A Historical Review of Echocardiographic Detection of Pericardial Effusion

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EARLY WORK:

Great scientific events happen quietly, often without recognition by one's contemporary colleagues. It is only with a historical perspective that one can see how a new technique or way of thinking could open a new era of diagnostic expertise. Such was the case of echocardiography and the noninvasive diagnosis of pericardial effusion.

The first echocardiograms of pericardial effusion were published by Dr. Inge Edler and Dr. C. H. Hertz of Sweden in 1954.^{1),2)} A representative echocardiogram is shown in Figure 1. The echogram was recorded on an industrial ultrasound reflectoscope used for nondestructive flaw detection in solid metals. In later studies, an electrocardiogram was reflected from the electrocardiograph to the ultrasonoscope's cathode ray tube via a mirror. Continuous film recording was achieved with a camera mounted in front of the oscilloscope. The origins of reflected sound from different parts of the heart were experimentally identified with preparations of isolated calf and cadaver hearts.^{2),3)} Echocardiographic inscriptions of the presumed anterior and posterior ventricular wall movements from living patients were correlated with their roentgenograms.³⁾

The potential clinical use of reflected ultrasound detection of pericardial effusion behind the living heart did not appear in the American literature until 11 years later in 1965.⁴⁾ Feigenbaum and associates had recorded systolic movement of the canine posterior left ventricular wall on an ultrasonoscope borrowed from the Neurology Department at Indiana University Medical Center. Small quantities of saline were injected into the pericardial sac via an indwelling catheter while continuously monitoring echographic posterior wall motion. Appearance of another, immobile echo indicated separation of the posterior wall from the pericardium. The saline was represented by the echo-free space between the echoes reflected from the mobile posterior ventricular wall and the immobile pericardium. Representative echographic patterns of motion are shown in Figure 2.

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Fig. 1. One of the first echocardiograms of progressive accumulation of pericardial effusion. Tracing represented fluid separating anterior right ventricular wall from inner chest wall. (Reprinted with permission: Edler I, Hertz CH.: The use of ultrasonic reflectoscope for the continuous recording of the movements of heart walls. Kugliga Fysiografiska Sällskapets i Lund förhandlingar. Bd. 24. Nr. 5, March 10, 1954).

Fig. 2. Echocardiograms from a patient with anteriorly and posteriorly distributed pericardial effusion. (Left panel): A-mode echogram from patient. Cardiac movement could not be appreciated on photograph. (Right panel): M-mode echogram from same patient. Space separating posterior wall echo (PW) from pericardium (P) represented small quantity of pericardial effusion. T=transducer; AW=anterior wall. (Reprinted with permission: Feigenbaum H, Zaky A, Waldhausen JA: Use of ultrasound in the diagnosis of pericardial effusion. *Ann Intern Med* 65(3): 443-452, 1966, Fig. 4, p. 447).

Aspiration of the saline from the pericardial sac allowed the immobile echo (pericardium) to move closer to and finally fuse with the echo which moved with cardiac systole (posterior wall). These investigators predicted that “. . . *this technique (reflected ultrasound) promises to be highly sensitive as well as reliable in detecting pericardial effusion.*”⁴⁾

These preliminary studies⁴⁾ were followed by confirmation of their clinical usefulness.^{5),6)} The presence of pericardial effusion was proven by pericardiocentesis, surgery, autopsy, cardiac catheterization, angiography, intravenous carbon dioxide radiographic techniques or a chest scan using intravenous radioactive albumin.

DEVELOPMENT OF EXAMINATION TECHNIQUES:

Following Feigenbaum's first description of techniques for echocardiographic examination for pericardial effusion,⁵⁾ use of this method rapidly gained popularity. The equipment was portable to the bedside of critically ill patients and without X-ray exposure to either the patient or the examiner. The patient could be examined in a supine or sitting position and usage of physician time was minimal—“*five minutes.*”⁷⁾

As of 1968, the echographic representation of pericardial effusion remained unchanged from Dr. Edler's and Dr. Feigenbaum's early work. The technique of examination was, however, becoming less simplistic and for the first time authors indicated that the technologist^{10),11)} and physician¹³⁾ must be well trained to obtain diagnostic echograms and interpret them correctly.

