Measurement of Right and Left Ventricular Systolic Time Intervals by Echocardiography

By Stephen Hirschfeld, M.D., Richard Meyer, M.D., David C. Schwartz, M.D., Joan Korfhagen, U.T., and Samuel Kaplan, M.D.

SUMMARY

One of the noninvasive methods of evaluating left ventricular performance is the measurement of left ventricular systolic time intervals (LVSTI). However, noninvasive measurement of right ventricular systole by this technique has been unreliable because of the inability to accurately time the onset of right ventricular ejection. Excellent correlation of LVSTI measured from the carotid pulse and those determined from the echocardiogram was demonstrated in 15 patients. STI of the right ventricle (RVSTI) were measured in a similar fashion from the pulmonary valve echo in 11 normal children. Right ventricular ejection time (RVET) was longer than left ventricular ejection time (LVET). Right ventricular pre-ejection period (RPEP) was shorter than left ventricular pre-ejection period (LPEP).

In 15 children with transposition of the great arteries (TGA) the situation was reversed. RVET was shortened and RPEP was prolonged as the right ventricle contracted against systemic resistance; whereas, the LVET lengthened and LPEP shortened with ejection into a low pressure pulmonary circuit.

Our studies in a total of 41 patients indicate that accurate, noninvasive measurement of right, as well as left, ventricular STI can be obtained with the use of echocardiography.

Additional Indexing Words:
Left pre-ejection period  Left ventricular ejection time  Right pre-ejection period
Right ventricular ejection time  Transposition of the great arteries

NONINVASIVE TECHNIQUES have become established in the study of cardiovascular disease. With these methods valuable anatomic and physiologic data may be obtained without risk to the patient. Noninvasive evaluation of left ventricular performance has been possible by the measurement of left ventricular systolic time intervals (LVSTI). These intervals are conveniently derived from the simultaneous high-speed recording of the electrocardiogram (ECG), the indirect carotid pulse tracing, and the phonocardiogram.

Three LVSTI are conventionally measured: total electromechanical systole (QS), the left ventricular ejection time (LVET), and the pre-ejection period (PEP). QS is defined from the onset of ventricular depolarization (Q wave of ECG) to the initial high frequency vibration of the aortic component of the second heart sound. LVET is derived from the onset of the upstroke of the carotid pulse to the incisural notch, and PEP is obtained indirectly by subtracting LVET from QS.

To date, noninvasive assessment of right ventricular performance by measurement of STI has not been possible because of the inability to define accurately the onset of right ventricular ejection. The purpose of this study was to demonstrate that right, as well as left, ventricular STI can be measured noninvasively by the use of ultrasound. In addition, patients with transposition of the great arteries (TGA) were studied because they have a unique reversal of systemic and pulmonic vascular circuits, which permitted evaluation of the effect of this reversal on RV and LVSTI.

Methods

The echocardiograms were obtained with a Hoffrel 101 ultrasonoscope. Simultaneous strip chart recordings of the echocardiogram, phonocardiogram, carotid pulse tracing and ECG were obtained with a Cambridge Multichannel Physiological Recorder, Amplifier Type 72352.

The ECG lead which most clearly demonstrated early ventricular depolarization, usually the Q wave, was chosen for timing the onset of electrical systole. The phonocardiogram was recorded with a piezo-electric, high impedance microphone having a frequency band of 100 to 600 cycles per second. Recordings were made at the base of the heart in the higher frequency sound spectrum.

The carotid pulse measuring equipment consisted of an electronic amplifier driven by a piezo-electric pulse transducer. The sensing device is a plastic cone connected...
by polyethylene tubing to the crystal enclosed in a molded cylindrical body. The transducer’s time constant is greater than 1.6 seconds. The system is air-filled and permits recording of an arterial pulse of sufficiently large amplitude to clearly define its onset and the incisural notch.

A 2.25 MHz, ¼ inch outside diameter transducer, focused at 5 cm, was used to obtain the echocardiograms. The aortic valve echoes were recorded from the third or fourth intercostal space at the left sternal border, in the manner previously described by Gramiak and Shah. After recording the mitral valve, the transducer beam was directed medially and superiorly to locate the aortic cusps. The pulmonic valve was recorded from the second or third intercostal space with the sonar beam aimed laterally and superiorly.

