CLINICS IN DIAGNOSTIC ULTRASOUND 17

Basic Doppler Echocardiography

Edited by

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CHURCHILL LIVINGSTONE

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CHURCHILL LIVINGSTONE
NEW YORK, EDINBURGH, LONDON, MELBOURNE
1986

Acquisitions editor: Robert Hurley
Copy editor: Nancy R. Terry
Production designer: Charlie Lebeda
Production supervisor: Sharon Tuder
Compositor: Kingsport Press
Printer/Binder: The Murray Printing Co.

Accurate indications, adverse reactions, and dosage schedules for drugs are provided in this book, but it is possible that they may change. The reader is urged to review the package information data of the manufacturers of the medications mentioned.

Distributed in the United Kingdom by Churchill Livingstone, Robert Stevenson House, 1–3 Baxter's Place, Leith Walk, Edinburgh EH1 3AF and by associated companies, branches and representatives throughout the world.

First published 1986

Printed in USA

ISBN 0–443–08431–9

7 6 5 4 3 2

Library of Congress Cataloging-in-Publication Data
Main entry under title:

Basic doppler echocardiography.

(Clinics in diagnostic ultrasound ; v. 17)
Includes bibliographies and index.
1. Ultrasonic cardiography. 2. Doppler effect.
I. Kisslo, Joseph A. (Joseph Andrew), date.
II. Adams, David B. III. Mark, Daniel B. IV. Series.
[DNLM: 1. Echocardiography. W1 Cl831BC v. 17 /
WG 141.5.E2 B311]
RC683.5.U5B37 1986 616.1'207543 85–19506
ISBN 0–443–08431–9

Manufactured in the United States of America

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CLINICS IN DIAGNOSTIC ULTRASOUND
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Dedicated to our families
Kitty, Shelly, Connie, Andy, Tony,
Lee,
and Lee

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Preface

We have prepared this volume in a simple and straightforward fashion in the hope of providing inexperienced users of Doppler echocardiography a means of getting started. The principles of Doppler and its clinical use are, indeed, complex, and beginners with this technique should not be lulled into overconfidence by our simplifications.

We thank those who stimulated our early interest in Doppler, Mr. Don Baker, Dr. Donald Kalmanson, and Dr. Simeon Rubenstein. We also thank those whose insights into the everyday clinical importance of this technique rekindled our interest: Dr. Bjorn Angelsen, Dr. Tony DeMaria, Dr. Liv Hatle, Dr. Walter Henry, Dr. Randy Martin, Dr. Alan Pearlman, Dr. Richard Popp, and Dr. David Sahn. We also thank Dr. Joseph C. Greenfield for providing us a means by which to study and prepare this volume.

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David Adams, R.C.P.T., R.D.M.S.
Daniel B. Mark, M.D.

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1 An Introduction to Doppler

JOSEPH KISSLO
DAVID ADAMS
DANIEL B. MARK

The current interest in Doppler echocardiography has reached a remarkable level in just the past few years. Indeed, to many physicians, it may appear that Doppler instrumentation only recently became available and that this technique is a new innovation. Papers on Doppler echocardiography in the major cardiology journals are more abundant now than ever before. Manufacturers of ultrasound equipment estimate that over 85 percent of current sales of two-dimensional echocardiographic equipment will contain added Doppler capabilities.

From our conversations with beginning students of the cardiac Doppler technique, it appears that most consider Doppler to be difficult to perform, understand, and interpret. We have also noticed that the learning curve for Doppler echocardiography is much slower than that of two-dimensional echocardiography. Two-dimensional images portray anatomical configurations which are well known to physicians and sonographers. Doppler, on the other hand, provides flow information, and many of the phenomena associated with Doppler, such as aliasing and spectral displays, make this technique seem foreign and too technical.

With all the excitement about Doppler, it appears to us that there are few introductory explanations of the technique and its potential applications to the clinical care of patients. Thus, the purpose of this volume of *Clinics in Diagnostic Ultrasound* is to satisfy the needs of those individuals who are beginners with cardiac Doppler, those who are considering its acquisition, and even those who have only a casual interest in learning a little more about what Doppler is all about. The first several chapters in this volume will provide some background on the development of Doppler, the physical principles and instrumentation involved, and the performance of a Doppler examination with the currently available instrumentation. Later chapters will explore its uses in specific clinical situations and will examine its diagnostic utility in those situations.

DOPPLER ECHOCARDIOGRAPHY IN PRACTICE

In our echocardiography laboratory Doppler has been in use for several years. We have achieved what we believe to be acceptable quality and facility with the technique after some time and effort. Thus, we acknowledge to the beginner that the commitment to learn Doppler for everyday practice is great.