Echocardiographic landmarks had not been established. Reflected echoes from the mitral annulus and ventricular septum had motion patterns similar to those reflected from the anterior and posterior ventricular walls. Investigators described potential sources of misinterpretation due to “*error in technic*”⁷⁾ presence of pleural effusion,⁸⁾ and intrapericardial thrombus,¹⁰⁾ whose echograms resembled pericardial effusion. The quantity of separation between the visceral and partial pericardiums, as an estimation of pericardial fluid volume, was not correlating well with estimates of volume derived by other methods.^{7),9),10)} However, the technique was found to be sensitive for detection of at least 40 or 50 cc of intrapericardial fluid.^{11),12)}

Evidence of experimentation with the transducer's position and angulation, and altered instrument settings appeared suddenly.^{17),18)} Landmarks were definitively established. One had to simultaneously record the left side of the interventricular septum and the endocardial and epicardial-pericardial interfaces of the posterior left ventricular wall at mid-ventricular level. Angulation of the transducer toward the patient's midline was (and is)

discouraged during examination of the left ventricle with M-mode echocardiography.

These technical requirements served to eliminate many potential false positive effusions due to unwitting recording of the mitral annulus or posterior mediastinal structures.¹⁹⁾ While recording, damping (pulse voltage) was changed from maximum to minimum to isolate pericardial echoes from the ventricular myocardium. Echo-free space between moving and nonmoving structures represented pericardial effusion (Figure 3).

Patients were altered from a supine position to a partial left lateral decubitus position. The transducer occupied other intercostal spaces and it was no longer held stationary during recording. Optimal mid-left ventricular studies were obtained by angling the transducer from the aorta toward the apex or scanning.²⁰⁾⁻²²⁾ Accidental slowing of the paper recording speed during a routine scan produced compressed scans which optically improved

Fig. 3. Echocardiogram from patient with (A) small pericardial effusion and (B) marked increase in quantity of fluid seen three months later. A: Echoes reflected from interventricular septum were required in routine study of left ventricle and evaluation for pericardial effusion. Signal attenuation (damping) was changed rapidly from maximum to minimum during photographic recording. Purpose of damping was threefold: to isolate pericardium; then add echoes from endocardial and epicardial interfaces; then fill in myocardial tissue. B: A large quantity of pericardial effusion allowed heart to oscillate freely. Only anterior and posterior wall and some portion of posterior papillary muscle were evident. All structures moved in unison. (Reprinted with permission: Feigenbaum H: Echocardiographic diagnosis of pericardial effusion. *Am J Cardiol* 26: 475-479, 1970).

our appreciation of the spatial distribution of posterior pericardial effusion.¹⁸⁾ Concurrent presence of pleural effusion suspended the pericardium between the two fluids (Figure 4).

CLINICAL USE AND INTERPRETATION:

Unrestricted cardiac movement within extremely large pericardial effusions was regularly described.^{10),33),34)} Using techniques of M-mode scanning,^{18),21)} LeMire,³⁴⁾ Greene,³⁵⁾ Martin,³⁶⁾ and their respective associates demonstrated echographic evidence of pericardial effusion located behind the left atrium (Figure 5). Effusions in this area were previously thought to be limited to pleural effusion.^{20),37),38)} This fluid accumulation was possible through an anatomical communication between the pericardial cavity and the oblique pericardial sinus.^{38),39)}

In a few laboratories, the echogram was used to assist localization and distribution of pericardial fluid prior to pericardiocentesis, thus eliminating "*. . . the necessity for stand-by X-ray equipment or moving the patient to the X-ray department.*"¹⁰⁾ Echocardiography was incorporated into the actual procedure of pericardiocentesis by Goldberg and Pollack.^{15),16)} While monitoring echographic displays of pericardial effusion, an aspiration needle was positioned through a central lumen in the transducer. The relationship between the tip of the needle and the cardiac epicardium could be monitored continuously during aspiration of effusion from the supine or sitting patient.

