PEDIATRIC ULTRASOUND

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PEDIATRIC ULTRASOUND

To my wife
Ozie
and children
Evan, Ziva & Kivi

J.O.H.

To my wife
Laura

M.S.

Preface

IT HAS BEEN only during the past ten years that individuals concerned with ultrasound have focused their attention on issues in pediatrics. The overwhelming popularity of pediatric ultrasound is due to the fact that it avoids harmful ionizing irradiation. When ultrasound was first used seriously as an imaging modality in medicine, it was only logical that the major thrust of activity be centered about obstetrical issues. Clearly, ultrasound has had a major impact on this field. After the fetus was thus studied, it seemed only logical that the next major thrust would be toward children, the group next most vulnerable to harmful x-rays. Yet this logical progression never took place. Only in the last few years have radiologists (primarily pediatric radiologists and sonographers) been publishing their images and clinical results in major journals. Indeed, as we embarked on this project there were no texts, atlases or monographs devoted purely to pediatric ultrasound. It is interesting that the history of pediatric ultrasound parallels to some extent that of pediatric radiology. It took nearly 50 years (except for Thomas M. Rotch's textbook on pediatric radiology*) before a formal text on pediatric radiology was written by Dr. John Caffey.† Fortunately, it does not appear that pediatric ultrasound will have to wait that long before it receives significant attention. With this book we take pride in joining our colleagues who are devoting their time to discovering the quickest, most efficient, safe and convenient way of working up problems unique to the pediatric patient.

This book is written for two particular audiences. First, it is intended to provide those concerned with imaging procedures, i.e., radiologists and sonographers, with an up-to-date review of current knowledge in ultrasound as applied to the pediatric patient. Second, it is intended for those who are concerned with the clinical aspects of pediatrics, such as pediatricians, surgeons and urologists, to acquaint them with the uses, advantages and capabilities of this modality. After all, without referral from clinical colleagues, sonographers can never hope to examine children.

Because this book is intended as a general text on gray-scale sonography as applied to pediatrics, it suffers from some of the problems inherent in all general texts; that is, in-depth discussions of many topics cannot be included. This of course is unavoidable. However, we have tried to cover as many of the general areas of pediatrics as possible, including, wherever feasible, gray-scale images on up-to-date equipment with digital and analogue processing.

Because so much has been written about echocardiography and echoencephalography, we felt that these topics are best discussed in monographs specifically devoted to these fields. We have thus limited ourselves to a discussion of B-mode ultrasound imaging of the chest and abdomen.

Photographic reproductions of sonographic images are rendered as we encountered them in both the black-on-white and white-on-black presentations. Also, where appropriate, we have included a schematic diagram of a child with notations of the parts of the body from which the corresponding sonographic sec-

*Rotch, T. M.: *Living Anatomy and Pathology: The Diagnosis of Diseases in Early Life by the Roentgen Method* (Philadelphia: J. B. Lippincott Co., 1910).

†Caffey, J.: *Pediatric X-Ray Diagnosis* (Chicago: Year Book Medical Publishers, Inc., 1945).

tions were obtained. (The section on the chest makes use of the radiograph for this purpose.)

Where appropriate we have included the radiographs that were pertinent to the development of a particular case. Schematic diagrams are also included for orientation. In order not to obscure the images, the letters used to identify specific organs on the sonograms have been inserted, for the most part, in small type.

It is hard to evaluate the role of sonography vis-à-vis other modalities: computerized tomography, radiography, and nuclear studies. At present, not enough cases of any particular disease have been studied with a correlative model. It is hoped that such studies will be forthcoming.

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JACK O. HALLER

MORTON SCHNEIDER

Note to the Reader on the Display of Sonographic Figures

ALL SONOGRAMS are displayed in the following manner:

Transverse scans: Supine and prone scans are viewed as if one were standing at the patient's feet and looking cephalad (supine = patient's right side on viewer's left, prone = patient's right on viewer's right).

Longitudinal scans: Supine and prone scans are displayed as if the patient's head were on the viewer's left and feet on the viewer's right.

