

*Cross-Sectional*  
ECHOCARDIOGRAPHY

ARTHUR E. WEYMAN, M.D.

# *Cross-Sectional* ECHOCARDIOGRAPHY

ARTHUR E. WEYMAN, M.D.

*Director, Cardiac Ultrasound Laboratory,*

*Massachusetts General Hospital*

*Associate Professor of Medicine,*

*Harvard Medical School*



Lea & Febiger • Philadelphia • 1982

Lea & Febiger  
600 Washington Square  
Philadelphia, PA 19106 U.S.A.

**Library of Congress Cataloging in Publication Data**

Weyman, Arthur.

Cross-sectional echocardiography.

Bibliography: p.

Includes index.

1. Ultrasonic cardiography. I. Title.

[DNLM: 1. Echocardiography. WG 141.5.E2 W549c]

RC683.5.U5W49 1981 616.1'207543 81-8440

ISBN 0-8121-0794-2

AACR2

Copyright © 1982 by Lea & Febiger. Copyright under the International Copyright Union.  
All Rights Reserved. This book is protected by copyright. No part of it may be reproduced  
in any manner or by any means without written permission of the publisher.

PRINTED IN THE UNITED STATES OF AMERICA

Print Number 3 2 1

# Preface

This book is the end product of 7 years of almost full-time commitment to the development of cross-sectional echocardiography. It is the sum of numerous individual and collaborative research efforts, the experience gained in attempting to teach both the technical and interpretive aspects of this imaging modality, extensive discussion and contemplation, and the often painful wisdom that results from paths taken in error and mistakes made. The text itself was begun nearly 3 years ago. It was originally intended as a simple guide to others starting out in cross-sectional echocardiography to facilitate their efforts and to help them to avoid many of the technical and interpretive pitfalls we encountered in the early years of this work. It was decided, at that point, to limit the discussion to cross-sectional echocardiography because there were a number of excellent books available on the M-mode method. Writing such a book did not appear to be a major undertaking because the clinical applications of cross-sectional echocardiography, at that time, were limited, and the scope of the text was, likewise, expected to be narrow. Unfortunately, a series of personal and professional transitions interrupted this undertaking almost at its start and delayed its completion for several years. During the intervening period, there has been enormous growth in both the technical and clinical applications of cross-sectional

echocardiography, and as a result, this volume is far larger than originally conceived.

Also during these years, the relative role of cross-sectional and M-mode echocardiography has shifted, and the cross-sectional technique, which was only a small component of the echocardiographic examination when this book was begun, has now become the primary imaging modality. As the role of the cross-sectional method expanded, that of the M-mode component of the echocardiographic examination became more restricted, and at this point, it would be much less of a task to include pertinent M-mode applications. This might seem even more appropriate because many of these applications, although not illustrated, are alluded to. Further, this omission might be taken to indicate that the M-mode examination is no longer considered important. This is clearly not the case. A discussion of M-mode echocardiography is omitted simply because it is almost impossible to change the philosophy of a book in mid-writing and attempting to do so would have delayed this project even further. The book, therefore, remains as it was initially conceived—a text almost exclusively confined to cross-sectional echocardiography. Anytime the term, echocardiography, is used in this context, it refers to the cross-sectional format.

One exception can be found in Chapter 12 in the section on interventricular septal

motion. It was impossible in writing this section to describe septal motion using the cross-sectional format alone, and it was necessary, in this one area, to include several M-mode records.

The text is conceptually divided into three sections. The first two chapters deal with the physical principles of ultrasound and its application in cross-sectional imaging. Similar information can be found at the beginning of most textbooks on echocardiography and is included here because of its critical importance in determining the nature and quality of the data that are available for clinical evaluation. These chapters are written at a relatively basic level, which is consistent both with my level of understanding and with the needs of the average clinician.

The second section, which includes Chapters 3 and 4, deals with the general principles of the cross-sectional examination and describes the standard imaging planes. I feel that this is the most important section in the book. Almost anyone can be taught to interpret a high-quality cross-sectional echogram. There are few skilled operators, however, who can consistently record high-quality cross-sectional images in the heterogeneous patient population encountered in the routine laboratory. Obviously, it is impossible to convey or teach a technical skill in a book. This section, therefore, approaches the examination from a conceptual viewpoint and, hopefully, will allow the reader to appreciate, at least in theory, the steps that are necessary to produce consistent images of optimal quality.