The sensitivity and specificity of echocardiographic diagnosis of pericardial effusion was re-assessed by Horowitz and associates.²³⁾ These investigators re-affirmed that "*. . . the classic pattern of an echo-free space persisting throughout the cardiac cycle between the epicardium and a poorly moving or flat pericardium relative to the epicardium was always associated with more than 15 ml of pericardial fluid.*"²³⁾ Further attempts to quantitate pericardial fluid volume have not progressed beyond designations of small, moderate and large.^{32),42)} "*The existance of a large anterior separation was associated with a moderate to large pericardial effusion only in the presence of a large posterior echo-free space.*"²³⁾ However, large anterior separations between the right ventricular wall and chest wall, in the absence of posterior effusions were later shown to be associated with intrapericardial cysts.²⁴⁾ This kind of echographic presentation was also consistent with a fluid-tissue tumor,^{25)-29),51)} epicardial fat or loculated pericardial fluid.²⁹⁾

In 1969, Feigenbaum considered the potential for characterization of the pericardial effusion when he indicated that "*any particulate matter, including red blood cells, will produce echoes if the sensitivity is high enough.*"¹³⁾ When the sensitivity is adequate to visualize the ventricular myocardium, homogeneous

Fig. 4. Patient with pericardial and pleural effusion showing parietal pericardium suspended between both fluid mediums. EN=endocardial surface of posterior left ventricular wall; LS=left septum; MV=mitral valve motion; PERI EFF=pericardial effusion. (Reprinted with permission: Chang S: M-MODE ECHOCARDIOGRAPHIC TECHNIQUES AND PATTERN RECOGNITION. Lea & Febiger, Philadelphia, 1976).

Fig. 5. A 76-year-old male with large pericardial effusion extending into oblique pericardial sinus located behind posterior left atrial wall. PE=pericardial effusion; EN=endocardial surface of posterior left ventricular wall; AO=aorta; LA=left atrium.

fluid remains relatively echo-free. Semisolid, or liquid fluid with free-floating particulate inclusions continuously prove to be echo-reflective, at least as much or more so than the ventricular myocardium.^{18),30)-32),51)} Of more importance has been the increased echo-reflectiveness of the visceral and parietal pericardiums and unity of movement in the presence of fibro-adhesive disease.^{23),51)} Figure 6 demonstrated thickening of the pericardium and probably adhesion between the visceral and parietal pericardiums. Figure 7 showed increased echo-reflectiveness from both the visceral and parietal pericardiums. Fibro-adhesive pericardial disease was subsequently proven with surgery.

Reports of unsuspected pericardial effusion increased as echocardiographic skills and recording equipment improved. Riba and Morganroth⁴⁰⁾ found echographic evidence of pericardial effusion in 189 of 1,225 consecutive patients. Analysis was applied to 111 of these patients in whom pericardial effusion was clinically unsuspected in 68 or 61%. Sixty percent (41/68) of these patients had underlying organic heart disease. These clinically un-

Fig. 6. A 30-year-old male; 8 days after removal of two mediastinal abscesses secondary to dental abscess. There was echographic evidence of a thickened pericardium (arrows) when echoes were attenuated. At surgery, pericardium was thickened with inflammation of pericardial surface. Very little effusion was present. Pericardial aspiration and window were not done. (Reprinted with permission: Chang S: ECHOCARDIOGRAPHY: TECHNIQUES AND INTERPRETATION. 2nd ed, Lea & Febiger, Philadelphia, 1981).

