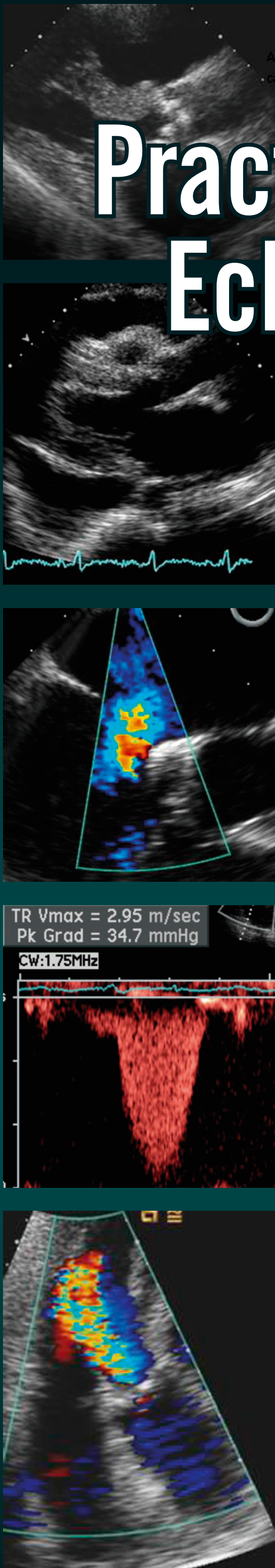
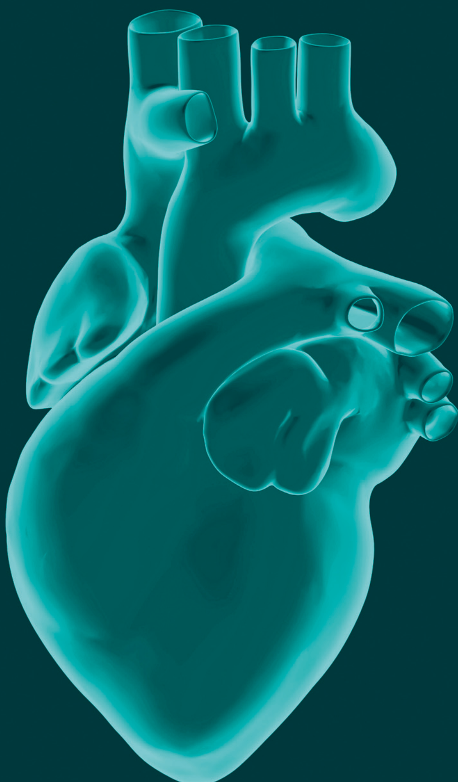
Practical Manual of Echocardiography
in the Urgent Setting

Edited by Vladimir Fridman
and Mario J. Garcia





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Practical Manual of Echocardiography in the Urgent Setting

To:

– Dr Balendu Vasavada, whose knowledge and dedication to echocardiography has been the basis of this textbook. Many of the images in this book are a direct result of his leadership at the echocardiography laboratory of Long Island College Hospital.

– Dr Steven Bergmann, who served as a great mentor throughout my training and clinical practice. His tremendous assistance and dedication to cardiology have made my career possible.

– Dr Cesare Saponieri, who is responsible for all I know about the practice of clinical cardiology. His pursuit of providing great care to patients is truly an inspiration.

– Of course, Dr Mario Garcia for spending countless hours going through all the text, figures, and tables in this book. Without him, this book would not be possible.

– All of my cardiology colleagues who made this book a reality.

Thank you.

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Preface

There will be times when you will need to read a comprehensive echocardiography textbook. However, there will be also times when you will need to access quick reference information to help you manage a crashing patient in an urgent situation. This reference guide will provide you everything you need to establish a differential and accurate diagnosis that will lead you to best manage a cardiovascular patient in an emergent situation.

With the first part devoted to basic instrumentation and image acquisition and the second part focusing on the different clinical situations that often require evaluation by echocardiography in the urgent setting, this book is the ideal companion to the physician who needs to implement rapid life and death decisions.

