, and Katrina, who were usually very tolerant of the hours upon hours of preparation and writing this edition bestowed upon all of our lives. The girls have grown up with these five editions and have volunteered their tiny hearts, and now abdominal vessels, for various illustrations throughout the book. They have vowed never to volunteer again.

CONTENTS

PART *I*

Foundations of Sonography

CHAPTER 1

Foundations of Sonography

Sandra L. Hagen-Ansert

Objectives

- Discuss the development of diagnostic medical ultrasound
- Describe the role of the sonographer
- List the qualities of a sonographer
- Identify resource organizations devoted to ultrasound
- Explain common medical abbreviations
- Discuss the descriptive sonographic terminology
- List the ultrasound criteria for a cyst, complex or solid mass
- Explain the key terms in basic ultrasound physics
- Define ultrasound
- Discuss the effects of acoustic impedance on the ultrasound beam
- Describe the piezoelectric effect
- List the various types of transducers and their applications
- Discuss the display modes in ultrasound
- List the component parts of pulse-echo instrumentation
- Explain the key terms of Doppler ultrasound
- Explain knobology and its clinical application
- Describe the types and characteristics of artifacts encountered in an ultrasound examination

KEY TERMS

acoustic impedance - measure of a material's resistance to the propagation of sound; expressed as the product of acoustic velocity of the medium and the density of the medium ($2 = pc$)

amplitude - strength of the ultrasound wave measured in decibels

angle of incidence - angle from the normal at which the sound beams strikes the interface

angle of reflection - the amplitude of the reflected wave depends on the difference between the acoustic impedances of the two materials forming the interface

attenuation - reduction in the amplitude and intensity of a sound wave as it propagates through a medium; attenuation of ultrasound waves in tissue is caused by absorption and by scattering and reflection

bulk modulus - amount of pressure required to compress a small volume of material a small amount

crystal - special material in the transducer that has the ability to convert electrical impulses into sound waves

cycle - measurement of the vibration of the crystal in frequency per second

decibel (dB) - unit used to quantitatively express the ratio of two amplitudes or intensities; decibels are not absolute units, but express one sound level or intensity in terms of another or in terms of a reference (e.g., the amplitude 10 cm from the transducer is 10 dB lower than the amplitude 5 cm from the transducer)

dynamic range - ratio of the largest to smallest signals that an instrument or component of an instrument can respond to without distortion

focal zone - the region over which the effective width of the sound beam is within some measure of its width at the focal distance

frame rate - rate at which images are updated on the display; dependent on frequency of the transducer and depth selection

frequency - number of cycles per second that a periodic event or function undergoes; number of cycles completed per unit of time; the frequency of a sound wave is determined by the number of oscillations per second of the vibrating source

gain - measure of the strength of the ultrasound signal; can be expressed as a simple ratio or in decibels; overall gain amplifies all signals by a constant factor regardless of the depth

gray scale - B-mode scanning technique that permits the brightness of the B-mode dots to be displayed in various shades of gray to represent different echo amplitudes

hertz (Hz) - unit for frequency, equal to 1 cycle per second

interface - surface forming the boundary between media having different properties

kilohertz (kHz) - 1000 Hz

megahertz (MHz) - 1,000,000 Hz

period - duration of a single cycle of a periodic wave or event

piezoelectric effect - generation of electric signals as a result of an incident sound beam on a material that has piezoelectric properties; in the converse (or reverse) piezoelectric effect, the material expands or contracts when an electric signal is applied

pulse duration - measure of the ring down time of a transducer after excitation

real-time - ultrasound instrumentation that allows the image to be displayed many times per second to achieve a "real-time" image of anatomic structures and their motion patterns

refraction - change in the direction of propagation of a sound wave transmitted across an interface where the speed of sound varies

resolution - ability of the transducer to distinguish between two structures adjacent to one another

spatial pulse length - spatial extent of an ultrasound pulse burst

time gain compensation (TGC) - also referred to as *depth gain compensation;* ability to compensate for attenuation of the transmitted beam as the sound wave travels through tissues in the body; usually, individual pod controls allow the operator to manually change the amount of compensation necessary for each patient to produce a quality image

transducer - any device that converts signals from one form to another

velocity - in ultrasound the tissue density determines the speed (velocity) of the ultrasound wave

wave - propagation of energy that moves back and forth or vibrates at a steady rate

wavelength - distance over which a wave repeats itself during one period of oscillation

