Systolic Time Intervals by Echocardiography

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SUMMARY

Technical difficulties in recording phonocardiogram or indirect carotid pulse occasionally preclude determination of the systolic time intervals. Accordingly, an alternative method was tested in 52 patients, using high-speed strip chart recording of the aortic valve echocardiogram. Satisfactory records were obtained in 36. The interval from opening to closing of the aortic valve (ejection time) was subtracted from the interval between the Q wave of the electrocardiogram and the closing of the aortic valve (total electromechanical systole) to provide the pre-ejection period. When these intervals and the pre-ejection period/ejection time ratio were compared to corresponding values obtained by conventional methods from the simultaneously recorded phonocardiograms and indirect carotid pulses, a high degree of correlation ($r > 0.97$) was found. Differences between the two methods for each interval were insignificant, being greatest in the case of the ejection time but never exceeding 16 msec. These findings indicate that the echocardiogram of the aortic valve provides an alternative, noninvasive method for determination of the systolic time intervals whenever the usual methods fail.

Additional Indexing Words:
Aortic valve echocardiogram Ultrasound

THE DURATION of the phases of left ventricular systole is thought to provide useful information concerning the performance of the left ventricle. Although these so-called “systolic time intervals” can now be retrieved at the bedside in most instances, they are unobtainable in certain patients because of technical difficulties in recording either the heart sounds or the indirect carotid pulses. An alternative noninvasive method, therefore, seemed desirable.

The movements of one or two of the aortic valve cusps can be traced with high-frequency pulsed ultrasound and photographed. Apart from their diagnostic value, such recordings provide evidence of the precise moment of the opening and closing of the aortic valve, and therefore, together with simultaneous electrocardiogram, they should also permit determination of the systolic time intervals.

After this study was launched Hirschfeld et al. reported excellent correlation between systolic time intervals calculated by echocardiography and the conventional methods in 25 children. Similar findings have also been reported recently by Vredevoe et al. The data which follow confirm their success and extend the test group to patients with a wide range of diseases and states of myocardial function.

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Received July 22, 1974; revision accepted for publication September 3, 1974.

Methods

Thirty-six patients (21 males, 15 females), whose age ranged from 8 to 92 years (average 32.8), formed the study population. Their clinical diagnoses were: congestive cardiomyopathy (8), systemic hypertension (7), rheumatic valvular heart disease (4), chronic renal failure (3), atrial septal defect (2), patent ductus arteriosus (2), ventricular septal defect (1), systemic lupus erythematosus (1), Hodgkin's disease (1), sickle cell anemia (1), acute glomerulonephritis (1), prolapsed mitral valve (1), mitral valve prosthesis (1), and no heart disease (3). The only criterion for selection was the ability to obtain aortic valve echocardiograms with easily identifiable points of opening and closing of the valve. This was not possible in an additional 16 from the original group of 52 patients in which the study was initially attempted.

Studies were conducted with the patient in the supine position during held expiration or (in a few cases) continuous shallow respiration, and consisted of simultaneous recording of the following: (1) electrocardiogram (ECG), lead I or II; (2) phonocardiogram, at medium or high frequency filter zone, from the area with the loudest aortic component of the second heart sound; (3) indirect carotid pulse, using a funnel-shaped sensing head connected to the transducer by air-filled tube, and manually held over one carotid artery; (4) echocardiogram of the aortic valve, using a Smith Kline Ekoline 20 Diagnostic Ultrasonoscope equipped with a 2.25 MHz focused transducer (Model C-12) and connected with the echocardiographic module of a Cambridge Multichannel Physiological Recorder. All four tracings were recorded on the same photographic strip.

*Cambridge pulse transducer (#53642) with a time constant > 1.6 sec.
†Smith Kline Instruments, Palo Alto, California.
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chart at paper speed of 100 mm/sec (34 patients) or 75 mm/sec, with timelines 0.04 sec apart.