Contents

1
Introduction

PHYSICS

ULTRASOUND was first used as a diagnostic modality in 1947; however, it had been used during World Wars I and II in the sonar detection of submarines and for mapping the ocean floor. Sonography works on the principle that sound waves are propagated through a molecular medium. As the waves pass through this medium, they cause condensations and rarefactions. Each condensation and rarefaction makes up a cycle, and cycles per second are expressed in units of hertz (Hz). Medical ultrasound uses a frequency in the megahertz (MHz; millions per second) range. Humans can detect sounds up to 20,000 Hz (Table 1-1).

Sound is produced by a transducer, which makes use of a principle called the *piezoelectric effect;* that is, when a mechanical stress (sound) is applied to a quartz crystal, it creates an electric potential. The electrodes in a transducer create an electric potential across a piezoelectric element (barium titanate, lithium sulfate and lithium zirconate). Because of the material encasing the transducer, the sound waves that are produced are directed out the front of the transducer perpendicular to the crystal surface. The sound produced is in the form of a pulse (small package), which passes into the body across a coupling agent (usually mineral oil used to make contact between the transducer and the body). When the pulse

TABLE 1-1.—SOUND FREQUENCIES

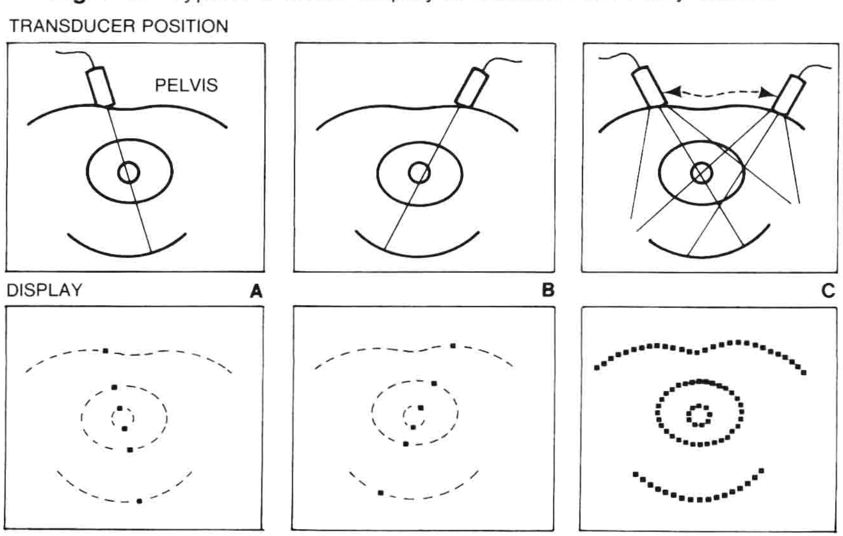
FREQUENCY (HZ)	DESCRIPTION
20	Lower limit of human hearing
4,186	High C on piano
20,000	Upper limit of human hearing
150,000	Upper limit of animal hearing
1,000,000	Lower limit of clinical diagnostic ultrasound (neurologic applications)
2,000,000	Common frequency for large-organ examination in adults
3,500,000 5,000,000 7,000,000	Common frequencies for pediatric diagnostic ultrasound
20,000,000	Upper limit of clinical diagnostic ultrasound (ophthalmologic applications)

From Becker, J. A., and Schneider, M.: Techniques and Applications of Sonography and Computed Tomography, in Witten, D. M., et al. (eds.): *Emmett's Clinical Urography* (Philadelphia: W. B. Saunders Co., 1977). Used by permission.

strikes an acoustic interface, i.e., a change in density, an echo is given off and returned to the transducer via the same route. The sound wave then creates an electric potential in the piezoelectric element. The transducer, which in this case acts as a receiver, amplifies a signal and displays it on an oscilloscope. The strength of the echo varies with the *disproportion* in acoustic density (impedance); when there is a huge mismatch, the beam has difficulty traversing the medium and most of the sound is reflected. This occurs when the sound waves encounter bone or air, as with the rib cage, lung or small-bowel gas. Solid masses tend to attenuate the sound beam; fewer sound pulses pass through the mass and fewer echoes are visualized posterior to it. Liquid structures, such as cystic masses, allow the sound to pass through them easily. They are subsequently reflected off the posterior wall and are said to "give good posterior echoes," which means that it is easy to visualize the structures behind a liquid structure. This phenomenon occurs when examining pelvic masses through the fluid-filled bladder. In adults, bone and air are major problems. In children, however, these problems are not so great. For example, in children's chests, masses are more likely to lie closer to the chest wall, given the small thoracic volume, and therefore the intervening lung (with its acoustically troublesome air) is usually not a problem. Similarly, since the calcium content of the bones of infants and children is not so great as that of adult bones, the impedance mismatch is less, and occasionally "bony" structures are traversed by the sound beam (as in echocardiography when the heart is visualized through the sternum).