HISTORICAL PERSPECTIVE OF SOUND

The development of materials, testing techniques, and sonar provided a major impetus in the development of diagnostic ultrasound. World War II brought sonar equipment to the forefront for defense purposes, and ultrasound was influenced by the success of sonar instrumentation. The further advancement of ultrasound was influenced by several individuals who would later prove the contributions ultrasound could provide for the medical community. These clinical investigations and the development of ultrasound are vividly described by of one it its early pioneers, Dr. Joseph Holmes, from the University of Colorado. His reflections are summarized in the following paragraphs.[3]

In 1947 K. Dussick 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 also discovered that tumors and other intracranial lesions could be detected by this technique.

Dussick went on to join Drs. R. H. Bolt and H. T. Ballantyne at the Massachusetts Institute of Technology acoustic laboratory in the early 1950s. The group continued to use through-transmission techniques and computer analysis to diagnose brain lesions through the intact skull. They discontinued their studies after concluding that the technique was too complicated for routine clinical use.

Around the same time, Dr. W. Fry, an electrical engineer who worked for the Office of Naval Research during World War II, became head of the Department of Electrical Engineering at the University of Illinois and selected ultrasound as his field of study. His primary research utilized ultrasound to pinpoint lesions within the central nervous system of animals by arranging several transducers to focus on a single point. Thus a destructive lesion could be produced at a selected distance without destroying normal tissue along the path of the beam. In addition, Dr. Fry observed that local heating by a second ultrasound beam would enhance echo reflection from adjacent structures.

Along with Dr. R. Meyers, Chief of Neurosurgery at the University of Iowa, Dr. Fry applied his "pinpoint" lesion technique to treat Parkinson's syndrome and other brain lesions. Questions arose as to whether this destruction technique was the most suitable for patients with Parkinson's syndrome, and because highly skilled investigators were required to perform the procedure, the project was terminated in 1959.

From 1948 to 1950 three investigators, Drs. D. Howry (Radiology), J. Wild (clinician interested in tissue characterization), and G. Ludwig (interested in reflections from gallstones), independently demonstrated that when ultrasound waves generated by a piezoelectric crystal transducer were transmitted into the body, ultrasound waves of different acoustic impedances would be returned to the transducer. Equipment development subsequently occurred in efforts to transform the naval sonar equipment into a clinically useful tool.

In 1948 Dr. Howry developed the first ultrasound scanner; it consisted of a cattle watering tank with a wooden rail anchored along the side. The transducer carriage moved along the rail in a horizontal plane while the object to be scanned and the transducer were positioned inside the water tank.

Dr. Howry developed the compound (back and forth) double scanning motion in an attempt to produce a more realistic anatomic image. The transducer carriage was moved in a 360-degree path around the object to produce reflections from all angular and curved surfaces (Figure 1-1). Many of the subjects were surgical candidates, so actual comparison of the tissue could be made with the ultrasound equipment.