When reading Chapter 3, several of our fellows felt that this section was overly long and repetitious. At one time, I considered shortening this chapter; however, after subsequently observing that the recording errors made by these same individuals could have been overcome by closer attention to the principles set forth in this chapter, I decided that possibly even more repetition would be helpful. I

strongly feel that if the concepts set forth in this chapter can be firmly grasped and incorporated into the routine examination, the attainment of high-quality cross-sectional images will be far easier than if one were to follow the natural tendency to rely on pattern recognition.

Chapter 4, which describes the standard imaging planes, is a tedious chapter that was difficult to write and I am sure will be difficult to read. It is based on the presumption that, in recording these standard planes, the observer actually looks at only a few points within the image and seeks to optimize the recording of these structures. This can be compared to photographing a ship on the horizon. If the ship is appropriately framed, then the sky and sea will be in their proper proportions. It is hoped that, by focusing on these primary structures, the orientation of the individual planes can be more easily envisioned and the effects of slight changes in angulation or rotation likewise understood. Much time is spent on describing the optimal method for recording these planes. This is again done because of a strong conviction that it is only through rigid standardization that useful quantitation is possible.

The third section of this book deals with the clinical applications of cross-sectional echocardiography. This section is organized and written from the perspective that cross-sectional echocardiography displays "functional anatomy." The individual chapters generally follow the path of blood flow through the left and right sides of the heart. The order in which individual structures are considered in each chapter is further influenced by their relative echocardiographic importance. I have attempted in these chapters to describe both the functional and pathologic anatomy of different structures and lesions in sufficient detail that the examiner can anticipate the principal anatomic variations that may be encountered. This, again, is done in the hope that the greater the level of



understanding, the less the reliance on pattern recognition.

The chapters that deal with ventricular structure and function are written at a time when methods for evaluating both the right and left ventricles are in rapid evolution. Because there are no generally accepted approaches to many of these questions, it was necessary to discuss a number of different alternatives and suggest those that, in my opinion, might be the most useful. In some areas, the approaches presented are recognized as less than optimal; however, there is no general agreement on a better method. An example is the segmental evaluation of left ventricular wall motion. The method presented in the text will probably not become the accepted standard. This particular system, however, has been used in a number of clinical studies and forms the basis for most of the correlations contained later in the chapter. It is included, therefore, as an example of how such a system might be employed and because the data derived using the nine-segment format are representative and should be clinically useful. Another example can be found in the truncated-cone method for defining endocardial surface area also contained in the chapter on the left ventricle. Again, it is not my intention that this method be viewed as the appropriate or only method to derive this type of data. The model and formulas are presented only as examples of one approach with the recognition that other figures or other models might, in time, prove more appropriate.

The discussion of the right ventricle is, likewise, highly theoretical. Little echocardiographic data are available concerning methods of deriving right ventricular volume or function. In the absence of this type of information, it seemed useful to review some of the figures and approaches that have been used in other imaging modalities because these have formed the basis for the echocardiographic evaluation of the left ventricle and, it can be assumed,

will likewise be used in approaching right ventricular volume and function.

The approach to congenital heart disease is significantly different from that found elsewhere. Isolated congenital lesions, such as the bicuspid aortic valve or Ebstein's anomaly, are included in the discussion of the aortic or tricuspid valves, respectively. Chapter 13, which presents a diagnostic approach to the patient with congenital heart disease, deals solely with those patients in whom there are multiple congenital anomalies. This chapter takes the approach that the echocardiographer is not presented with a patient with double-outlet right ventricle or tetralogy of Fallot, but rather with an unknown patient with suspected complex, congenital heart disease. It is only during the course of the examination that the various components that lead to an appropriate overall diagnosis become apparent. As a result, this chapter presents an organized and orderly method for assembling the various pieces of the puzzle rather than a description of how the puzzle looks when it is completed. This presumes that the observer can recognize the whole from the sum of its parts. Although unorthodox, this is an approach that I have found helpful in teaching residents and fellows and that, hopefully, will help the reader when faced with an unknown patient with complex, congenital disease.

