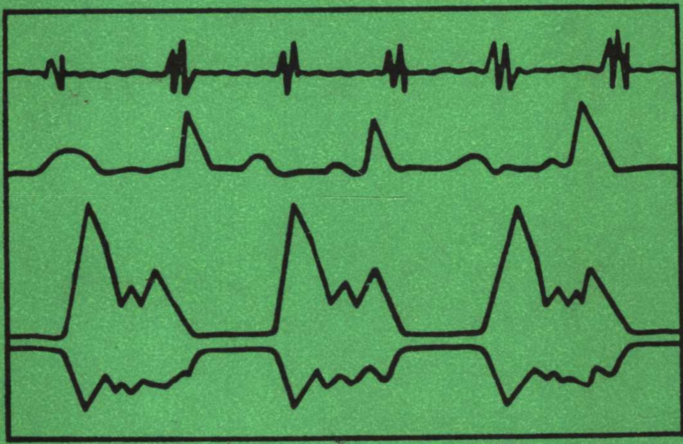
Manual of Echocardiographic Techniques

PHILLIPS



Manual of Echocardiographic Techniques

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FOREWORD

The quality of the M-mode echocardiogram is more dependent on the ability of the individual performing the test than on any other factor. Unfortunately, failure to recognize the importance of the echo technologist's skill and underestimation of the time and effort required to attain that skill remain critical barriers to the universal attainment of excellence in cardiac ultrasound. The *Manual of Echocardiographic Techniques* is adequate testimony to the magnitude of knowledge that must be learned before this level of competence can be achieved.

Ms. Betty Phillips is one of the pioneers among those responsible for today's rapidly advancing state of the art. In clinical and research laboratories in the early 1970's, she was one of the first to demonstrate that both misuse of instrumentation and incorrect transducer angle were important causes of false-positive and false-negative diagnoses. Yet, although almost 10 years later the lessons we learned then about transducer angle and instrument control are more important than ever, they still remain sadly neglected in the literature.

In the *Manual of Echocardiographic Techniques*, Ms. Phillips presents the technical intricacies of performing an echocardiogram both by means of the written text and by carefully selected illustrations of tracings. However, she leaves no question that technique alone does not suffice in her discussions of cardiac anatomy and the disease processes that affect cardiac structure and function.

Finally, although the importance of technique and knowledge of cardiac anatomy and pathology cannot be overemphasized, Ms. Phillips so rightly presents an additional dimension in the technologist's approach to her task. This dimension is the human aspect alluded to, for example, in her discussion of patient comfort. We should always remember that an echocardiogram does not represent simply a cold interaction between man and machine but also a meeting between two human beings, a fact so often forgotten in our age of ever-increasing technology.

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PREFACE

This volume is intended as a textbook for the student of adult echocardiography and as a practical reference handbook for the physician utilizing echocardiography for clinical medicine and for practicing sonographers who wish to further their knowledge of this technique. It presents the techniques of conducting the echocardiographic examination to produce accurate images and methods of interpretation necessary to evaluate the quality of those images.

The sequence of chapters is deliberate. Each topic is dependent upon the one that precedes it, and the order is that which I have found best suited to guide the reader to a solid understanding of the basic techniques of the echocardiographic examination and its important pitfalls.

Repetition is freely used whenever it is felt necessary to emphasize important topics, especially in overlapping areas or in different contexts.

Chapter 1 provides the reader with the basic concepts and physical properties that constitute the ultrasound principle. Chapter 2 presents a detailed account of all that is involved in performing the echocardiographic examination, and Chapter 3 demonstrates in detail the value of recording a simultaneous electrocardiogram. Chapters 4 through 12 deal with the echocardiographic technique of recording the various cardiac structures. Each of these chapters demonstrates the anatomy of these structures, familiarizing the reader with the many variations of normal and pathological conditions and how these variations appear on the echocardiogram.

To these ends, this book emphasizes the technical and diagnostic aspects of adult M-mode echocardiography, leaving a discussion of its research uses to others in the field of investigation.

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Leading all acknowledgments must be mine to Jacklyn L. Ellis, M.A., R.D.M.S., my associate and friend, who in addition to having performed a masterful job of writing what in my opinion was the most difficult chapter (Chapter 12 – Prosthetic Valves), was also an invaluable participant throughout the entire writing of this book. Her unfaltering support and assistance in resolving the countless details that are encountered in such an endeavor has truly made this book possible.

Also, my deep gratitude goes to:

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Karen A. Keeton, a good friend and the artist who is responsible for the excellent illustrations of the heart. I am most grateful to Ms. Keeton not only for her outstanding drawings but also for her enthusiastic cooperation, innovative ideas, and total dedication to never settling for less than perfection.