Fig. 7. A 58-year-old male; chronic renal failure, amyloidosis, anemia, hypertension. Echocardiogram showed pericardial effusion (PE) distributed along anterior and posterior cardiac borders. Increased echo-reflectiveness from pericardium and epicardium suggested thickening of these structures. Progressive constrictive pericarditis required surgical removal of thickened parietal pericardium and thickened, constrictive epicardium (epi). RV=right ventricle; LV=left ventricle; MV=mitral valve motion.

suspected effusions were evaluated within the clinical setting and were considered to be hemodynamically insignificant.⁴⁰⁾ Berger and colleagues⁴¹⁾ reviewed echographic records on 2,106 patients and found 178 patients (8.5%) with pericardial effusion. The effusion was unsuspected in 41% (70/171). The majority of these patients also had underlying organic heart disease, with and without congestive heart failure.

While quantitation of pericardial fluid volume remained equivocal, evaluation of fluid distribution was much more accurate with application of two-dimensional echocardiographic techniques.^{29),36),45)-49)} Using a variety of cross-sectional views, one can identify areas of greatest fluid accumulation and monitor total cardiac movement within the fluid. Two-dimensional echocardiography has been ideal to identify areas of compartmentalization within the pericardial fluid.^{50),52)} Its clinical utility was demonstrated in a

patient whose early echographic evidence of effusive-adhesive pericardial disease progressed into constrictive pericarditis requiring surgical pericardectomy (Figures 7, 8).⁵²⁾

SUMMARY:

The 26 year history of echocardiographic detection of pericardial effusion ideally demonstrates the scientific method. The initial observations by Edler and Hertz in 1954 lead to animal experiments by Feigenbaum⁴⁾ and Soulen³⁷⁾ many years later. Human applications were confirmed again and again with cardiac catheterization, surgery, autopsy and radiologic procedures. Older

Fig. 8. Two-dimensional, long-axis, apical echocardiograms from same patient whose M-mode echogram appears in Figure 7. (March 26), A large quantity of pericardial effusion with adhesive strands (arrowheads) separated lateral left ventricular wall from pericardium. (April 3), Quantity of pericardial effusion decreased following aspiration of 200 ml sanguineous fluid. Adhesions were still present and more echo-reflective. (April 10), Individual adhesive strands were poorly differentiated. More echo-reflective material appeared in effusion. Patient developed clinical cardiac tamponade each time hemodialysis was attempted. Patient was referred to surgery for pericardectomy at which time the pericardium was found to be adherent to underlying structures consisting of grumous material and a tough, constrictive epicardium. (Reprinted with permission: Chang S, Chang JK: Progressive constrictive pericarditis. in RECENT ADVANCES IN ULTRASOUND DIAGNOSIS, II. International Congress Series, No. 498. Proceedings of International Symposium on Recent Advances in Ultrasound Diagnosis. Excerpta Medica, Amsterdam, 1980).

methods of effusion detection were compared to this new and noninvasive method and found lacking. Echocardiography has been a safe, reliable and accurate method to establish the presence of pericardial effusion in the symptomatic and asymptomatic patient.^{22),23)} It has been used as the diagnostic standard for other detection methods.⁵³⁾⁻⁵⁵⁾ Investigators and clinicians are now utilizing echocardiography to explain cardiac physiology when pericardial effusion is present; and to follow the effects of their therapeutic interventions. While the presence of pericardial effusion has proven to be more prevalent than expected, the pathologic and hemodynamic significance of unsuspected effusion has not yet been established. Experimental and clinical studies are continuing with the aid of computerized technology for data retrieval and analysis. Thousands of patients are examined yearly with echocardiography and their statistics roll from the pages of scientific and clinical publications. The world's literature is at one's fingertips. But—the echocardiogram and its derived data are only as good as the knowledge and skill of the examiner, technologist and physician alike who “. . . *must understand the physics of ultrasound, the operation of a complex electronic instrument, the nature of intracardiac anatomy, and clinical cardiology as well as echographic manifestations of normal and disease conditions. Information can seldom be extracted retrospectively from the echocardiogram that was not deliberately depicted at the time of the examination.*”²²⁾

More than a quarter of a century has honed present day skills to record and interpret echocardiographic tracings of pericardial effusion. Yet, it is sobering to consider how primitive our best efforts are compared to methods still unknown which will be used by technologists and physicians fifty years from now.

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