The technique of recording the echocardiogram of the aortic valve has been described by Gramiak and Shah and by Feigenbaum. The transducer was placed on the anterior chest wall, close to the left sternal border, at the intercostal space (usually the third or fourth) from which the mitral valve echocardiogram could be obtained with the transducer pointed directly posteriorly (position 1). With this contact point kept steady, the transducer was tilted first inferiorly and laterally where the echocardiogram of the left ventricular cavity could be seen on the oscilloscope (position 2), and then superiorly and medially toward the lower angle of the right scapula until the echoes from the anterior and posterior aortic wall could be seen as two parallel thick lines 3–5 cm apart, moving anteriorly during systole and posteriorly during diastole (position 3). In moving from position 2 to positions 1 and 3, the transducer described a sector lying on an imaginary plane perpendicular to the surface of the bed and oriented obliquely, along an axis between the right shoulder and the left iliac crest. From position 3 small adjustments in the angle of the transducer were usually necessary to visualize the echoes from the valve cusps which are about halfway between the echoes from the anterior and posterior aortic wall. Throughout the examination a very gradual depth compensation slope was employed, starting close to the transducer artefact and ending (maximum compensation) 20 or more cm away from the chest wall. The reject control was set at step 1 which provided better recording of the weak aortic valve echoes but also allowed flooding of the background by “noise” echoes. Whenever the latter jeopardized easy recognition of crucial areas of the aortic valve echocardiogram, a compromise was sought using step 2 of the reject control, and if this was unsuccessful, the study was abandoned.

Normal aortic valve echocardiograms have a characteristic appearance shown in figure 1. During diastole, echoes from two aortic cusps appear as either two adjacent parallel lines 1–2 mm apart or a single thick line, located about halfway between the anterior and posterior walls of the aortic root. Shortly after the onset of systole these echoes separate abruptly, one moving anteriorly and the other posteriorly, until they come close to the respective aortic wall and remain parallel to it throughout ejection. At the end of systole they come sharply together, meeting near the center of the aortic lumen, where they remain united until the next ejection. In such “complete” aortic valve echocardiograms with the “box-like” appearance, the points of separation and reunification of the two cusp echoes are easily identified and were used in this study to represent the moment of aortic valve opening and closing, respectively (fig. 1). Complete aortic valve echocardiograms, however, were obtained in only 12 of the original 52 patients (23%). In 24 (46%), the aortic valve echocardiograms were incomplete in that the opening and/or closing movement of a single cusp was absent or the opening movement of one cusp and the closing movement of the other were absent. Deletion or fragmentation of the systolic parts of the echocardiogram forming the roof and floor of the “box,” as well as of the diastolic segment, were ignored since they were not necessary for timing systolic ejection. The details of determining the moments of opening and closing of the valve on these incomplete echocardiograms are described in figure 2. In the 16 patients who were excluded, aortic valve echoes were either unobtainable or of unacceptable quality.

A representative study is shown in figure 1. Measurement of the total electromechanical systole (EMS) and ejection time (ET), and calculation of the pre-ejection period (PEP) and the PEP/ET ratio was made according to the conventional method employing ECG, phonocardiogram, and indirect carotid pulse. These time intervals were used for comparison with the corresponding systolic time intervals (EMS, ET, PEP and PEP/ET ratio) determined from the aortic valve echocardiogram, using the same cardiac cycles, as follows:

1) EMS: The interval from the onset of the Q wave of the ECG to the closure of the aortic valve on the echocardiogram;
2) ET: The interval from the opening to the closing of the aortic valve on the echocardiogram; and
3) PEP: The difference between (1) and (2), (EMS − ET).

No correction was applied for electronic transmission delay. Measurements of the various intervals were made to the nearest 0.5 mm which was equivalent to 5 msec for

![Figure 1](http://circ.ahajournals.org/)

Determination of systolic time intervals by the conventional method using phonocardiogram (PHO) and indirect carotid pulse (CAR), and by the proposed method employing the aortic valve echocardiogram which in this case is complete. An electrocardiographic lead (ECG) is necessary in both methods. The aortic valve echoes appear halfway between those of the anterior (AW) and the posterior (PW) walls of the aortic root. The opening (O) and closing (C) moments of the aortic valve are shown by the arrows. EMS and EMSe = total electromechanical systole determined by the conventional and the echocardiographic method, respectively. ET and ETe = ejection time determined by the conventional and the echocardiographic method, respectively.