David Sansbury, Biomedical Engineer, St. Joseph's Hospital and Medical Center, for his collaboration with me in the presentation on the physics of ultrasound in Chapter 1.

I would also like to express my appreciation to Edward B. Diethrich, M.D., the Arizona Heart Institute, and St. Joseph's Hospital and Medical Center, who made many of the studies described in this text possible.

I do not really know how to thank my co-workers at Ultrasound Diagnostic Services for their patience with what seemed at times like a ramshackle and never-ending project. My thanks to them for never saying so, and for their indefatigable good spirits.

Lastly, I would like to gratefully acknowledge the wholehearted cooperation of the W. B. Saunders Company in the production of this book, with special thanks to Jack Hanley who believed in it from the beginning and to Wendy Phillips for her positive attitude and tenacity in keeping open the lines of communication.

BETTY J. PHILLIPS, R.D.M.S.

CONTENTS

Chapter 1

PHYSICAL PROPERTIES OF ULTRASOUND

Although it is not necessary for the technologist to deal with the physical principles of ultrasonic energy in a quantitative sense, i.e., with numerical values and formulae, an understanding of the qualitative or behavioral aspects of this type of energy is essential. Knowledge of how it is produced, how it behaves, and how it can be employed in the clinical setting is fundamental to developing the techniques and judgments that yield useful diagnostic information.

Inasmuch as the character of ultrasound is paramount in this discussion, a rigorous treatment of its physical principles will not be attempted. In fact, it may be useful at times to simplify the concept by thinking of ultrasound as something in between the light and sound energy familiar to our senses. An excellent analysis of the subject has been provided by Wells.[1]

The goal here is to provide the technologist with an understanding of how ultrasonic energy is generated, what happens to it as it traverses the biological medium, why it is reflected, how it is detected, and how it may be used in diagnostic ultrasound.

DIAGNOSTIC ULTRASOUND SYSTEMS

There are two types of ultrasound that are useful in clinical medicine, the Doppler system and the pulse-echo system. In both types, ultrasonic energy is generated by a transmitting transducer* that is placed in physical contact with the biological medium (body tissue).

Transmitted energy enters and traverses the body tissue until it encounters a reflective component (an organ or skeletal member). At the point of encounter, a portion of the transmitted energy is reflected back to a receiving transducer. The balance of the transmitted energy may subsequently encounter other reflective components, giving rise to additional transmitted and reflected signals (Fig. 1–1). Reflected energy returns through the biological medium until it reaches the point at which it is sensed (detected) by a receiving transducer. The ultrasonic energy of both the Doppler and the pulse-echo systems behaves in this manner. The two techniques differ primarily in the way in which the transducers are excited and in the means used to process the return information. (Fig. 1–2).

Doppler Ultrasound

With Doppler ultrasound, the transmitter is continuously excited with a single high

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*A transducer, in the broad sense, is any device that converts energy from one form to another. The ultrasound transducer converts electrical energy to ultrasonic energy (transmitting transducer), or it converts ultrasonic energy into electrical energy (receiving transducer). The transmitter and the receiver may be the same device or two separate instruments.