You should use this book as a quick reference guide to echocardiography in the urgent setting. It is designed to help in situations where seconds and minutes can really make a difference in the lives of patients. Even one extra saved life will justify the large amount of work that the authors have put into this work.

Vladimir Fridman and Mario Garcia

Ultrasound physics

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CHAPTER 1

Echocardiography is one of the most valuable diagnostic tests for the evaluation of patients with suspected cardiovascular disease in the acute setting. Even though echocardiography has become more widely available, its performance and interpretation require practice and knowledge of the principles of image formation. Although the physical principles and instrumentation of ultrasound can be quiet complex, there are a few basic concepts that every echocardiographer and interpreting physician must understand to maximize the diagnostic utility of this test and avoid misinterpretations. These key concepts are covered in this chapter.

The echocardiogram machine (Figure 1.1) is made up of few distinct components:

1 Monitor
2 CPU (central processing unit), responsible for all functions of the echocardiogram
3 Transducer
4 Keyboard/controls
5 Printer

The control panel of any echocardiogram looks similar to that shown in Figure 1.2a. The panel is shown in more detail in Figures 1.2b–d, with the important controls labeled. Although slight changes in control positions are noted between machines from different companies, all machines have the key controls that are shown in these images.

The panel from above image, is split into three frames, and the important controls are labeled below.

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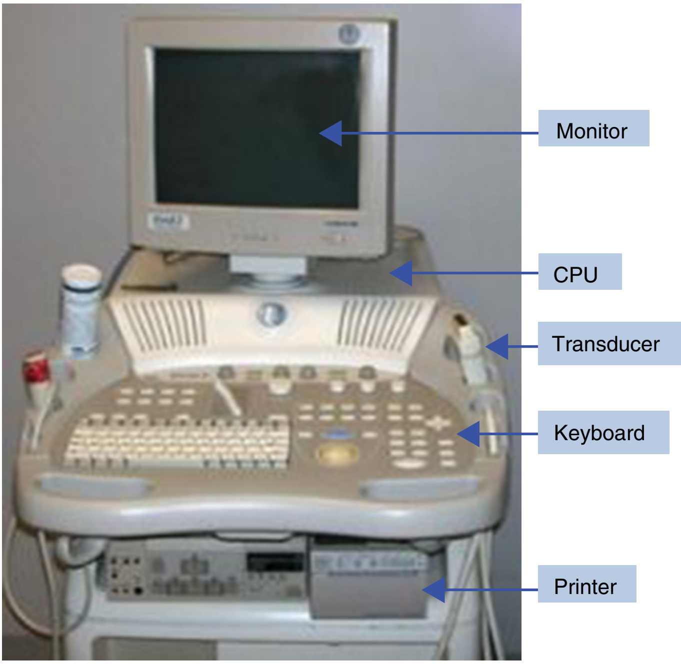


Figure 1.1 Echocardiogram machine.

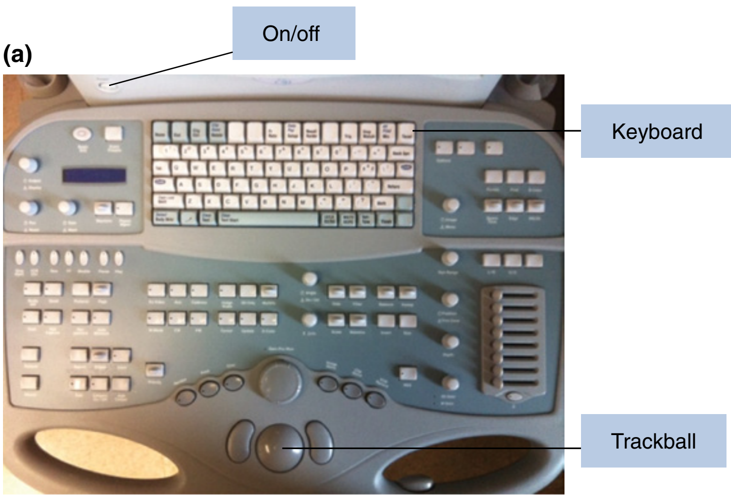


Figure 1.2 Typical echocardiogram control panel.