The proper resolution of the ultrasound beam is critical, especially in pediatric applications. High-frequency transducers are particularly effective for examining structures that are close to the transducer. That is why the 5-MHz transducer (as opposed to the 3.5- and 2.5-MHz transducers) is used for examining structures such as the thyroid, which is just below the skin surface, and the pediatric gallbladder, which is closer to the skin surface than it is in adults. Lower-frequency transducers are good for visualizing posterior structures in the adult, such as the kidneys (in a supine scan). Similar structures in a child are best visualized with a 3.5-MHz transducer.

Fig 1–1.—Typical B-mode display of bladder with Foley catheter.



This book primarily discusses B-mode scanning. In B-mode scanning the range and amplitude signal is displayed on an oscilloscope using a brightness-modulated time base. Thus the brightness of the dot on the oscilloscope is a function of the echo amplitude and is displayed at a location corresponding to each echo-producing interface of the object scanned. It is therefore possible to construct a two-dimensional image by storing several B-mode lines that result from moving the transducer across the area to be investigated (Fig 1 – 1).

Other display modes, not discussed in this text, include A-mode, which displays only one spatial dimension – echo amplitude versus time on a single line. This is used in diagnostic echoencephalography. Doppler scanning does not produce images, but rather a frequency alteration is noted as the reflecting surfaces (red blood cells in blood vessels) change position relative to the transducer.

PSYCHOLOGICAL ISSUES IN PEDIATRIC ULTRASOUND

OSNA L. HALLER

At first glance, a discussion of the psychological issues related to pediatric ultrasound might seem unnecessary. Ultrasonography has none of the traumatic aspects of diagnostic radiography, such as the injection of contrast agents into various orifices or the need to void during studies of the genitourinary tract. However, the psychological stresses associated with diagnostic procedures have not all been eliminated for pediatric patients. While the technology associated with the procedures has changed, the way a child may react to illness and diagnostic examinations has not. Advances in the field of ultrasound have been of such magnitude that they obscure the fact that the fears and fantasies a child experiences as he or she faces an unknown diagnostic procedure have not changed similarly. Contrasting the adult view of an ultrasound procedure with that of the child demonstrates this point. For the adult, the sonographic exam is perceived as painless, noninvasive and diagnostically meaningful. For the child, such words as threatening, punitive and mutilating would apply – a different and more negative constellation of terms. To clarify the child's response, it is helpful to review the attitudes toward illness and diagnostic procedures commonly observed in pediatric patients.