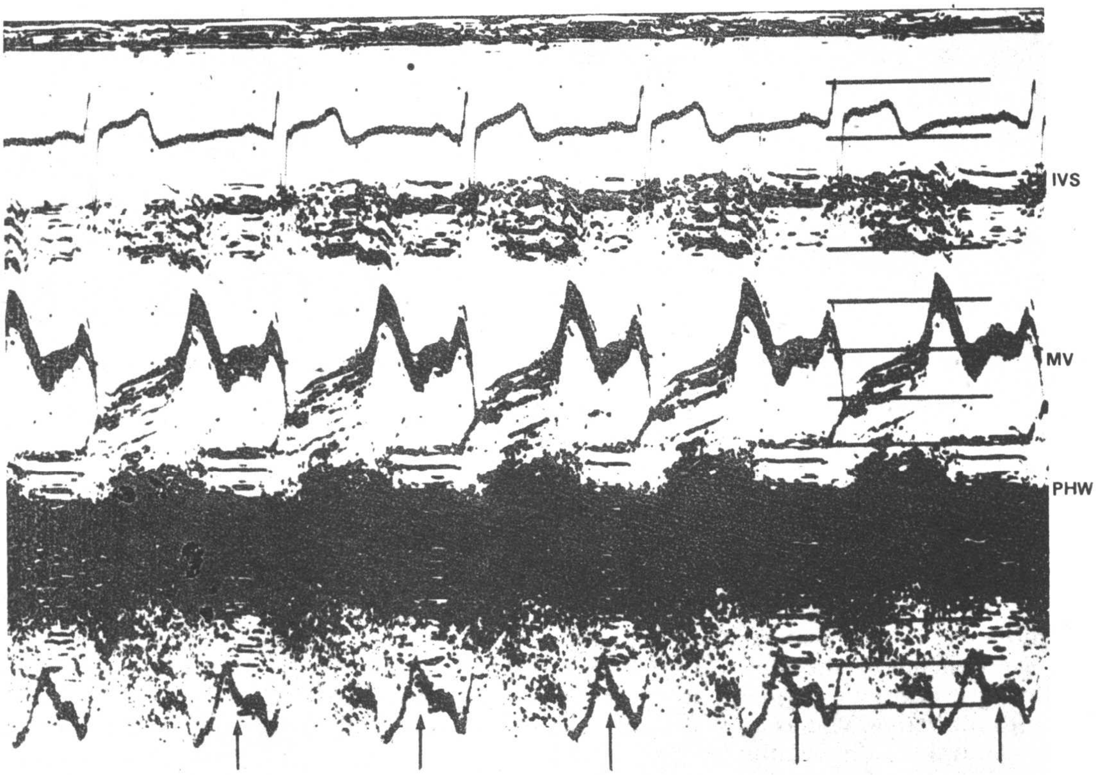

Figure 1–1. Reflections. Sound waves can be reflected more than once before returning to the transducer. In this M-mode recording of the mitral valve (MV), an inverted image of the mitral valve (arrows) is seen behind the posterior heart wall (PHW). This is not an uncommon occurrence in thin-chested individuals, as some of the returning echoes from the mitral valve are reflected off two other structures, such as the chest wall and sternum, before returning to the transducer (IVS = interventricular septum).

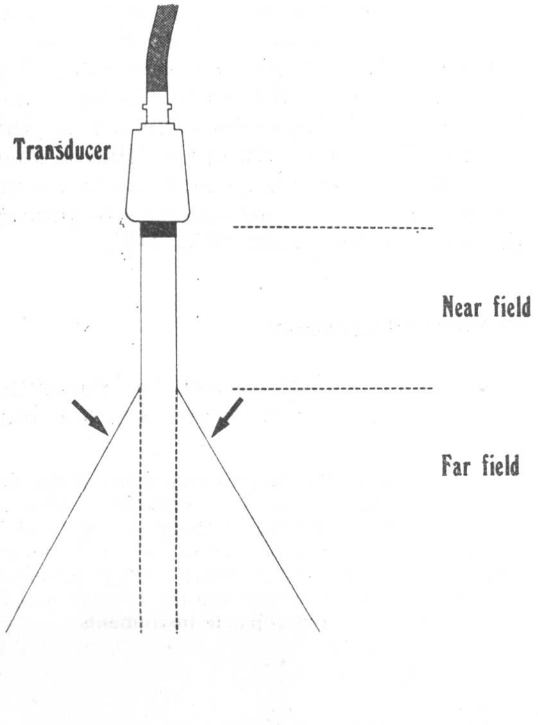

Figure 1–2. The sound beam. In the near field, the beam width remains equal to the diameter of the transducer. In the far field, beam divergence occurs (arrows).

frequency. The frequency of the returned energy differs from the frequency of the transmitted energy, and that difference is proportional to the velocity of the reflecting component encountered. In clinical practice, the reflecting component is most commonly blood flowing in arteries or veins, so the frequency change (Doppler shift) is indicative of blood velocity. Since the transmitting transducer is continuously generating ultrasonic energy, it is common to employ a second transducer as a receiver.

Pulse-Echo Ultrasound

With pulse-echo ultrasound, the transducer is excited at intervals, and energy is transmitted in short bursts. Since the speed of ultrasonic energy is relatively uniform in biological tissue, the time elapsed from transmission of the burst (pulse) to reception of the reflection (echo) is representative of the distance between the transducer and the reflective component (Fig. 1–3). Since the transducer is transmitting only in bursts, the same device can be used for receiving the echo. Thus, it is common to employ only a single transducer with pulse-echo ultrasound. Less than one half of 1/100 of one second is required for the generation, transmission, reflection, and return of ultrasonic energy. Therefore, it is possible to apply the pulse-echo sequence (energy generation, transmission, reflection, echo detection) frequently, thus determining the position of an internal organ with time.