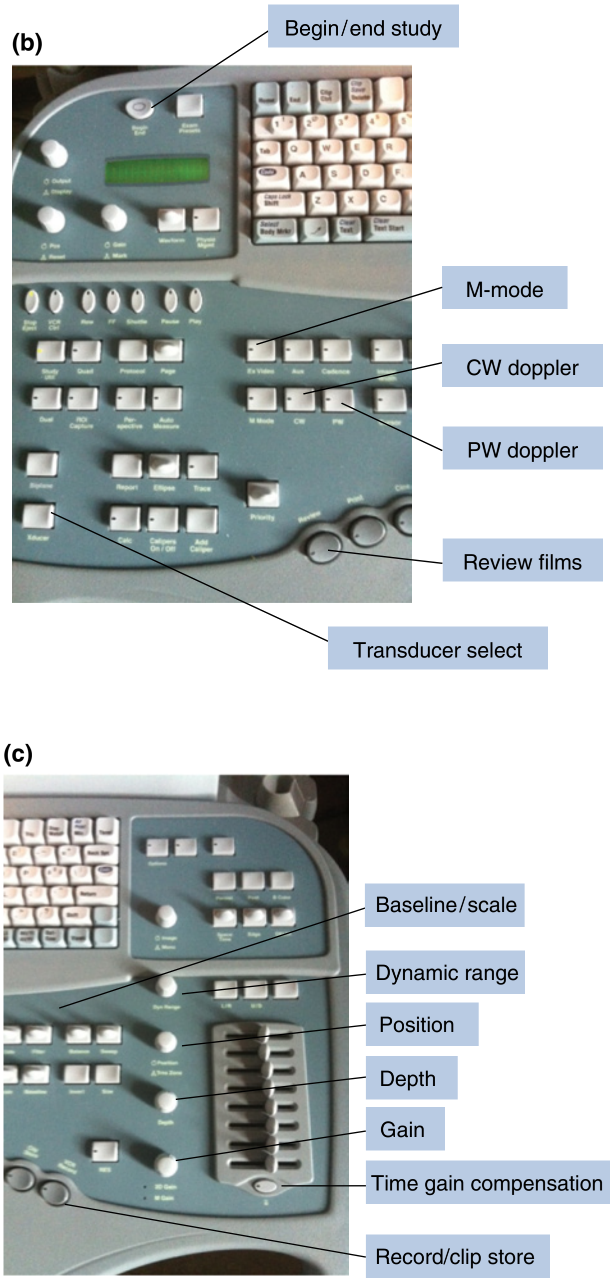
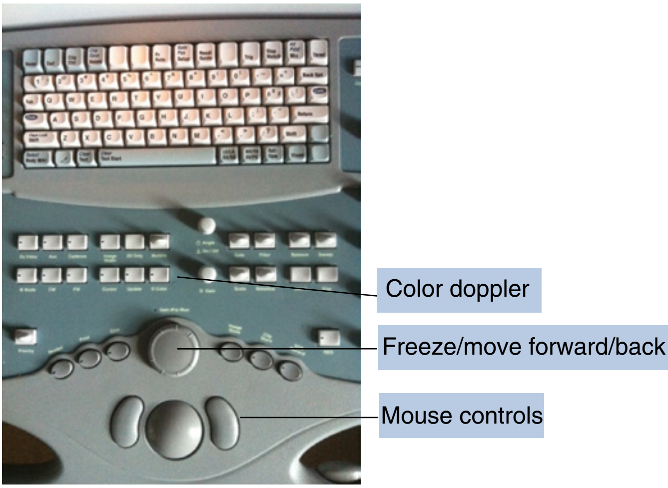


Figure 1.2 (*Cont'd*)

(d)



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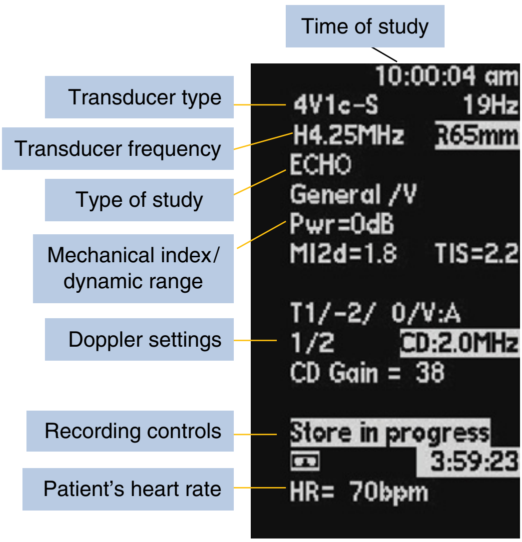

Figure 1.3 Echocardiography settings.