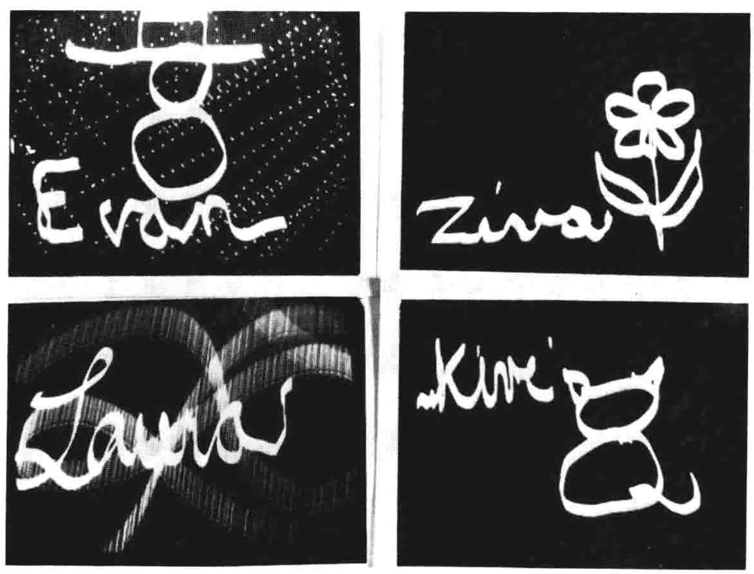
For children and adolescents, illness is not something easily comprehended. Children have a primitive and unsophisticated understanding of the world around them. Their sense of the separateness of reality and fantasy is not rigid. Many aspects of reality are open to misinterpretation as a result of this more limited understanding of reality and the intrusion of fantasy. Children tend to view illness as self-induced, well-deserved punishment for some sort of personal misdeed, such as disobedience, disregard of the rules or neglect of prohibitions. From their perspective, corrective surgery may represent punishment, catheterization might be seen as castration and diagnostic procedures may represent manipulation and attack on one's person. The fears assume different forms depending on the stage of the child's development. Parents may inadvertently play a role in fostering some of these fears. Well-intentioned parental attempts to clarify medical procedures may be bound by the parents' limited knowledge as well as their emotional concerns about their children's health. The overall result of these factors is that misinterpretations and fears tend to combine with unconscious anxiety and fantasy so that diagnostic procedures are viewed as threatening.

For the sonographer (physician or technician), an awareness of these psychological factors is important so that there can be appropriate management of the pediatric patient, and perhaps also the parents. Though easily overlooked, the pediatric patient's emotional response, physical discomfort and separation from the parent are within the sonographer's domain.

This section on psychological issues was written by Osna L. Haller, who is completing her doctoral studies in counseling psychology at New York University.

It is interesting to note that the American Institute of Ultrasound in Medicine has published a simple pamphlet to prepare an adult for an ultrasound exam. Preparation is no less important for a child, yet comparable material usually does not exist and when available may be beyond the comprehension and reading level of many children. The task falls to the sonographer to prepare the child for the procedure. In assuming this role, the sonographer's job is more complex than just providing information. While explaining the procedure to the patient, the sonographer can make the procedure a positive experience by confronting and challenging the child's fantasies about it. Some examples will demonstrate how the sonographer can address the child on two levels: by imparting specific information about the exam and by confronting some of the child's underlying fear. The first example concerns the way a young child may view the machinery. Although it may sound absurd to adults, a young child often fears that the complex and imposing machinery may devour and destroy him. The sonographer can "demonsterize" the machinery by using the transducer to draw an animal, house or person and write the child's name under the picture (Fig 1–2). This simple 2-minute digression provides a concrete demonstration of the procedure and diminishes some of the mystery of the equipment. The picture also allows the child to demonstrate to family and friends that he overcame his initial fear and was able to cooperate and master the task. A second example focuses on the question of sexual normalcy that comes to the forefront when a child, but more commonly an adolescent, faces an ultrasound exam. The sonographer could begin by detailing the general outlines of the procedure, the role of the mineral oil, the manner in which the transducer is used, and the way in which the echoes are reproduced on the oscilloscope. This information, however, is concrete, and attending to additional, perhaps nonverbalized, concerns is a more delicate matter. The sonographer may find it helpful to tell the patient that it is not unusual to be somewhat embarrassed by the procedure or that this type of examina-

Fig 1–2. — Transducer art.



tion often raises questions that the patient might want to ask. Cookbook answers are not available to the sonographer when dealing with a patient; however, awareness of some of the patient's psychological stresses can help the sonographer respond to the patient with factual material as well as with openness regarding underlying concerns.

Pediatric ultrasound procedures can be threatening to a child simply because they require restrictions of mobility. Passivity can be threatening since a child is concerned with active mastery of the environment. Restrictions can make a child feel that his immediate environment is beyond his control. By allowing the child to participate, the sonographer helps to alleviate these feelings. Any activity that the child can participate in, such as applying the mineral oil or moving the transducer, gives him a sense of control. In this way, the sonographer reduces the apparent discomfort during the ultrasound examination.