Full Doppler examinations now add an average of 30 minutes to the echocardiographic examination time for sonographer and patient. As subsequent chapters will reveal, Doppler tracings are not always of high quality and may be very difficult for a physician-interpreter to understand without the assistance of the person who performed the examination. Our laboratory is organized in a way that allows the sonographer who performed the Doppler examination to be present and interact with the physician during the interpretive session.

UNDERSTANDING DOPPLER

Understanding Doppler echocardiography begins with an understanding of certain basic principles about Doppler. The first principle is that the Doppler effect can be used to examine and record flow through the heart. The second principle is that a Doppler machine is a device specifically designed to measure the Doppler effect. These principles will be discussed in detail in Chapter 2.

The next step is to understand a bit of the history of Doppler echocardiography, for the technique is not new. The physical principles involved in its use have been understood for well over a century, and Doppler has been used in echocardiography for over 25 years. A brief review of the history of Doppler helps us to understand its current role in the noninvasive laboratory.

THE DOPPLER EFFECT DESCRIBED

The first scientific description of the physical principle commonly termed the "Doppler effect" is credited to Johann Christian Doppler, an Austrian mathematician and physicist who lived during the first half of the nineteenth century. In 1842, Doppler read a paper before the Royal Bohemian Society of Learning[1] in which he postulated that certain properties of wave phenomena (such as light or sound) depend on the relative motion of the observer and the wave source. Unfortunately, he followed an accurate description of the Doppler effect with the suggestion that the colored appearance of certain stars was caused by their motion relative to the earth, the blue ones moving toward earth and the red ones moving away. Thus, despite his correct description of the principle, he drew some erroneous conclusions, largely because of a misunderstanding about the composition of the electromagnetic wave spectrum, of which visible light is a part.

Accordingly, the Doppler effect drew great criticism at first. Experimental verification of the principle was difficult, since there was little instrumentation available at the time to accurately measure the frequency of any light or sound wave.

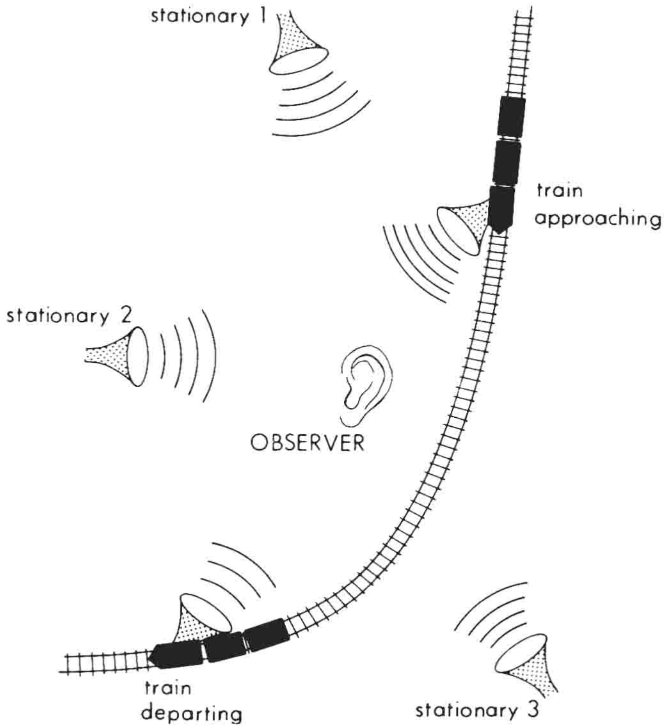

FIG. 1.1 A schematic recreation of the experiment of 1845 which proved the Doppler hypothesis. The observer with perfect musical pitch heard the sounds emanating from three stationary trumpets, each playing the same note. As the trumpeter on the approaching train played the note, it sounded higher pitched to the observer. From the train departing, the note sounded lower in pitch.

The ingenuity of one of Doppler's critics provided a means for the first known experimental test of the hypothesis in 1845 (Fig. 1.1). The "measurement instrument" used was an observer with the ability to describe the absolute pitch of musical sounds. This person compared the pitch of a trumpet sounded from several stationary positions with the pitch of a trumpet sounded from the top of a moving railroad car. He concluded that the sounds from the various stationary trumpets all had the same pitch, whereas the pitch of the moving trumpet increased as it approached and then decreased as it moved away from him, just as Doppler had predicted.