The important echocardiographic settings as displayed on the monitor of most ultrasound machines are shown in Figure 1.3. These settings can be changed, as needed, to adjust the image quality.

The different echocardiographic modes that are available, which are described later in this book, are:

- M-mode: a graphic representation of a specific line of interest of a two-dimensional image (Figure 1.4).

- 2D: a two-dimensional view of cardiac structures that can be visualized as time progresses (Figure 1.5).
- Color Doppler: a color representation of blood flow velocities superimposed on a two-dimensional image (Figure 1.6).
- CW/PW Doppler: the representation of flow velocities as plotted with time on the x axis and velocity on the y axis (Figure 1.7).
- Tissue Doppler: the measurement of tissue velocities (Figure 1.8).

The controls, as shown in the figures, switch between the different modes of echocardiography. However, before moving on to performing and

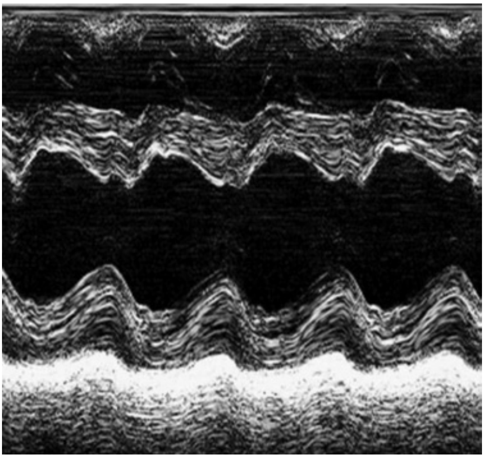

Figure 1.4 M-Mode: a graphic representation of a specific line of interest of a two-dimensional image.

Figure 1.5 2D: a two-dimensional view of cardiac structures that can be visualized as time progresses.

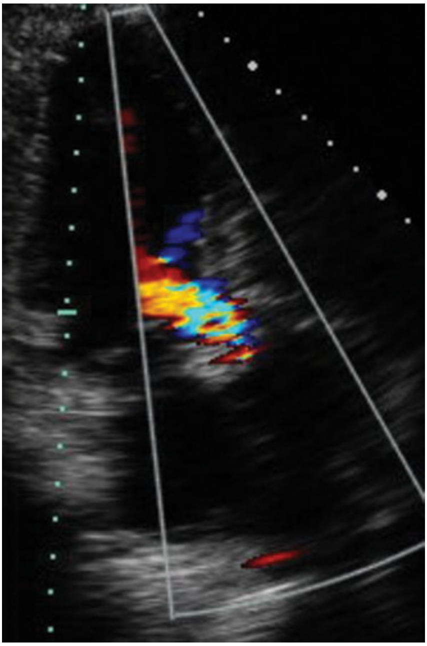

Figure 1.6 Color Doppler: a color representation of blood flow velocities superimposed on a two-dimensional image.

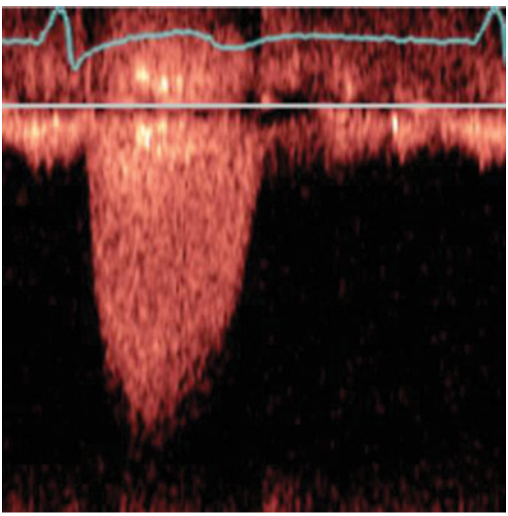

Figure 1.7 CW/PW Doppler: the representation of flow velocities as plotted with time on the x axis and velocity on the y axis.