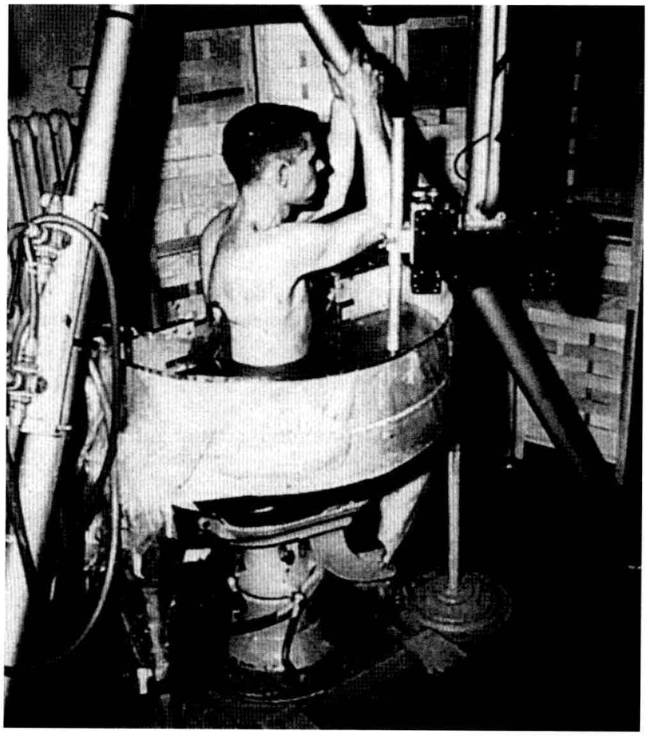

Figure 1-1 One of the early ultrasound scanning systems utilized a B-52 gun turret tank with the transducer carriage moved in a 360-degree path around the patient.

The water bath ultrasound device was modified for patient use by building a half-pan scanner with a plastic window along its flat side. The membrane was then oiled, and the patient pressed his or her abdomen flush against it. The transducer rotated through a 180-degree arc with a 4-inch compound sector.

Along with medical applications of ultrasound, it was also used to determine the lean to fat ratio of cattle and other animals ready for slaughter. The cattle were greased with 30-weight motor oil instead of mineral oil to provide a coupling for the transducer and the skin.

In 1954, echocardiographic techniques were developed by Drs. C. H. Hertz and I. Edler in Sweden. These investigators soon found they were able to distinguish normal heart valvular motion from the thickened, calcified valve motion that was observed in patients with rheumatic heart disease.

The early obstetric contact compound scanner was built by Tom Brown and Dr. Ian Donald in Scotland in 1957. Dr. Donald went on to discover many fascinating image patterns in the obstetric patient, and his work is still referred to today. Meanwhile, in Philadelphia, Dr. Stuart Lehman designed a real-time obstetric ultrasound system (Figure 1-2).

The development of the contact static scanner in North America came in 1962 from the University of Colorado. The instrument was constructed so the transducer moved in a mechanical sector scan 30 degrees to each side of the perpendicular while the carriage moved over the surface to be scanned. The initial evaluation of the pregnant woman revealed the placenta localization, fetal age, and gross abnormalities of the fetus.

Shortly thereafter the grants terminated for the various ultrasound projects, and the engineers left the University of Colorado to build the first commercial Physionics ultrasound system, which was later acquired by the Picker Corporation for distribution throughout the country.

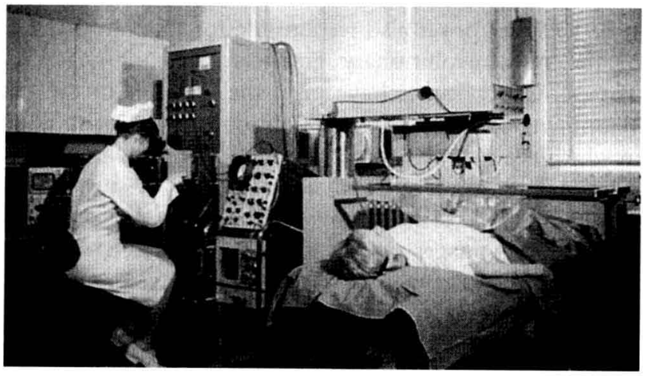

Figure 1-2 Dr. Lehman used a water path system to scan his obstetric patients.

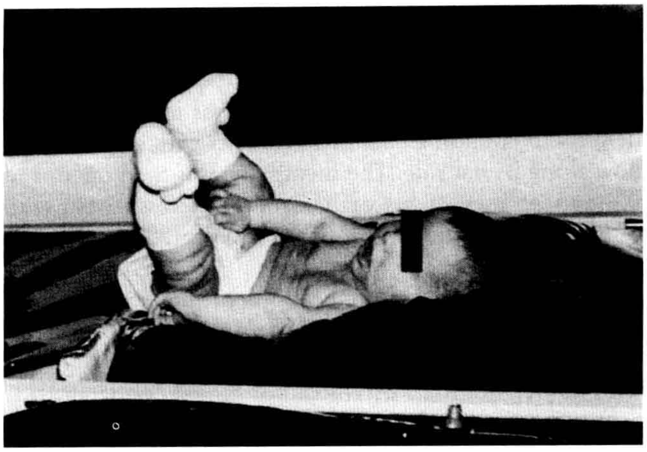

Figure 1-3 The Octoson utilized eight transducers mounted in a 180-degree semicircle and completely covered with water. The patient would lie on top of the covered waterbed, and the transducers would automatically scan the patient.