As with all things, it is only in doing something that one learns how to do it. So it was with this first edition, which was a learning process in many ways. As one learns how to assemble material and organize thoughts, there is a great temptation to go back and rewrite earlier sections. This is particularly true of areas that are rapidly evolving and in which important new information is appearing almost daily. At some point, however, a project such as this must come to an end.

This book, although written primarily by a single author, obviously could not have been accomplished without support

and input from a number of other sources. So many people have aided by gathering the data on which this work is based, by proofreading, by commenting, and by just being generally supportive that it is impossible to acknowledge all of these contributions. There are a number of people, however, who have played a particular role in the completion of this endeavor and whose contributions must be acknowledged. First of all, I would like to thank my family, Jean, Jenny, Shannon, and Robert, for their patience and continued encouragement throughout the writing of this book. Much of the time spent in preparing this text was, of necessity, taken away from family activities, and despite this, they were always fully supportive of this effort. Likewise, Mrs. Willie Mae Tate, without whose help neither this family nor this text could have been completed.

I should also like to thank Dr. Charles Fisch, who provided the environment, support, and, most importantly, the time to pursue these endeavors. Dr. Harvey Feigenbaum, in whose laboratory the vast majority of this work was undertaken and without whose enormous knowledge and historical perspective in M-mode echocardiography these efforts could not have been accomplished. Mrs. Sonya Chang, who initially taught me echocardiography, instilled in me a great respect for the technical demands of this technique, and helped me to understand that the technician is at the heart of all quality echocardiographic studies.

Over the course of these 7 years, I have had the good fortune to work with a number of highly skilled technical specialists who performed many of the studies on which this book is based. These persons include Janie Stewart, Jane Marshall, Deb-

bie Green, Kevin McInerney, M.C. Clark, and Licia Mueller. It is because of the personal and professional quality of such people that this is such an enjoyable profession to be a part of.

Many of my colleagues throughout the years have, to a large part, been responsible for the clinical and research efforts on which this text is based. Their names can be found scattered repeatedly throughout the bibliography to the various chapters. There are others, however, who were of particular help in the actual preparation of this manuscript. These persons include Reg Engleton, Frank Fry, Tom Franklin, Ken Johnston, and Paul Goldberg, who provided much of the basic science input for the earlier chapters and aided in the critical review of these sections; Drs. Tom Gibson, Bob Godley, Larry Rink, Dan Doty, John Butterly, Pres. Wiske, and Mary Etta King, who aided in proofreading many of these chapters and provided invaluable editorial critique; and Phil Wilson, who was responsible for much of the art work found in the first four chapters and without whose enormous talent and creativity the preparation of this text would not have been possible. Also, Nancy Kriebel, Cheryl Childress, and Brent Bauer who helped with many of the diagrams and charts found throughout the clinical section. The typing of this manuscript was, likewise, an enormous task, and for this, I thank Linda Williams and Kathleen Cavanaugh. And last, but not least, I must acknowledge the early efforts of my good friend Dr. Dennis Greenbaum, who "first translated Weyman into English."

Boston, Mass.