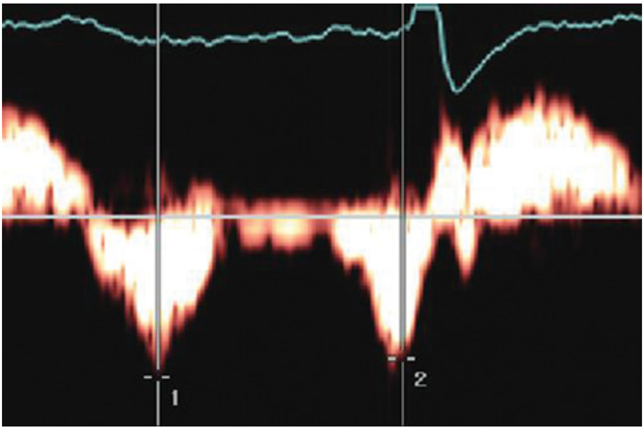

Figure 1.8 Tissue Doppler: the measurement of tissue velocities.

interpreting echocardiograms, it is necessary to be aware of the physics behind this imaging modality.

Ultrasound generation

Ultrasound is a cyclic sound pressure waveform whose frequency is greater than the limit of human hearing. This number is generally considered to be 20 kHz, or 20 000 Hz (Hertz). Echocardiography usually relies on sound waves ranging from 2 to 8 MHz. The echocardiograph, or any other medical ultrasound machine, produces these high frequency sound waves using transducers that contain a piezoelectric crystal.

A piezoelectric crystal (such as quartz or titanate cyramics) is a special material that compresses and expands as electricity is applied to it. This compression and expansion generates the ultrasound wave. The rate (frequency) of compression and expansion is based on the current that the ultrasound machine applies to the piezoelectric signal, which in turn is based on the settings the operator has selected on the machine.

An ultrasound wave, as all sound waves, has some basic physical properties (Figure 1.9). These are:

- Cycle – the sum of one compression and one expansion of a sound wave.
- Frequency (*f*) – the number of cycles per second.
- Wavelength (λ) – the length of one complete cycle of sound.
- Period (p) – the time duration of one cycle.
- Amplitude – the maximum pressure change from baseline of a sound wave.
- Velocity (*v*) – speed at which sound moves through a specific medium.

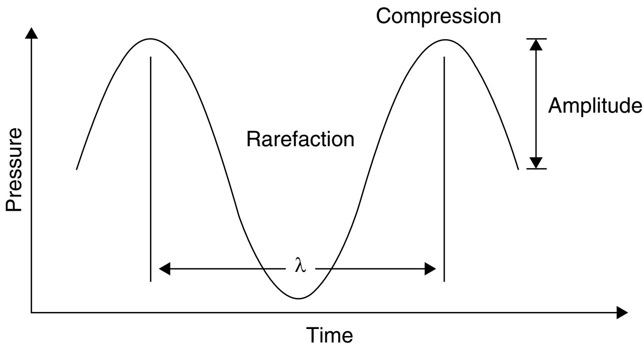

Figure 1.9 A sound wave is made up of varying pressure cycles formed by repeating of compression and rarefaction. The distance between similar points in a wave is called the wavelength (λ) [1].

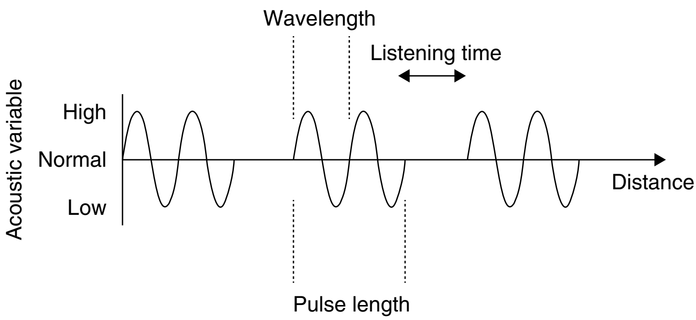

Figure 1.10 A pulse can consist of multiple wavelengths of a sound wave. In this figure, three pulses are shown, each the length of two wavelengths (Reproduced from Case [2], with permisison from Elsevier).