As often happens in the scientific community, the same hypothesis was independently put forward by H. Fizeau, a French physicist, and John Scott Russell, a British scientist, in 1848. In 1868, the British astronomer, William Huggins, presented the idea again. Huggins and subsequent workers demonstrated the correctness of Doppler's hypothesis in the realm of light and sound. In this century, the Doppler effect has become a major tool in astronomy.

Among other things, the "big bang" theory of the origin of the universe is based in part on observations using the Doppler effect.

THE DOPPLER EFFECT AND SOUND WAVES

There was little practical application of the Doppler acoustic effect until the second decade of this century. The sinking of the Titanic by an iceberg in 1912 sparked an interest in developing some method for detecting underwater objects. The advent of submarine warfare in World War I made the development of such instruments necessary, and practical sonar devices came into being.

Sonar developed as a technique which used reflected sound waves to detect objects underwater. Research on sonar between the two world wars provided important advances in transducer technology as well as improved understanding of the principles of ultrasound generation and reception. At the same time, intensive research was being carried out on the use of radio waves for detecting flying objects; the result was radar.

MEDICAL APPLICATIONS

Following World War II, the technological advances of sonar concerned with ultrasound generation and transducer design were joined with the methods of pulsed echo generation and signal processing from radar to produce the earliest ultrasound machines for medical use.

Pioneering work in the early 1950s culminated in the report of 1954 by Edler and Hertz[2] describing the first M-mode echocardiograph system for imaging cardiac structures. Interestingly, the first medical Doppler instrument was built in Japan by Satomura[3] in 1955 and described in a report published 2 years later. During the later 1950s and early 1960s, Doppler instruments were developed by Franklin, Rushmer, Baker, and their colleagues[4–6] that measured mean or average blood flow velocity.

Although the use of ultrasound for imaging the heart rapidly advanced through M-mode to two-dimensional echocardiography, the interest of the medical community in Doppler did not develop concurrently. During the 1960s, work by McLeod,[7] Baker et al.,[8] Peronneau et al.,[9] and Wells[10] resulted in pulsed Doppler systems for medical use that were able to examine the direction of blood flow and localize qualitative disturbances of flow in selected areas of the heart.

During the same period, Light,[11] Kalmanson et al.,[12] and others were in the process of developing continuous wave Doppler ultrasound for medical use. By 1980, the main accomplishments of pulsed and continuous wave Doppler echocardiography were in the investigation of patterns of blood flow in the heart and great vessels. Doppler could be used to differentiate abnormally fast from normal blood velocity. It provided a detector for the presence of valvular lesions, both stenosis and regurgitation, and for the presence of common congenital lesions such as atrial or ventricular septal defects.

What standard echocardiographic methods were for visualization of cardiac anatomy, Doppler was for the assessment of flow through the heart. Still, the general popularity of Doppler echocardiography could not keep pace with its imaging counterparts. Worldwide applications of M-mode and two-dimensional echocardiography boomed, whereas Doppler had its support among only a few determined individuals who saw its potential.

The limitations of Doppler echocardiography that prevented its more general use were many. First, the sensitivity of the early systems, especially in the realm of signal processing, was limited, and determination of absolute blood flow velocity was not easy. Second, system records of disturbed flow were poor, and Doppler examiners were generally limited to the audio output of the instrument for use in diagnostic studies. Third, Doppler studies were generally conducted in a blind fashion or with crude M-mode images, since interfaces of Doppler instruments with two-dimensional instruments had not yet been readily accomplished. Combined with the difficulty physicians had in understanding the nature of Doppler-detected flows, these factors made Doppler less appealing when compared with two-dimensional echocardiography.

DOPPLER TODAY

Today, however, there is a great deal of excitement concerning the clinical applications of Doppler. Much of this can be attributed to the efforts of Hatle and Angelsen[13] to make Doppler readily understandable to physicians and applicable to clinical care of patients. Doppler can now give reliable information about flow velocities through the heart. New developments in electronic components have provided the means to achieve excellent sensitivity in most instruments, making detection of normal and disturbed flows easier. Likewise, recent technological advances have made it feasible to generate spectral velocity recordings that serve as a permanent record of the Doppler study. In addition, interfaces with the two-dimensional echocardiographic system are providing means for physicians and sonographers to familiarize themselves with the relationships between anatomy and blood flow through the heart. Finally, based upon the work of early pioneers in the field, there is now a general agreement that Doppler echocardiography provides unique information regarding the patterns of normal and abnormal blood flow and estimates of pressure gradients and output that, heretofore, were not obtainable in a noninvasive way.

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