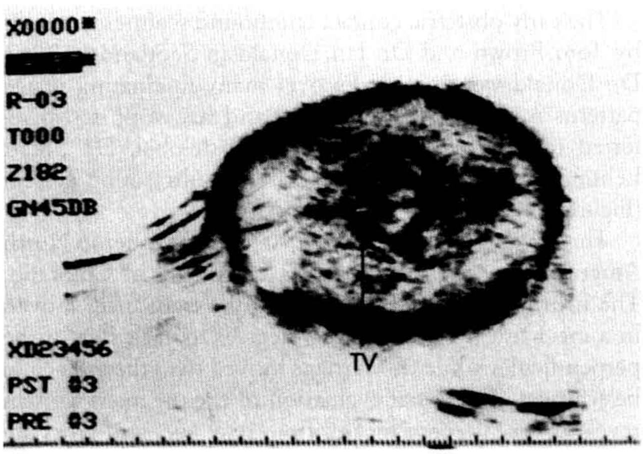

Figure 1-4 Real-time image of the neonatal head. *TV,* Third ventricle.

In 1959, G. Kossoff, H. P. Robinson, and W. Garrett, at the Commonwealth Acoustic Laboratories in Australia, developed diagnostic B-scanners with the use of a water bath to improve resolution of the image (Figures 1-3 and 1-4). This group was also responsible for the introduction of the new revolutionary gray-scale imaging in 1972. Kossoff and collegues have been the pioneers in the development of large-aperture, multitransducer technology in which the transducers are automatically programmed to operate independently or as a whole to provide a panoramic image in seconds. This technique provided high-quality images without operator intervention as found with the contact static scanners.

At the same time, real-time scanners with improved resolution that provided a quick assessment of the area in question without physically creating an image (with the contact static scanners) were beginning to enter the market. The flexible real-time transducers now are now universally accepted in performing high-quality ultrasound examinations. The mobile real-time systems quickly overtook the automated multitransducer systems, which were bulky and permanent in their location.

Today, every hospital and clinic has some form of ultrasound instrumentation to provide the clinician with an inside look at the soft tissue structures within the body. Manufacturers are still defining better image acquisition, improved transducer design, and updated computer assessment of the information acquired. The two-dimensional information is now able to be recreated into a three-dimensional format to provide a surface rendering of the area in question.

To obtain even more information from the ultrasound image, various companies have been developing contrast agents that may be ingested or administered intravenously into the blood stream to facilitate the detection and diagnosis of specific pathologies.[2,6,9] Early attempts at producing a contrast effect with ultrasound imaging involved administration of aerated saline or carbon dioxide. The research today focuses on the development of gas microspheres that are injected into the patient to provide a visual contrast during the ultrasound study.

THE ROLE OF THE SONOGRAPHER

What is the role of the sonographer as a member of the allied health profession? A *role* is a specific behavior that an individual demonstrates to others. A *function* involves the tasks or duties one is obligated to perform in carrying out a role. Therefore a *sonographer* is one who performs ultrasound studies and gathers diagnostic data under the direct or indirect supervision of a physician.

QUALITIES OF A SONOGRAPHER

The sonographer must possess specific talents that should include the following characteristics[1]:

- Intellectual curiosity
- Perseverance to obtain high-quality images
- Ability to conceptualize two-dimensional images into a three-dimensional format
- Quick-thinking and analytic capabilities
- Technical aptitude
- Good physical health (continuous scanning may cause strain on back, shoulder, arm)
- Independence and self-direction
- Emotional stability to deal with patients in times of crisis
- Communication skills with peers, clinicians, and patients
- Dedication

ADVANTAGES AND DISADVANTAGES OF A SONOGRAPHY CAREER

Sonographers with specialized education in ultrasound have shown that skills and abilities make a difference in their ability to produce high-quality consistent ultrasound images. Sonographers have earned the respect of allied