The Displacement Cardiograph

A Noninvasive Technique for Recording Myocardial Wall Motion

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SUMMARY The displacement cardiograph (DCG) is a noninvasive device employing an electromagnetic field to record tissue motion within the body. The sensing coil need not be in contact with the patient since the field penetrates air and stationary tissue without significant distortion. Disturbances in the field which result from ventricular wall motion are electronically converted to an analog output and a pattern inscribed on the paper of a physiological recorder. In an attempt to determine the reliability of the DCG in detecting regional areas of abnormal left ventricular wall motion, displacement cardiograms were obtained from 70 patients who underwent cardiac catheterization and left ventriculography. The DCG interpretations were in agreement with the ventriculographic picture of left ventricular wall motion in 67 of the 70 patients. There were two false positive and one false negative DCG diagnoses. The results indicate that the DCG can be employed as a reliable noninvasive method for repetitive assessment of the pattern of contraction of the anterior, anterolateral and posterior left ventricular wall.

LEFT VENTRICULOGRAPHY has become firmly established as the most accurate technique for the detection of segmental myocardial dysfunction. However, cardiac catheterization and left ventriculography entail risks inherent in any invasive diagnostic procedure.

As early as 1875, Marey described a method to record chest wall movement which he believed was a reflection of cardiac motion. His technique and subsequently more sophisticated instruments such as the apexcardiograph and the kinetocardiograph are restricted to recording only those vibrations which are transmitted to the precordium.

In an attempt to overcome the limits imposed by these techniques, other studies utilized electrical fields to detect myocardial signals (Geselowitz, D., personal communication). However, these methods were not extensively adopted because of lack of other reliable techniques for evaluation and interpretation of the results. For example, these techniques were not compared with hemodynamic catheterization or angiocardiography.

The displacement cardiograph (DCG), which was introduced in 1967, is a noninvasive device which exploits an electromagnetic field for recording tissue movements within the body without any physical contact with the patient. Studies in animals have shown that the DCG tracing is not significantly influenced by chest wall tissue. The recordings from the intact chest are similar to those obtained after removal of precordial skin and soft tissue down to the rib cage. The penetration of the electromagnetic field and proof that the DCG recording is not dependent upon transmitted impulses to the precordium has been presented in a previous report. The DCG tracings from human subjects were not altered when surface movement of the chest was eliminated by pressing a rigid plexiglass plate firmly against the precordium.

The present study was therefore undertaken to determine if the DCG could be employed as a reliable method to detect regional areas of abnormal ventricular wall motion.

Methods

The Instrument

The sensing device is a 100 mm diameter planar spiral coil which is part of a high frequency, low power oscillator. A plexiglass frame containing the coil is strapped to the body so that the coil is located 0.5–2.5 cm from the patient's chest (fig. 1A). The coil need not be in contact with the chest wall because it has been shown that the electromagnetic field of the DCG is not significantly distorted by stationary tissue or an air gap of up to 2.5 cm.

Motion of the segment of ventricular wall underneath the coil distorts its electromagnetic field, thereby changing the frequency of the oscillator F₀ (fig. 1B). This frequency is compared with Fₕ, the frequency of a reference oscillator inside the instrument. The output from the comparator (mixer) has a frequency F₄ where F₄ represents the difference of the two frequencies (i.e., F₄ = Fₕ - F₀). This frequency difference is fed to a frequency-to-voltage converter. The converter output-voltage is then amplified and appears as an analog output. Baseline control of this output is achieved by varying F₀ automatically through a low-pass feedback network.