In practice, the equipment is designed to produce approximately one pulse-echo sequence per millisecond. Velocity as well as positional information are therefore available with pulse-echo ultrasound. For example, suppose that the elapsed time of a pulse-echo sequence indicated the position of a mitral valve leaflet to be 8.20 cm from the transducer (skin surface). Suppose that the elapsed time of the pulse-echo sequence one millisecond later indicated the

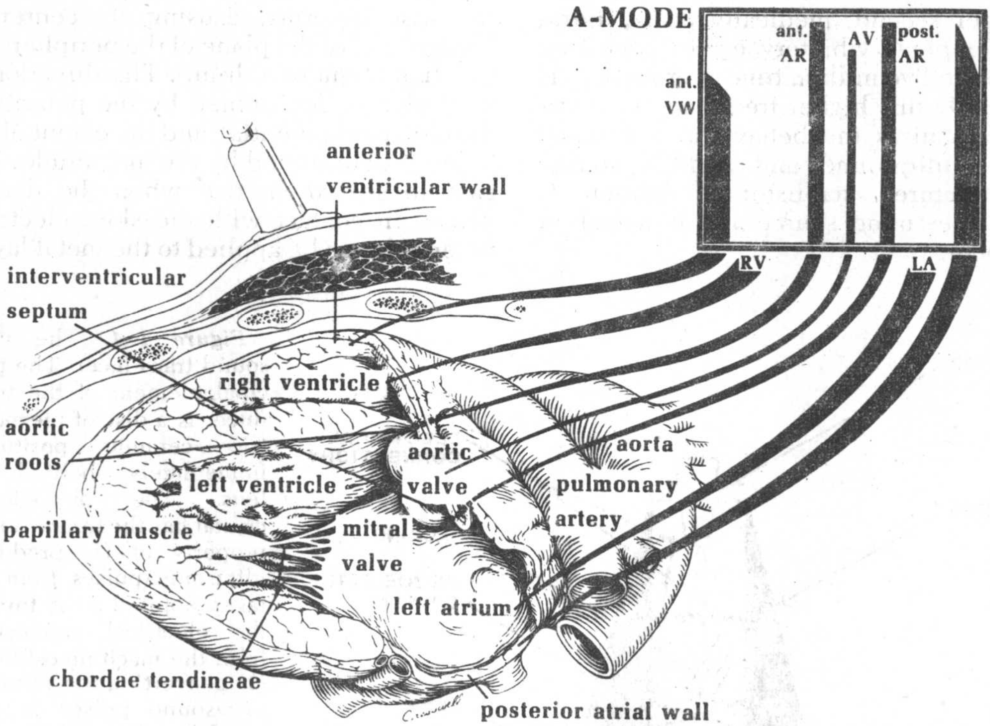

Figure 1–3. A-mode signal representation of the cardiac structures. Ultrasound echoes are displayed on the oscilloscope as individual peaks directly related to their anatomical location and their reflector strength. Key: Ant. VW = anterior ventricular wall; RV = right ventricle; Ant. AR = anterior aortic root; AV = aortic valve; Post. AR = posterior aortic root; LA = left atrium; Post. AW = posterior anterior wall.

same leaflet to be 8.24 cm from the transducer. The positional change from 8.20 cm to 8.24 = 0.04 cm, which divided by the time interval between pulses (0.001 sec) yields the velocity (40 cm per sec). The fact that the leaflet was more distant during the second pulse-echo sequence indicates the direction of motion to be away from the transducer (mitral valve closing).

GENERATION OF ULTRASONIC ENERGY

Although it is beyond the range of human hearing, ultrasonic energy is sound energy in the true sense, and it is generated in much the same way as audible sound. In essence, a structure in mechanical vibration establishes regions of compression and rarefaction in the medium that it contacts. The speaker of a radio, for example, vibrates and creates sound energy in the air surrounding it. Ultrasonic energy is generated in precisely the same manner, but at a much higher vibratory rate. While vibrating cycles for audible sound occur from 30 to 15,000 times per second, medically useful ultrasound employs vibratory cycles occurring from two to five million times per second. It is primarily this higher frequency of vibration that causes the behavioral difference between ultrasound and audible sound. The structure establishing vibration is termed the sound source and is usually a transducer.

ULTRASOUND TRANSDUCERS

The speaker of a radio is an audio-sound transducer. It converts electrical energy, via vibratory motion, into sound energy. While not normally used as such, a radio speaker can also convert vibratory motion into electrical energy. The mass and size of a radio speaker prohibit vibrations much beyond 20 thousand cycles per second (20 kHz).