Arthur E. Weyman

# Contents

## SECTION 1

Physical Principles of Ultrasound and Its Application in

Cross-Sectional Imaging ..... 1

**Chapter 1 Physical Principles of Ultrasound** ..... 3

Properties of Sound ..... 5

Properties of Ultrasound ..... 7

The Ultrasonic Beam ..... 7

Reflection, Refraction, and Transmission ..... 8

Resolution ..... 11

The Transducer ..... 13

Attenuation and Absorption ..... 16

Choice of Appropriate Transducer Frequency ..... 16

The Echograph ..... 17

Methods of Amplification ..... 18

Display Formats ..... 20

System Controls ..... 25

System Gain or Coarse Gain ..... 25

Time-Gain Compensation (TGC) or Gain as a Function of Depth ..... 26

Near-Field Gain ..... 26

Damping Circuit ..... 26

Reject Circuit ..... 26

Biologic Effects of Ultrasound ..... 26

**Chapter 2 Cross-Sectional Scanning: Technical Principles and**

**Instrumentation** ..... 31

History of Cross-Sectional Imaging ..... 31

Scan Formats ..... 34

Instrumentation ..... 35

Dynamic Cross-Sectional Imaging Systems ..... 37

Mechanical Sector Scanning ..... 37

Transducer Arrays ..... 40

Linear Arrays ..... 40

Phased Arrays ..... 41

Principles of Dynamic Cardiac Imaging Common to All Systems ..... 47

The Pulse or Line Repetition Frequency ..... 48

Frame Rate ..... 49



Scan Angle .....	49
Field Versus Frame .....	49
Side Lobes .....	50
Dynamic Range—Gray Scale .....	53
Persistence .....	55
Complex Signal Processing .....	56
Image Recording Techniques .....	58
Factors Affecting the Cross-Sectional Display Characteristics of a Point Target .....	58
<b>SECTION 2</b>	
The Cross-Sectional Examination—General Principles and Standard Imaging Planes .....	63
<b>Chapter 3 Cross-Sectional Echocardiographic Examination</b> .....	65
The Cross-Sectional Examination .....	67
Preliminary Steps .....	67
Initial Approach to the Patient .....	67
Difficult or Uncooperative Patients .....	69
Selection of a Transducer .....	70
Initial Control Settings .....	73
Examination Sequence .....	74
Locating the Heart .....	74
Three-Dimensional Cardiac Anatomy .....	79
General Plane Orientation .....	82
Initiating the Examination .....	85
Structure Identification .....	86
Fine Plane Positioning .....	89
<b>Chapter 4 Standard Plane Positions—Standard Imaging Planes</b> .....	98
Parasternal Long-Axis Planes .....	100
Parasternal Long Axis of the Left Side of the Heart .....	100
Parasternal Long Axis of the Right Ventricular Inflow Tract .....	105
Parasternal Long Axis of the Right Ventricular Outflow Tract .....	106
Parasternal Long Axis of the Main Pulmonary Artery .....	109
Parasternal Long Axis of the Left Ventricular Apex .....	109
Parasternal Short-Axis Planes .....	109
Parasternal Short Axis of the Aortic Valve and Left Atrium .....	112
Parasternal Short Axis of the Left Ventricle (Mitral Valve Level) .....	114
Parasternal Short Axis of the Left Ventricle (Papillary Muscle Level) .....	114
Parasternal Short Axis of the Left Ventricle (Apical Level) .....	116
Apical Views .....	116
The Apical Four-Chamber View .....	119
The Apical Five-Chamber View .....	122
The Apical Two-Chamber View .....	123
The Apical Long Axis of the Left Ventricle .....	124
Subcostal Examination .....	126
Subcostal Long Axis of the Heart .....	127
Subcostal Long Axis of the Right Ventricular Outflow Tract .....	128
Noncardiac Structures That Can Be Examined from the Subcostal Location .....	129
Suprasternal Views .....	129