Circulation, Volume 51, January 1975
Examples of incomplete aortic valve echocardiograms with their diagrammatic representation shown at the lower one-third of the picture. When the opening movement of the anterior aortic cusp (panel 1) or posterior aortic cusp (panel 2) is missing, the valve opening is defined as the point (O) where the echo of the other cusp meets with the linear extrapolation of the terminal diastolic (actually, pre-ejection) segment of the valve echo, after the onset of Q wave of the electrocardiogram. When the closing movement of either cusp is missing, the closing moment is defined as the point (C) where the echo of the other cusp joins the first diastolic segment of the aortic echogram (panels 1 and 3) or its extrapolation (panel 2). A and P refer to echoes of the anterior and posterior wall, respectively, of the aortic root.

The results are depicted graphically in figure 3. The correlation between values for the various systolic time intervals as determined by the two methods was very high. The correlation coefficient ($r$) in patients with complete aortic echograms was 0.891 for EMS, 0.995 for ET, 0.990 for PEP, and 0.991 for the PEP/ET ratio. In the group with incomplete aortic echograms, the $r$ values were 0.997, 0.986, 0.957, and 0.952, respectively. When all patients were considered together, the $r$ values were 0.997, 0.991, 0.977, and 0.980 for EMS, ET, PEP and PEP/ET ratio, respectively.

Differences between values obtained by both paper speed of 100 mm/sec and to 6.67 msec for paper speed of 75 mm/sec. The average values from at least five, not necessarily consecutive, cardiac cycles were used. Statistical analysis of the results was done on a programmed calculator* using the two-tailed Student's $t$-test for paired data. The level of statistical significance was set at $P < 0.01$. All values are given as mean ± standard error of the mean.

Discussion

The clinical usefulness of the systolic time intervals as a bedside method for evaluation of left ventricular function has been documented by several investigators. Determination of systolic time intervals currently requires analysis of high-speed simultaneous recordings of one electrocardiographic lead, phonocardiogram, and indirect carotid pulse. They are easily obtainable in the majority of cases but in certain patients several difficulties are encountered. Thus, severe pulmonary emphysema, extreme obesity, large pericardial effusion, stertorous breathing associated with faint heart sounds, or the presence of loud murmurs may preclude precise identification of the heart sounds; extreme emaciation with protuberant ribs may render application of suction microphones on the chest impossible; apprehensive children may cry continuously during the examination; and carotid pulse waves may be difficult or impossible to obtain if the neck is very short, the jugular venous pulsations vigorous, or the carotid arteries inaccessible or hypersensitive. It is for this minority that an alternative method should be useful. One additional advantage of the proposed technique is that it is not dependent on the time constant of the carotid pulse transducer and recording equipment.

The echocardiographic method also has certain limitations. Satisfactory aortic valve echocardiograms cannot always be recorded. This was true for 31% of the patients in our series. In 46% the image of the cusps was incomplete but still usable, and in only 23% was it complete. Other investigators have had comparable difficulties. Special problems may also be encountered in patients with emphysema or heavily calcified aortic valves and in exercising subjects. Cooperation of the patients in controlling respiration, and long echocardiographic strips permitting selection of these cycles which display most clearly the opening and closing of the valve, significantly enhance the chances of success.

The aortic valve echocardiogram represents a non-invasive and harmless technique, currently available in most diagnostic centers. Our data indicate that, despite its limitations, it can be successfully employed as an alternative method of obtaining systolic time intervals.
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Figure 3

Relations of various systolic time intervals determined by conventional (C) and echocardiographic methods (E). Patients with complete (crosses) or incomplete aortic valve echogram (circles) exhibit practically the same scatter. The correlation coefficients (r) refer to both groups considered together. EMS = total electromechanical systole; ET = ejection time; PEP = pre-ejection period.

Acknowledgments
The authors wish to extend appreciation to Mrs. Beryl Wilson for the excellent technical assistance provided in this study. They also acknowledge the expert secretarial help of Mrs. Yvonne Harrop and Mrs. Kitty Brittingham.

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Circulation, Volume 51, January 1975
Systolic time intervals by echocardiography.
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Circulation. 1975;51:114-117
doi: 10.1161/01.CIR.51.1.114

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

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the World Wide Web at:
http://circ.ahajournals.org/content/51/1/114

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