The high frequencies of ultrasound are produced by piezoelectric crystals, which form the basis of all ultrasound transducers. The piezoelectric effect is the unique quality of a material to deform under the influence of electrical excitations or, likewise, to create electrical signals when it is mechanically deformed. Quartz crystals have this quality, but the substance most commonly used in medical applications is the synthetic piezoelectric material PZT (lead-zirconate-titanate). For use in a transducer, both sides of a PZT disc are coated with metal (usually silver), which is then connected with the electronic equipment. When an electrical potential is created between the two metal layers, the piezoelectric disc deforms, causing its center to "bulge" out of the plane of the periphery (as the diaphragm of a drum). The direction of the bulge is determined by the polarity of the electrical potential, and the extent of the bulge is determined by the magnitude. It is easy to see, then, that when the disc is placed in contact with the skin, electrical potentials can be applied to the metal layers

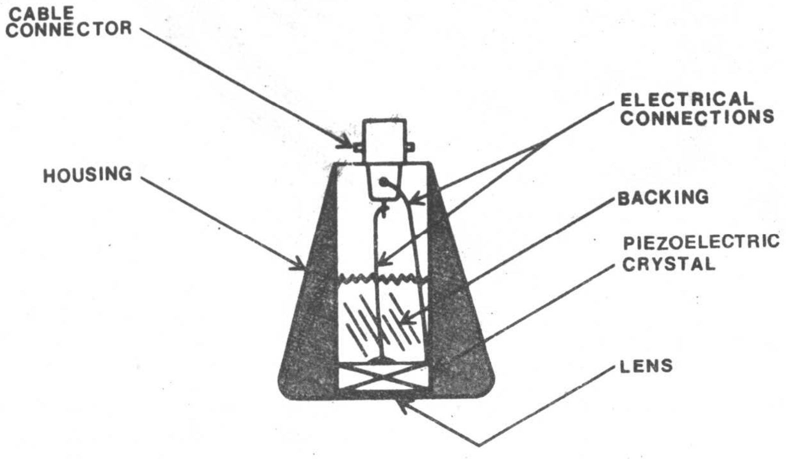

Figure 1–4. The ultrasound transducer. The principal element of the transducer is a disc of piezoelectric ceramic positioned immediately behind the lens. The piezoelectric crystal has the innate double property of (1) producing ultrasonic pulses from voltages applied to it through the electrical connections from the machine cable and (2) converting the returning ultrasound pulses to electrical impulses that represent the echo on the oscilloscope (see Figure 1–3). The sound waves generated back into the transducer are absorbed by an insulating material within the transducer housing.

either to push against the skin or to pull away from it. In practice, a metal-coated piezoelectric disc is mounted on a plastic material through which the ultrasound vibrations are conveyed to the skin. This is done to electrically isolate and mechanically protect the fragile piezoelectric disc. The disc and the plastic sound conductor are encased in a structure that is easily held and that provides strain relief for the electrical wires leading to the energy source. While it has numerous mechanical characteristics, the ultrasound transducer is essentially a metal-coated piezoelectric disc with a plastic rod connecting it acoustically to the medium, electrical wires connecting the metal coatings to the energy source, and a casing designed for protection and ease of handling. The basic structure of a pulse-echo ultrasound transducer is shown in Figure 1–4.

The vibrations of a radio speaker, particularly at low frequency, can be seen and felt. As the vibrations increase in frequency, the speaker diaphragm motion is less perceptible because the excursions are shorter and more rapid. The vibrations of the piezoelectric material are imperceptible to the human senses because the excursions are many times smaller than in a radio speaker. Nevertheless, the action is essentially the same.

NATURE OF ULTRASONIC ENERGY

The pushing and pulling of the transducer against the biological medium sets up disturbances called regions of compression and rarefaction. Since cells of tissue are interconnected, the disturbances (vibrations) are transferred through the tissue, and, at each point along the path, the vibratory motions are the same as those experienced by the transmitting transducer. That some internal point is set into vibratory motion is evidence that energy is entering and traversing the medium. Ultrasonic energy travels by wave motion and is governed by the applicable physical principles.

Velocity

The velocity of ultrasonic energy is controlled by the medium through which it travels. In biological material, for example, ultrasonic energy travels at an approximate velocity of 1500 meters per second (M/sec). While the material itself does not experience any net motion, the position of a compressive disturbance will change. An analogy can be drawn to the toy intercom made of tin cans and a string. The string does not experience any net motion, but energy obviously travels through the string from tin can to tin can. The concepts of importance are (1) that ultrasound energy travels through a medium without the medium experiencing net motion and (2) that the velocity of travel is dependent solely on the qualities of the medium.

The Ultrasound Beam

Unlike the sound energy from a radio speaker, ultrasonic energy does not travel away from its source in all directions. It travels more like a beam of light, and only a slight beam spreading (divergence) is exhibited (see Figure 1–2). This "beam" quality of ultrasonic energy derives from the relative dimensions of the source (transducer) and the wavelength of the ultrasound. Since wavelength is inversely related to frequency, the very high frequencies of ultrasound are accompanied by very short wavelengths. A wavelength can be imagined as the distance between adjacent regions in compressive disturbance. Obviously, the time between adjacent compressive regions is determined by the vibratory frequency of the transducer.