Suprasternal Long Axis of the Aortic Arch .....	131
Suprasternal Short Axis of the Aortic Arch .....	131
M-Mode Component of a Cross-Sectional Examination .....	134
<b>SECTION 3</b>	
Clinical Applications of Cross-Sectional Echocardiography .....	137
<b>Chapter 5 Left Ventricular Inflow Tract, Part 1: The Mitral Valve</b> .....	139
The Mitral Valve .....	139
Anatomy .....	140
Methods of Cross-Sectional Examination .....	141
Normal Mitral Leaflet Motion—Long-Axis View .....	143
Normal Mitral Leaflet Motion—Short-Axis View .....	144
Normal Mitral Leaflet Motion—Apical Four-Chamber View .....	145
Factors Affecting Timing, Amplitude, and Rate of Mitral Leaflet Motion .....	146
Effects of Abnormal Pressure and Flow on Mitral Valve Motion .....	148
Abnormal Mitral Valve Echogram .....	149
Abnormalities Associated with Restricted Left Ventricular Inflow .....	150
Rheumatic Mitral Stenosis .....	150
Mitral Commissurotomy .....	159
Mitral Stenosis and Prolapse .....	161
Mitral Stenosis and Insufficiency .....	162
Congenital Mitral Stenosis .....	163
Parachute Mitral Valve .....	164
Supravalvular Mitral Ring .....	165
The Mitral Valve in Aortic Insufficiency .....	165
Abnormalities Associated with Mitral Insufficiency .....	167
Rheumatic Mitral Regurgitation .....	168
Mitral Valve Prolapse .....	169
Severity of Mitral Valve Prolapse .....	173
Ruptured Chordae Tendineae .....	175
Flail Mitral Leaflet .....	175
Papillary Muscle Dysfunction .....	176
Cleft Mitral Valve .....	179
Structural Abnormalities of Leaflets or Supporting Structures .....	180
Mitral Annular Calcification .....	180
Mitral Valve Vegetations .....	181
Prosthetic Mitral Valves .....	185
<b>Chapter 6 Left Ventricular Inflow Tract, Part 2: Left Atrium, Pulmonary Veins, and Coronary Sinus</b> .....	193
Left Atrium .....	193
Anatomy .....	193
Examining Planes and Linear Dimensions .....	193
Normal Cyclic Variations in Left Atrial Dimensions .....	197
Left Atrial Tumors .....	198
Left Atrial Thrombi .....	201
Congenital Aneurysms of the Left Atrium .....	204
Cor Triatriatum .....	204
Pulmonary Veins .....	205
Normal Appearance .....	205

Total Anomalous Pulmonary Venous Return .....	207
Coronary Sinus .....	209
<b>Chapter 7 Left Ventricular Outflow Tract .....</b>	<b>212</b>
The Aortic Valve .....	213
Normal Anatomy .....	213
Examining Planes .....	213
Relationship of Aortic Leaflet Motion to Cardiac Output and Transvalvular Flow Patterns .....	216
The Abnormal Aortic Valve Echogram .....	217
Valvular Aortic Stenosis .....	217
Adult Calcific Aortic Stenosis .....	217
Congenital Aortic Stenosis .....	224
Bicuspid Aortic Valve .....	226
Aortic Leaflet Thickening without Stenosis .....	230
Aortic Insufficiency .....	231
Rheumatic Aortic Insufficiency .....	232
Aortic Valve Vegetations .....	232
Fenestrated and Flail Aortic Leaflets .....	233
Septal Abscess .....	234
Hemodynamic Sequelae of Aortic Endocarditis .....	234
Aortic Insufficiency Associated with Congenitally Stenotic and/or Bicuspid Valves .....	236
Aortic Valve Prolapse .....	236
The Aorta .....	236
The Ascending Aorta .....	237
Supravalvular Aortic Stenosis .....	237
Aneurysms of the Ascending Aorta .....	239
Congenital Aneurysms of the Aorta .....	240
Acquired Aneurysms .....	242
The Aortic Arch .....	244
Coarctation of the Aorta .....	246
Aortic Arch Aneurysms .....	249
The Descending Aorta .....	250
The Thoracic Aorta .....	251
The Abdominal Aorta .....	252
The Subvalvular Left Ventricular Outflow Tract .....	252
Discrete Subaortic Stenosis .....	253
Discrete Membranous Subaortic Stenosis .....	253
Diffuse Fibromuscular Subvalvular Obstruction .....	253
Postoperative Studies .....	255
Functional Subvalvular Aortic Stenosis .....	256
Idiopathic Hypertrophic Subaortic Stenosis .....	257
Other Causes of Functional Outflow Obstruction .....	260
<b>Chapter 8 Left Ventricle .....</b>	<b>267</b>
General Principles of Echocardiographic Imaging Pertinent to the Left Ventricular Examination .....	268
Examining Planes and Linear Dimensions .....	271
The Parasternal Long-Axis Views .....	271
Short-Axis Planes .....	274