Clinical Studies

The displacement cardiograms were recorded with a simultaneous lead II ECG and second left intercostal space phonocardiogram from 70 patients who had cardiac catheterization and left ventriculography within 48 hours of the noninvasive study. These were 45 males and 25 females ranging in age from 16 to 75. The sex distribution and the
final diagnoses are shown in Figure 2. The six normal subjects were patients who were referred for cardiac catheterization and angiography because of clinical suspicion of cardiac disease. All 70 patients had DCG recordings from areas corresponding to electrocardiographic positions V₄ and V₅₆. These positions were chosen to use the electrocardiogram as evidence that the probe was placed over the left ventricle. The possibility of recording posterior left ventricular wall motion was not appreciated early in the study. Later it became apparent that satisfactory recordings could be obtained from the posterior left thorax. Therefore, the last 21 patients in this series had displacement cardiograms taken with the sensor placed 2 inches below the tip of the left scapula. The DCG, ECG and phonocardiogram were recorded on photographic paper of an Electronics for Medicine DR-8 multichannel physiological recorder at a paper speed of 100 mm/sec with 0.02 second time lines. All records were taken with the breath held at the end of normal expiration, while the DCG gain was adjusted to obtain maximum amplitude. Left ventricular cineangiograms were obtained in the 25° right anterior oblique and 45° left anterior oblique projections after the injection of 30 cc of 76% sodium and meglumine diatrizoates. The study was designed to employ a strict double blind method for data analysis. The ventriculograms were analyzed by two cardiologists, and infrequent discrepancies in interpretations were resolved by a third. The DCG tracings were interpreted independently by a fourth investigator, who had no knowledge of the clinical diagnosis or ventriculographic findings. The correlative analysis was undertaken after compilation of the independent analysis.

**Figure 1** A) The displacement cardiogram (DCG) sensor is a spiral coil in a plexiglass frame. There is an air gap between the skin and coil. B) Block diagram of the DCG.

**Figure 2** Sex distribution and final diagnosis of 70 patients in this study. F = female, M = male, CAD = coronary artery disease, MVD = mitral valve disease, MCP = myocardiopathy, AVD = aortic valve disease, ASD = atrial septal defect, Nor. = normal.

**Figure 3** Normal DCG pattern from the anterior (A), anterolateral (B), and posterior (C) ventricular wall. Movement toward the chest wall is recorded as an upward deflection and movement away from the chest wall is indicated by a downward deflection.
The characteristic normal DCG patterns from the anterior, anterolateral and posterior left ventricular wall are shown in figure 3. Tracing A was recorded from the V₄ position, tracing B was obtained from the V₆ position, and tracing C was recorded with the probe placed 2 inches below the tip of the left scapula. Earlier reports have been concerned only with the DCG tracing from the apical area.¹⁴⁻¹⁶

In early systole there is movement toward the sensor, which is recorded as an upward deflection on the graph. The amplitude of this wave is most pronounced near the cardiac apex (fig. 3A) and is less apparent in other areas (fig. 3C). This brief outward motion is followed by movement away from the sensor and chest wall during the ejection phase of left ventricular systole.

Figure 4 shows the DCG and tracing of the left ventriculogram of a patient with an akinetic area of the posterior left ventricle. The DCG shows essentially no movement during ventricular ejection.

Figure 5 illustrates the DCG and left ventriculogram from two patients with segmental dyskinesia or paradoxical systolic expansion of a portion of the ventricular wall.¹, ² The DCG reflection of this type of asynergy is a mid or late systolic (fig. 5A) or pansystolic (fig. 5B) outward bulging.

Results

The characteristic normal DCG patterns from the anterior, anterolateral and posterior left ventricular wall are shown in figure 3. Tracing A was recorded from the V₄ position, tracing B was obtained from the V₆ position, and tracing C was recorded with the probe placed 2 inches below the tip of the left scapula. Earlier reports have been concerned only with the DCG tracing from the apical area.¹⁴⁻¹⁶

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Figure 6 represents another pattern from a very localized area of disordered contraction. Both the DCG and the left ventriculogram showed apparent normal motion in early systole and a paradoxical outward movement in late systole.

Figure 7 is the DCG and the tracing of the left ventriculogram from a patient with asynchronous contraction of the anterolateral wall. The ventriculogram demonstrated two separate bulges at different times during systole, and the DCG tracing accurately represented this abnormality as two separate upward deflections in mid and late systole.