A basic property of all sound waves is: Velocity = Frequency (f) x Wavelength (λ). This formula shows that frequency and wavelength are inversely related, since the velocity of a sound wave depends on the density of the medium the wave is traveling in.

In an echocardiogram machine, current is applied to the piezoelectric crystal, which then emits ultrasound energy into human tissue. The ultrasound is emitted in pulses that usually consist of several consecutive cycles of a sound wave with the same frequency separated by a pause (Figure 1.10). An extremely important concept for ultrasound is the frequency of pulses that the ultrasound emits; this is called the Pulse Repetition Frequency (PRF). The inverse of PRF is the Pulse Repetition Period (PRP), which is the time from the beginning of one ultrasound pulse to the next:

$$PRF = 1 / PRP$$

The actual length of the pulse – the spatial pulse length (SPL) – is equal to the wavelength multiplied by the number of cycles in a pulse.

Once an ultrasound pulse is emitted from the transducer, the entire mechanism enters the "listening" phase. At this time, the ultrasound machine is waiting to receive back the pulse it emitted after it was reflected from distant structures. It is important to know that the ultrasound machine spends almost 99% of the time listening for, and 1% of the time generating, a signal.

Image formation

As the ultrasound wave exits the echocardiogram probe, it enters the human tissue. When the ultrasound waves encounter a change in tissue density, such as the endocardium–blood interphase, some of them will be reflected back while others will penetrate deeper into the tissue. Thus, ultrasound energy is greater near the transducer and is progressively lost as it penetrates into the tissue. The ultrasound systems typically compensate by amplifying more the signals that are received from the far field to make the image homogeneous. The interaction of ultrasound with human tissue is also very complex. However, it is important to know that within soft tissue the velocity of ultrasound is fairly constant at 1540 m/s. In fact, it is usually assumed that this is the velocity of sound in human tissue. However, it is not always the truth. The velocities of ultrasound in various human tissues are shown in Table 1.1.

This concept is extremely important, since the ultrasound machine is not able to recognize whether the ultrasound it receives back from the body traveled mainly through bone, through soft tissue, through air, or any combination of the above structures. As such, it computes the distance the ultrasound traveled based on a velocity of 1540 m/s. Therefore, objects can be misplaced on an ultrasound image because of this velocity assumption, which is built into the ultrasound machine. This explains

Table 1.1 Velocity of ultrasound in various human tissues.

Medium	Velocity (m/s)
Air (the slowest)	330
Soft tissue	1540
Blood	1570
Muscle	1580
Bone (the fastest)	4080