The final topic concerns issues of parent-child separation. Such separation occurs with any diagnostic or therapeutic procedure, and anxiety is most evident with young children and toddlers. However, in this regard, sonography has some advantages over radiography. First, an ultrasound procedure does not require a dark room, which is potentially threatening for young children. Second, the sonographer has greater flexibility in allowing the parents to stay in the room during the examination. This flexibility is directly related to the differences inherent in each modality, sonography versus radiography. Specifically, in sonography, there is no harmful exposure to x-irradiation, immobilization devices are not necessary and injections are not required. These factors combine to reduce the anxiety that parents may experience, thus making them helpful observing participants. Even when their presence is not deemed beneficial, it is still possible to allow children to retain some familiar object such as a doll, blanket or teddy bear without disrupting the procedure.

Bergmann and Freud (1965) comment that children are spared the full knowledge of their illness because of their more limited understanding of reality. However, they continue, children are also more easily overwhelmed by events. Thus, they become less able to accept frustration, manage anxiety or utilize coping skills. For the sonographer, an understanding of what children experience when they face an ultrasound procedure can be an asset. Thoughtful intervention by the sonographer can help the patients reduce anxiety, check fears and maintain their coping skills. This will result in a more positive experience for the pediatric patient and a better study for the sonographer.

THE PEDIATRIC PATIENT—GENERAL COMMENTS

Children of different ages, even within the already narrowed age range of pediatrics, require different approaches during a sonographic examination.

The child under the age of 2 years rarely needs sedation. The best methods are (1) providing the infant with a pacifier during the examination, (2) withholding one of the child's feedings prior to the examination and then feeding the child with a bottle during the examination and (3) (rarely) holding the child in place physically, so that single sweeps can be taken to detect gross abnormalities.

The child aged 2–5 years is probably the most difficult. Of all the children requiring sedation, the majority are in this age group, although even in this group sedation is rarely required. By making use of the various methods described in the previous section, e.g., drawing transducer pictures and allowing the child to participate, the patient is gently persuaded to allow an ultrasound examination to be performed.

Children from the ages of 5 years through puberty rarely, if ever, need sedation and, in much the same manner as above, should be given a 5-minute picture drawing and experimental session to put them at ease.

The age group from puberty to young adulthood is particularly important since the vast majority of scans, usually of the pelvis, are performed on persons in this age group. It is worth keeping in mind that many of these patients are pregnant for the first time and have all the associated fears of motherhood as well as the problems of coming to grips with their own sexuality. Patient modesty should be kept in mind at all times and there should be a minimal amount of "traffic" through the ultrasound suite.

Patient Preparation

Most examinations of the chest and abdomen need no prior preparation other than possibly withholding feeding. For pelvic examinations, the bladder should be full, and in most cases children are given a bottle (where appropriate) or a glass of water to drink 1 hour before the examination. For gallbladder examinations children should be kept on a fat-free diet for 12 to 14 hours prior to the examination.

This lack of extensive preparation is most important for pediatricians to note since patients in renal failure, in incubators, on respiratory therapy or in other circumstances that make routine radiologic imaging procedures difficult are not disqualified from having a sonogram.

Sedation

It is tempting to provide a dosage schedule of typical sedatives for pediatric patients who are undergoing sonography. However, since sedation is so uncommon and since most sonographers are not acquainted with its hazards for children, the authors feel that it would be wise to consult clinicians for the proper sedation of a given child. Similarly, since some sedatives have unpredictable effects on very young children, it may be wise to have a clinician present during the examination to avoid any complications. Heavier sedation is often necessary when minor surgical procedures done with ultrasonic guidance are planned. For sedation used at Downstate Medical Center see section in invasive procedures.

Consent

Consent is not needed for routine sonographic evaluation. It is needed, however, for any invasive procedures that use ultrasonic guidance. These include biopsy, nephrostomy, antegrade pyelography, Whitaker test, pleural tap and cyst or mass lesion aspiration. Consent is not needed for routine bladder catheterization.