If the velocity with which the disturbance travels away from the transducer is known, then the distance between adjacent disturbances can be determined. Suppose a piezoelectric disc with a diameter of 1 cm were used to generate sound or ultrasonic energy. With the disc vibrating at 1000 Hz, the resulting wavelength in the biological tissue would be 200 cm — 2000 times the source dimension, and significant divergence could be expected. At 2000 Hz, however, the wavelength would be only 1 mm, or 0.1 of the source dimension, and little beam divergence would result.

Just as a beam of light can be focused, the ultrasound beam can be concentrated. This is accomplished by forming a concave surface in the sound-coupling material of the transducer where it contacts the skin. The important concept here is that the high frequencies of ultrasound mitigate energy spreading (or divergence), so that ultrasonic energy travels through the medium as a beam.

Resolution

Generation of an energy "beam" is not the only reason for employing high-frequency ultrasound as a diagnostic tool. As previously stated, a portion of the transmitting energy is reflected and returned to the transducer, where it is processed to provide positional information. Physical contraints dictate that a sizable portion of the returned energy wavelength be received simply to identify its presence. A sizable portion of the 22-cm wavelength of a 1000-Hz signal might represent 40 cm of distance and would not provide useful information. Knowing the position of an internal organ within 0.2 of the 1-mm wavelength of a 2-MHz signal, however, is significant. As a general observation, then, the high frequencies of ultrasound are commensurate with higher resolution (positional certainty).

Attenuation

If it is true that higher frequency is accompanied by low ultrasound beam divergence and high resolution, then why not use frequencies even higher than the 2 to 4 MHz commonly employed? The reason for limiting the frequency is to reduce attenuation. As ultrasonic energy travels through the body, it is absorbed and scattered by minute surfaces. Because the degree of absorption and scattering is proportional to frequency, an increase in ultrasound frequency will increase the attenuation.

The overall attenuation also depends on the distance that the ultrasonic energy travels entering and returning from the body. Attenuation combined with the fact that only a small portion of incident energy is reflected from internal organs results in an exceedingly faint echo at the receiving transducer. At 2.5 MHz, echoes from organs

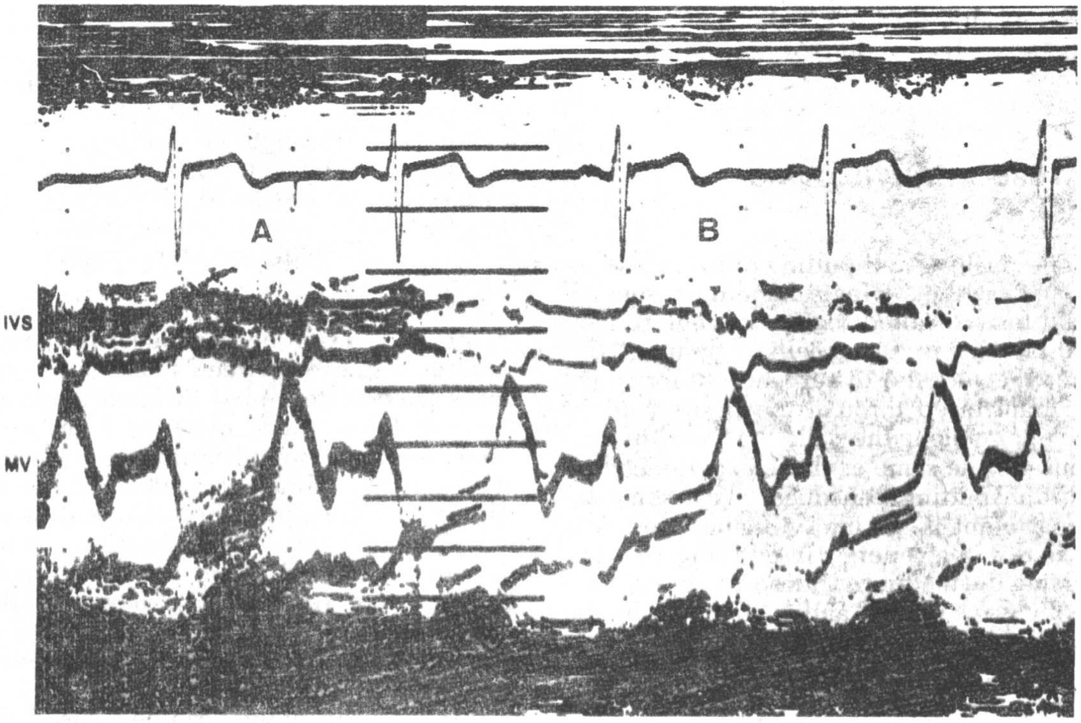

Figure 1–5. The near gain control (not visible) is properly positioned in the area designated A during the first two beats; as a result, the full interventricular septum (IVS) and the mitral valve leaflets (MV) are clearly seen. In the area designated B, following the second beat, the delay (attenuation) is incorrectly adjusted, and the septum and mitral valve leaflets are poorly visualized.

proximal to the transducer may return only 0.25 per cent of the transmitted energy.