The Apical Views .....	277
The Subcostal Views .....	281
Left Ventricular Volume .....	283
Ventricular Volume Calculations Using the Prolate Ellipsoid Model ..	283
Simpson's Rule Method .....	292
Combined Geometric Figures .....	294
Summary .....	296
Left Ventricular Mass .....	297
Simpson's Rule Method .....	300
Combined Geometric Figures .....	300
Single-Figure Method .....	301
Relationship of Mass to Volume .....	301
Dynamic or Ejection Phase Indices of Left Ventricular Performance ..	302
Left Ventricular Response to Exercise .....	304
Regional Wall Motion Abnormalities .....	304
Acute Myocardial Infarction .....	305
Chronic Ischemic Heart Disease .....	317
Left Ventricular Scar .....	319
Left Ventricular Aneurysms .....	319
Left Ventricular Diverticula .....	321
Ventricular Septal Rupture .....	322
Left Ventricular Thrombi .....	324
Left Ventricular Tumors .....	325
Cardiomyopathies .....	326
Congestive Cardiomyopathies .....	326
Restrictive Myopathies .....	327
Infiltrative Cardiomyopathies .....	328
<b>Chapter 9 Right Ventricular Inflow Tract .....</b>	<b>338</b>
The Tricuspid Valve .....	338
Anatomy .....	338
Methods of Cross-Sectional Examination .....	339
Normal Tricuspid Leaflet Motion—Long Axis .....	341
Normal Tricuspid Leaflet Motion—Short Axis .....	342
Normal Tricuspid Leaflet Motion—Apical Four-Chamber View .....	342
Factors Affecting the Timing, Amplitude, and Rate of Tricuspid Leaflet Motion .....	343
The Abnormal Tricuspid Valve Echogram .....	346
Right Ventricular Inflow Obstruction .....	346
Rheumatic Tricuspid Stenosis .....	346
Tricuspid Stenosis in Endomyocardial Fibrosis (Löffler's Endocarditis) .....	347
Lesions Associated with Tricuspid Incompetence .....	347
Indirect Echocardiographic Methods for Detecting Tricuspid Regurgitation .....	349
Echocardiographic Features of Specific Lesions Associated with Tricuspid Regurgitation .....	350
The Right Atrium .....	356
Anatomy .....	356
Examining Planes and Linear Dimensions .....	357

The Eustachian Valve .....	359
Right Atrial Tumors .....	359
Venous Catheters .....	360
The Venae Cavae .....	362
The Inferior Vena Cava .....	362
The Superior Vena Cava .....	363
<b>Chapter 10 Right Ventricular Outflow Tract .....</b>	<b>368</b>
Examining Planes .....	368
The Pulmonary Valve—Normal Orientation and Motion .....	369
Valvular Pulmonary Stenosis .....	370
Pulmonary Valve Endocarditis .....	372
The Subvalvular Right Ventricular Outflow Tract—The Conus	
Arteriosus or Infundibulum .....	373
Infundibular Pulmonary Stenosis .....	374
Infundibular Obstruction in Tetralogy of Fallot .....	376
The Pulmonary Artery .....	376
Pulmonary Artery Dilatation .....	377
Pulmonary Artery Bands .....	378
Generalized Abnormalities of the Right Ventricular Outflow Tract .....	378
<b>Chapter 11 Right Ventricle .....</b>	<b>382</b>
Right Ventricular Examining Planes and Linear Dimensions .....	383
Right Ventricular Volume Determinations .....	386
Right Ventricular Volume Overload .....	391
Right Ventricular Hypertrophy .....	393
Right Ventricular Involvement in Ischemic Heart Disease .....	394
Right Ventricular Infarcts .....	394
Right Ventricular Tumors .....	394
<b>Chapter 12 Interatrial and Interventricular Septa .....</b>	<b>396</b>
The Interatrial Septum .....	396
Anatomy .....	396
Development .....	396
Examining Planes .....	397
Spatial Orientation of the Interatrial Septum .....	399
Interatrial Septal Motion .....	400
Atrial Septal Defects .....	402
Patent Foramen Ovale .....	405
Effects of Balloon Atrial Septostomy and Surgical Septectomy on	
the Interatrial Septum .....	406
Atrial Septal Aneurysms .....	406
Atrial Septal Thickness .....	407
The Interventricular Septum .....	408
Anatomy .....	408
Development .....	408
Examining Planes .....	409
Interventricular Thickness, Thickening, and Scar .....	411
Interventricular Septal Motion .....	412
Left Bundle Branch Block .....	422
Ventricular Septal Defects .....	423