Heat Loss

Maintaining an infant's body temperature is a problem well known to those who perform diagnostic imaging procedures on children. However it is so important that it is worth mentioning again, especially in relation to a new procedure (ultrasound). Infants may rapidly lose body heat and have subnormal temperatures in the often cool environment of the ultrasound department. Since the presence of metal or electric devices does not interfere with the sonographic image (as it does in radiography), the ultrasound suite should be equipped with heating devices (identical with those used in the neonatal intensive unit) to keep children warm during the examination.

Clinicians

When the ultrasound examination was first applied to pediatrics, the nature of the equipment and the lack of experience on the part of those performing the examination resulted in very poor images. Normal anatomical structures were hard to image and the credibility of the new modality suffered. Now, however, new technology in the form of computer processing and higher frequency transducers has allowed for greater ease in visualizing the anatomy of children. Every opportunity should be taken to make pediatricians and surgeons aware of the new advances. The more familiar that clinicians are with sonography—its indications as well as the actual images—the more likely they are to send patients for examination.

BIOEFFECTS

Since the utilization of ultrasound in medicine depends primarily on the various interactions of ultrasound with human tissues and since excessive doses of all energy forms can harm biologic systems, there are potential hazards associated with ultrasound. An ever-increasing amount of experimental evidence is now available on the biologic consequences of ultrasound. Yet in order to appreciate fully this body of literature, it is necessary to understand, at least to some degree, the various basic modes of sonic interactions with human tissues. This section will review those aspects of bioeffects that have a bearing on the potential hazards in the application of sound to clinical pediatric practice.

History

Langevin first generated ultrasound successfully when he electrically excited a quartz crystal into mechanical oscillation at one of its resonant frequencies. While conducting this work for naval purposes, he noted that small fish exposed to this radiation were killed. Also, humans experienced pain when the hand was immersed and subjected to the same sound beams. Other investigators later subjected various organisms to sound and drew the same conclusions. Throughout the ensuing decades, a host of researchers experimented with various applications of this new form of radiation in the therapy of various disorders, concentrating primarily on tissue destruction and modification. While much was learned about the scientific basis of ultrasonic interaction with tissues, few medically useful applications evolved from the pre–World War II era. The next major phase of development occurred during the 1940s when emphasis gradually shifted from therapy to diagnosis. The fundamental knowledge already gained, together with the development of radar and sonar use by the military, accounts for the early work in sonographic diagnostic imaging.

While the development of ultrasound techniques progressed in both diagnostic and therapeutic spheres, it was not until the 1960s that the issues of safety and potential hazards became real concerns. Subsequently, there has been a deliberate effort to utilize a minimum of ultrasonic energy by decreasing the time and intensity and the number of procedures performed. Also, clinical and experimental investigations were undertaken to determine the parameters of safe exposure. However, it is important to remember that despite active research, conclusive evidence on the safety of this and any other new technique cannot be established completely within our generation. We can rely only on available experimental and clinical observations which, in and of themselves, remain in a state of infancy.

The process of absorption of ultrasound by a biologic structure involves the transfer of energy into tissues, which results in various effects. The variables that control these effects depend on the material that is absorbing the energy, the rate of transfer of energy and the amount of energy transferred.

Thermal Effects

The primary effect of ultrasonic absorption by tissue is thermal. This is accomplished by the irreversible transfer of coherent mechanical energy to molecular or structural energy levels, which ultimately appear as heat. Heat is removed from the material by conduction, convection or radiation. When the heat of human tissues reaches about 50 C, irreversible damage starts to occur. This damage has been found to be a linear function of the duration and intensity of the radiation. It has been shown in studies on brain tissue that a threshold temperature exists below which no cellular damage occurs with sonic radiation. Thermal effects may be used beneficially as in physical therapy.

Cavitation

In liquids, when the normal populations of submicroscopic gas bubbles are subjected to ultrasound, they grow in size relative to the ultrasonic wavelength. These bubbles act as resonant cavities, which in turn act in either a stable or an unstable fashion. Stable cavitation involves resilient cavities that resonate at the ultrasonic frequency and allow the surrounding particles to vibrate at an increased amplitude. This has both cellular implications, resulting in streaming and shearing of cell membranes, and chemical implications, such as free-radical formation. Stable cavitation appears to occur with continuous ultrasound exposure and is probably inhibited by pulses