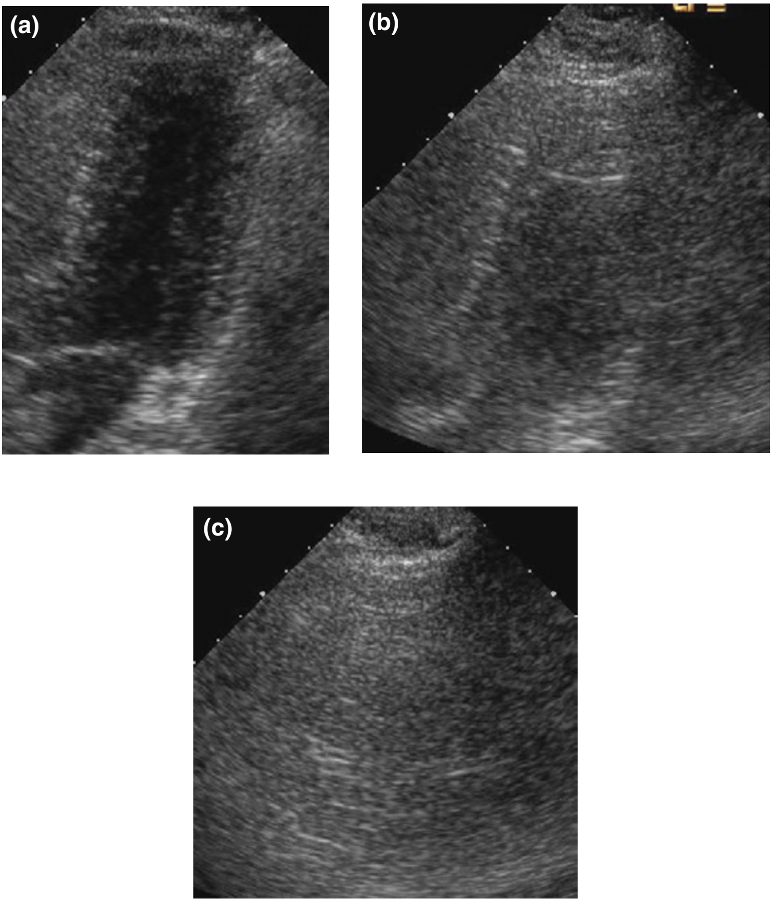

Figure 1.11 An apical four-chamber view of the same patient when the patient has exhaled **(a)**, as the patient is inhaling **(b)**, and as the patient is fully inhaled **(c)**. As clearly seen, the quality of the myocardial image declines acutely as more air enters the lung of the patient, to a point where no myocardium is seen in full inhalation **(c)**.

why interposition of ribs or lung tissue between the transducer and the heart will produce severe imaging artifacts and make part of the image uninterpretable (Figure 1.11).

Another important point to remember is the behavior of the ultrasound beam as it emerges from the transducer (Figure 1.12). The ultrasound beam is initially parallel and cylindrical (near zone). However, after its narrowest point, the focal zone, it begins to diverge and acquires a cone shape (far zone). For reasons outside the scope of this book, the imaging is much better if the object of interest is located near the focal zone. The near zone length is calculated via: near field = (radius of transducer)^2/wavelength of ultrasound. The location of the focal zone can be adjusted electronically.

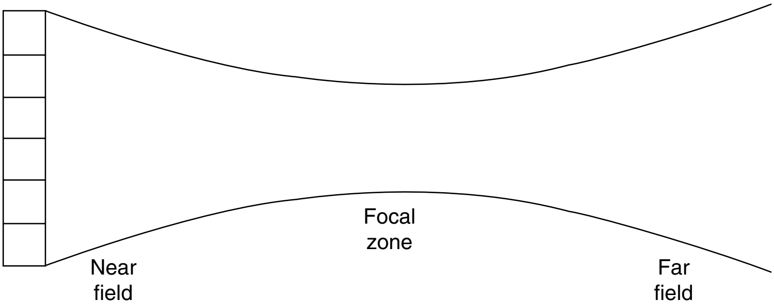

Figure 1.12 Behavior of an ultrasound beam as it comes out of the ultrasound probe (Reproduced from [2] Case, TD. Ultrasound Physics and Instrumentation. Surg Clinc N Am. 1998;78(2):197–217).

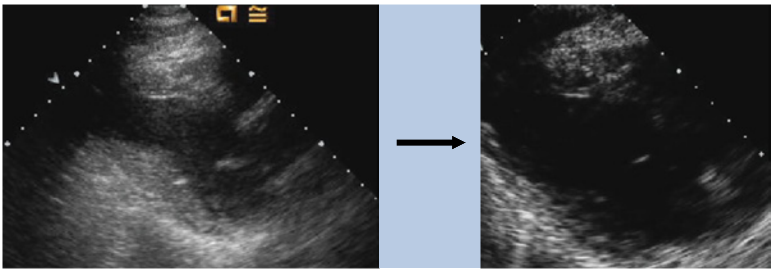

Figure 1.13 Image changes with a decrease in ultrasound frequency.