Ventricular Septal Aneurysms .....	427
Endocardial Cushion Defects .....	428
<b>Chapter 13 Complex Congenital Heart Disease—A Diagnostic Approach ..</b>	<b>434</b>
Ventricular Number, Size, Orientation, and Identity .....	435
Great Vessel Orientation and Identity .....	441
Ventricular-Great Vessel Relationships .....	446
Presence and Location of Intracardiac Shunts .....	450
Location and Presence of Outflow Obstruction .....	454
<b>Chapter 14 Coronary Arteries .....</b>	<b>458</b>
Coronary Anatomy .....	458
Examining Planes .....	459
Normal Echocardiographic Anatomy .....	461
Coronary Artery Stenosis .....	464
Recent Technical Improvements That Facilitate Coronary Visualization .....	466
Coronary Artery Aneurysms .....	469
Anomalous Origin from the Pulmonary Artery .....	470
Anomalous Origins from the Aorta .....	474
<b>Chapter 15 Pericardial Diseases .....</b>	<b>480</b>
Cross-Sectional Evaluation of the Pericardium .....	481
The Normal Pericardium .....	481
Pericardial Effusion .....	482
Effects of Positional Change on Pericardial Fluid Distribution .....	485
Interpericardial Fibrous Bands .....	485
Loculated Pericardial Effusion .....	486
Pericardial Thickening and Adhesions .....	487
Pericardial Calcification .....	488
Neoplastic Involvement of the Pericardium .....	489
Cardiac Tamponade .....	490
Relationship of Pericardial Effusion to Pericarditis .....	491
Relationship of Cross-Sectional and M-Mode Echocardiography in the Detection of Pericardial Effusion .....	491
Appendices .....	493
Index .....	509



## **Section 1**

# Physical Principles of Ultrasound and Its Application in Cross-Sectional Imaging



## Chapter 1

# Physical Principles of Ultrasound

Sound is a mechanical vibration in a physical medium, such as air or water, that, when it stimulates the auditory apparatus, produces the sensation of hearing.<sup>1</sup> Ultrasound is sound with a frequency higher than the audible range for man or greater than 20,000 cycles per second. The acoustic laws that govern the behavior of low-frequency sound (audible sound) also apply to ultrasound. Ultrasound, however, can capitalize on properties that are not so apparent at lower frequencies (because of the relatively large wavelength to object size relationship). These properties make ultrasound particularly useful in clinical medicine. Most significantly, ultrasound can be beamed in a particular direction and is reflected by relatively small objects (in the millimeter and submillimeter range).<sup>2</sup> The use of pulsed reflected ultrasound to visualize intracardiac structures noninvasively is termed echocardiography.<sup>3</sup>

Historically, echocardiography can be traced to the demonstration by the Curie brothers in 1880 that a suitably cut plate of quartz, when subjected to a mechanical stress, develops electrical charges on its

surface (Fig. 1-1).<sup>4</sup> This production of electrical energy or voltage by the application of a mechanical stress to a crystal is known as the piezoelectric or pressure-electric effect.

The following year (1881), the same observers noted the converse of this principle; specifically, when a piezoelectric crystal is appropriately placed in an alternating electric field, it rapidly changes shape or is thrown into vibration in a characteristic fashion (Fig. 1-1). These basic principles of piezoelectricity—the transformation of electrical energy into mechanical energy and the subsequent transformation of mechanical energy into electrical energy—form the basis for all ultrasonic cardiac visualization.

Figure 1-2 illustrates, in simplified form, the application of these principles in clinical echocardiography. Initially, a piezoelectric crystal or transducer is briefly subjected to a rapidly alternating electrical voltage. This alternating pulse shock excites the crystal, thereby causing it to change shape rapidly or to vibrate (Fig. 1-2, A). As the crystal vibrates, it produces alternating areas of rarefaction and con-