The DCG correctly identified 42 of 43 areas of anterior wall dyskinesis, but defined one as normal. Fourteen of 14 angiographically dyskinetic apices were correctly identified by the DCG. Akinesis of the anterior wall was detected by both methods in six cases. One angiographically akinetic area near the apex was considered dyskinetic by the interpreter of the DCG. Five of six normal anterior walls as defined by the ventriculograms were normal by DCG criteria, whereas one appeared dyskinetic. Dyskinetic areas of the posterior wall were found in six patients by both the DCG and left ventriculogram. Four patients with akinetic areas of the posterior wall were found with both techniques. The ventriculograms of 11 patients showed normal posterior wall motion. The DCG was normal in ten of these, but defined one as akinetic.

When judged against the left ventriculogram, the DCG had an error of one false positive and one false negative in the anterior and anterolateral wall. It also had one false positive diagnosis in the posterior wall motion analysis.

**Discussion**

Interest in the detection of segmental abnormalities of left ventricular contraction resulted from studies that indicated that localized areas of asynergy were related to anatomical areas of myocardial ischemia. Regional areas of abnormal contraction that can be responsible for hemodynamic disturbances leading to heart failure have also been found in patients with cardiomyopathy, rheumatic heart disease and other conditions which cause ventricular hypertrophy.

Previous attempts to define asynergy by noninvasive methods have not produced uniformly satisfactory results. Apexcardiography and kinetocardiography, based upon recording impulses transmitted to the chest wall, have some inherent limitations. The apexcardiogram gives information from a limited area, and obesity, variations in chest wall configuration, and lung disease may preclude a satisfactory
Kinetocardiograms yield information from larger areas of the heart and the technique is not as severely limited by obesity or pulmonary disease. However, the large volume of lung between the posterior chest wall and the heart prevents satisfactory kinetocardiographic recording of movement of the posterior left ventricle. Echocardiography can detect some areas of abnormal left ventricular contraction. Conventional M-mode scans have the inherent limitation of a narrow beam one-dimensional system, while two-dimensional echocardiographic instruments have the advantage of simultaneous recording of movement of contiguous areas. However, all reflected ultrasonic techniques are restricted by the failure of ultrasound to adequately penetrate air and air-filled lung.

In contrast to other noninvasive methods that have been used to study asynergy, the electromagnetic field of the DCG penetrates deeply into the body. Therefore, motion patterns from the anterior, anterolateral and posterior left ventricular walls can be recorded. To date, we have not encountered a patient in whom a satisfactory DCG tracing could not be obtained.

In 67 of the 70 patients in this series, the DCG tracings accurately reflected the pattern of segmental myocardial wall movement which was seen on left ventriculography. One false positive and one false negative DCG interpretation were found in the 70 patients in whom the anterior and anterolateral wall motion was studied. The DCG gave one false positive diagnosis in the group of 21 patients in whom posterior wall contraction was recorded. The minimal area of asynergy that can be detected by the displacement cardiograph was not definitely determined in this study. However, the DCG tracing and ventriculogram shown in figure 6 illustrate one of the smallest segments of abnormal wall motion found in this study. The abnormally contracting segment, measured by the technique of Feild et al. was 9% of the end-diastolic circumference. The DCG clearly depicted this relatively limited area of disordered contraction.

The DCG is an extremely focal instrument which responds to movement directly beneath the coil. All of our records were obtained with a 100 mm diameter coil, and asynergy anywhere within this area should be depicted on the recording. Theoretically, it should be possible to gain quantitative information by using a small diameter coil to outline the boundaries of an abnormally contracting segment that is detected with the 100 mm coil. Although quantitation was not attempted in this group of patients, the results of the study indicate that the displacement cardiogram is reliable as a noninvasive method to describe segmental myocardial wall motion.

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Circulation. 1976;53:139-143
doi: 10.1161/01.CIR.53.1.139
Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
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