Resolution versus penetration

The behavior of the beam within tissue determines the lateral resolution of the ultrasound, or the ability to distinguish two objects located side by side on an ultrasound image. The axial resolution, or the ability to distinguish two objects one in front of the other, on an ultrasound image is determined by ultrasound transducer frequency (1/wavelength). At higher frequency, axial resolution increases. However, since the ultrasound signal is attenuated as it travels through the tissues, more attenuation occurs. In general, high frequency is preferred for imaging structures that are closer to the transducer and lower frequency for those that are far. In the case shown in Figure 1.13, a parasternal long axis view loses its definition as the transducer frequency is changed from 4.0 MHz to 2.0 MHz.

As the ultrasound comes back to the transducer, the same piezoelectric properties of crystal that allow the ultrasound waves to be made allow the conversion of the received ultrasound waves into electrical signals. A typical 2D ultrasound transducer has 128 or 256 individual crystal-electronic interphases. In M-mode imaging, the ultrasound beam is emitted and received only at 90°. By alternating the time and sequence in which these are stimulated, the ultrasound beam can be steered at almost any angle. By steering rapidly while emitting and receiving at sequential angles a two-dimensional image is formed (Figure 1.14).

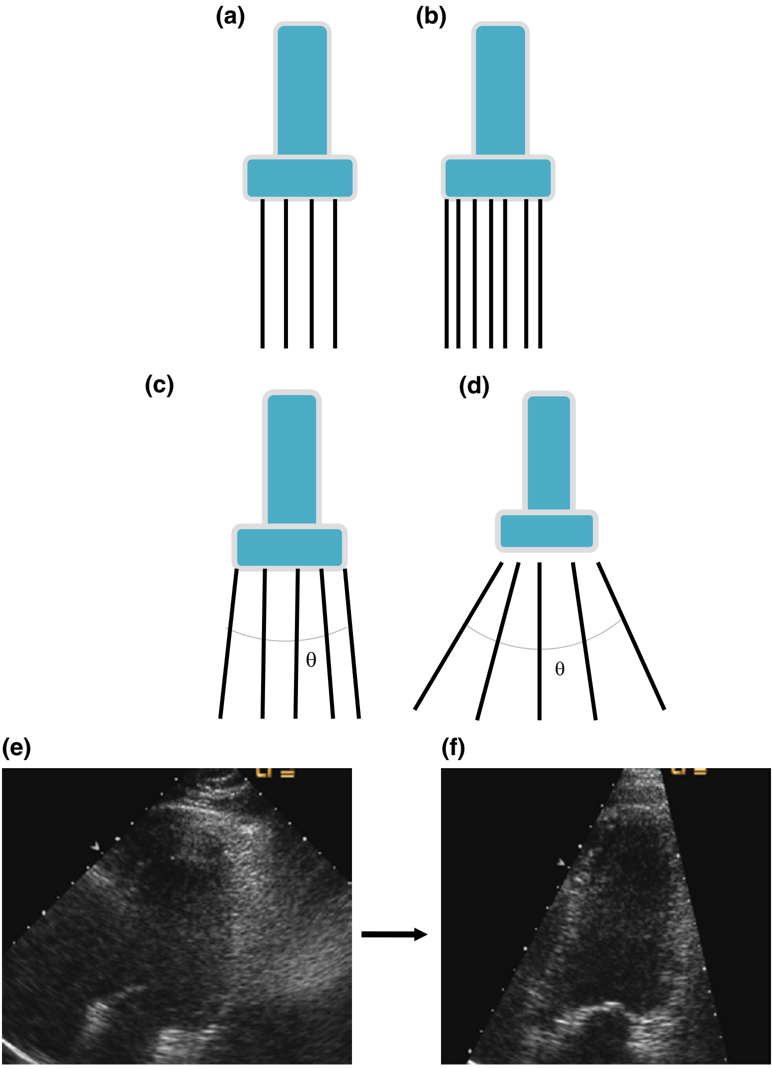

Figure 1.14 As the scan line density increases **(a→b)**, the accuracy and resolution of the image increase. As the sector angle (θ) increases **(c→d)**, more structures are noted as the area being interrogated by the ultrasound beam increases. However, going to a narrower angle **(e→f)** increases resolution, as is seen in this set of images where a wider view **(e)** shows multiple structures, while the same view with a narrower sector angle **(f)** more clearly shows the endocardial definition of the left ventricle.