Since echoes from distal surfaces are many times smaller than echoes from proximal reflection sites, greater amplification is required for distal echoes. Commercially available ultrasound instruments provide a time-gain control for this purpose. Since distal echoes occur later in time, the technologist may select the amplification that will produce the most meaningful information. Such controls normally provide for selecting both the time at which the amplification increase will start after each ultrasonic energy burst and the rate of increase once amplification increase has commenced. If, for example, the internal structure of interest lies between 5 cm and 12 cm below the body surface, the technologist would set the amplification increase to begin at a time representing 5 cm. The rate of amplification increase would then be selected so that echoes from the 12 cm surface would be intelligibly amplified. Echoes from beyond the 12 cm depth, then, would not be pronounced, owing to attenuation. While the time-gain controls are conceptually quite simple, they provide the technologist with a powerful tool for eliciting the desired information (Fig. 1–5).

Reflections

The various components of the body (tissue, muscle, bone, blood, and so on) have a property called acoustic, or characteristic, impedance. Although the property is a measure of the components' ability to conduct ultrasound waves, it is sufficient here to understand its relationship to echoes (reflections). When an ultrasound beam encounters the surface between two media of different characteristic impedances, a portion of the incidental energy is reflected from the interface surface back into the first medium, and the balance enters the second medium (see Figure 1–1). The amount of energy reflected depends on the difference in the characteristic impedances. The portion of incident energy reflected from the interface surface increases as the difference in characteristic impedance between the two media increases. Except for bone, most biological materials have nearly equal characteristic impedance. For this reason, echoes from an interface surface are generally small. For example, the surface between the heart and the blood reflects only about 1 per cent of the incident energy. Bone, however, has a very high characteristic impedance, as does air. A muscle-bone interface reflects nearly 50 per cent of the incident energy. This is the fundamental reason that the intercostal spaces must be used to view the heart — otherwise, the rib bones would return most of the energy immediately to the transducer and impede any echoes that did derive from the heart itself. Several biological components, in order of increasing characteristic impedance, are: fat, brain, blood, kidney, tissue, spleen, liver, muscle, and bone. A stronger echo would be expected from the fat-epicardium interface than from the endocardium-blood interface just beyond. Echoes do not occur without a homogeneous material. Therefore, no echoes would be expected from the area between the epicardial and endocardial surfaces.

As with light, the angle of reflection and the angle of incidence of the ultrasound beam are equal. In practice, however, it is not necessary to have the ultrasound beam strike a surface at right angles. While the echo will be stronger with orthogonal incidence, surfaces are sufficiently rough to reflect some energy back to the transducer. To derive the best echo from the surface of interest, the technologist may compromise orthogonal incidence for beam path length.

REFERENCE

1. Wells PNT: *Physical Principles of Ultrasonic Diagnosis.* New York, Academic Press, 1969.

Chapter 2

THE ECHOCARDIOGRAPHIC EXAMINATION

Most patients approach any type of medical test with some degree of apprehension. Even an individual who feels certain that he is healthy may be concerned, particularly when he is undergoing a test that is not familiar to him. A great deal of strain can be relieved if the technologist simply presents a confident and friendly appearance.

For the patient who has never had an echocardiogram, the basic procedure should be explained, emphasizing that the examination is safe and painless and that the knowledge gained from the test will assist the physician in the evaluation of the patient's heart. It is also advisable that the technologist explain that this information will be taken from a graphic recording (not an actual picture of the heart), which is carefully measured and interpreted by a physician. By informing the patient of such details, the technologist will gain his confidence and interest and will facilitate the performance of the examination.

A further consideration is the patient's modesty, which is particularly important for the female patient. The examiner should leave the room while the patient is changing for the examination or provide a screened changing area. A hospital gown worn with the opening in the front will afford the technologist sufficient space in which to position the transducer and still maintain the patient's modesty.

Some patients, especially elderly persons, become easily chilled. It is therefore a good practice to keep either an extra sheet or a blanket at hand, as warmth is essential to relaxation.

Finally, the attitude of the technologist can also have a significant effect on the quality of the echocardiographic examination. A positive, confident approach to even the most difficult situation will reduce tension and can contribute significantly to the successful performance of the examination.

PATIENT POSITIONING

Technically superior recordings are most often obtained with the patient positioned on his left side. When this position is not possible, the patient should lie supine. In either position, the patient should be encouraged to make himself as comfortable as possible. When the patient is comfortable, he will not tire as easily, and the incidence of echocardiographic artifact due to muscle tension will be lessened (Fig. 2–1).

OBSERVERS

The number of persons observing each examination should be kept to a minimum. When observers are present, it is important to introduce these people to the patient. Only the person actually performing the test should communicate with the patient, as unnecessary talking can be disruptive and distressing. Questions or opinions voiced by observers can be misconstrued by the patient as an indication that he has some cardiac problem. All discussion should therefore be reserved until the examination is complete and the patient has left the area.

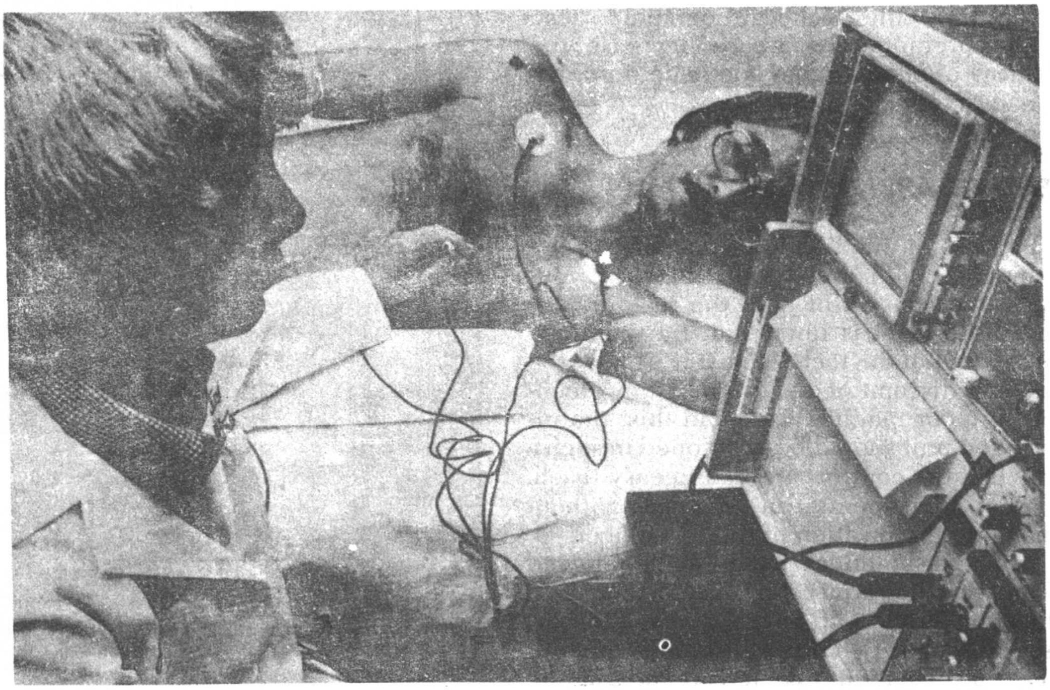

Figure 2–1. The comfort of both the technologist and the patient is an important factor in producing an echocardiographic recording of good technical quality. The following features illustrate this. The patient is resting comfortably on his left side, thereby lessening the incidence of echocardiographic artifact due to muscle tension. The proximity of the technologist to both the patient and the ultrasound unit enables her to manage transducer placement with ease and, at the same time, to make the necessary control adjustments without disturbing the position of the transducer. The arm holding the transducer is resting on a rolled-up towel. In addition to relieving arm and shoulder tension, this also serves to stabilize management of the transducer.

The patient must never be placed in the position of feeling that he is a teaching object.

PATIENT DATA

Prior to the performance of an echocardiographic examination, the technologist should learn as much as possible about the patient. Knowledge of the reason the physician ordered the test allows the technologist to pay particular attention to the area of concern. For example, if the physician has noted a mid-systolic click, particular attention to the motion of the mitral leaflets during mid- and late systole may be critical.

In the case of the hospitalized patient, data can be obtained easily from the medical record. This will provide the technologist with a review of the patient's history and physical examination, the physician's progress notes, nurse's notes, and, in many cases, electrocardiographic and catheterization data. This information will usually provide an indication of what specific disorders the physician suspects if they are not stated on the echocardiogram order sheet. For example, it will be indicated if the patient has had a history of rheumatic fever, coronary disease, cardiac murmurs, or pericardial friction rub.

In the case of an out-patient for whom there is insufficient information on the prescription, the referring physician should be contacted. The technologist should learn what diagnoses the physician is considering. In the event that the physician cannot be consulted, tactful questioning of the patient may reveal why the test was ordered, but this approach should be a last resort.

In summary, the technologist should make every effort to see that the patient is relaxed and comfortable and to learn the