In infants the pulmonary artery was located by rotating the transducer laterally from the aorta to the pulmonary artery without moving the transducer. If the great arteries were transposed, the aortic cusps were recorded at the left sternal border in the fourth intercostal space with the transducer directed posteriorly and superiorly. The pulmonary artery was recorded at the midalvicular line in the third or fourth intercostal space, scanning medially and superiorly.

The aortic valve echo had a characteristic box-like configuration, which permitted precise recognition of cusp opening and closure (fig. 1). The rapid departure of the fine cusp echoes from the thick, closed valve echoes marked the onset of ejection. The merging of the leaflets into a thick valve echo indicated the termination of ejection. The PEP was the interval from the Q wave of the ECG to aortic valve opening. Total electromechanical systole measured from the echocardiogram (QA) was the sum of pre-ejection and ejection time.

RVSTI were measured using the pulmonary valve echo in a manner similar to the aortic valve echo. The timing of the onset and termination of right ventricular ejection was facilitated when the anterior and posterior pulmonic cusps could be recorded simultaneously (fig. 2). However, when only the posterior pulmonic cusp could be recorded, the onset of ejection was chosen as the point of rapid posterior leaflet motion at which the closed-valve echo changed from a thick line to a very fine one (fig. 3). The termination of ejection was determined by the junction of the fine leaflet echo with the thick closed-valve echo following rapid anterior motion. RPEP was measured directly from the Q wave of the ECG to the onset of pulmonic valve opening. Right ventricular electromechanical systole (QP) was the sum of RPEP and RVET.

Validation for this method of measuring RVSTI was accomplished by obtaining simultaneous pulmonary arterial pressure tracings and pulmonary valve echoes in patients with a variety of congenital heart diseases (fig. 4). The pulmonary artery pressure tracing was obtained with a 5 French Swan-Ganz flow-directed infant angiography...
catheter,* which was connected to a P23db Statham strain
gauge. The pressure was recorded on a Cambridge
Multichannel Physiologic Recorder, which permitted
simultaneous recording of the pulmonary artery pressure
tracing and the pulmonary valve echo. RVET measured
simultaneously from the pulmonary arterial pressure tracing
and by echo differed by less than 5 msec in the nine patients
studied (table 1).

STI derived from our echocardiographic tracings were
measured at 75 mm/sec or 125 mm/sec. At a paper speed of
75 mm/sec, it was recognized that there was a potential
error of 5-10 msec,1,2 which was judged insignificant. Time
lines were recorded at 40 msec intervals. Measurements
were made during the expiratory phase of respiration in
older children. In infants with a rapid respiratory rate the
shortest STI were selected to minimize the influence of the
respiratory variation. Five separate complexes were
measured and averaged to obtain the final STI.

Patients

Forty-one patients, age 2 weeks to 14 years, were
evaluated. Group 1 consisted of 15 children with congenital
heart disease who were studied by simultaneous echocardio-
diagram, phonocardiogram, and carotid pulse tracing in
order to compare the techniques for determining LVSTI by
echocardiography and by carotid pulse tracing.

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Figure 3

Right ventricular STI as measured from the posterior pulmonic cusp
echo. RPEP = right pre-ejection period; RVET = right ventricular
ejection time, QP = right electromechanical systole; PA = pul-
monary artery. Time lines, 40 msec.

Figure 4

RVET (right ventricular ejection time) measured by simultaneous
PA (pulmonary arterial) pressure and PA echo. Time lines, 40 msec.

Group 2 was composed of 11 normal children, age 3 to 14
years, who served as controls. Pulmonary and aortic valve
echoes were obtained in order to compare RV and LVSTI.

Group 3 consisted of 15 patients, age 2 weeks to 8 years,
with transposition of the great arteries in whom both RV and
LVSTI were determined (fig. 5). Fourteen patients had
an intact ventricular septum, and the two-week-old infant had
a small ventricular septal defect. Eleven children previously
had undergone a Mustard procedure,4 and in this group the
peak systolic left ventricular pressure measured less than 45
mm Hg. One patient who previously had undergone a
Mustard procedure had a left ventricular pressure of 60 mm
Hg, which was approximately one-half of the systemic
pressure.

Echograms in the three remaining patients with

Table 1

<table>
<thead>
<tr>
<th>Patient</th>
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Abbreviations: ASD = atrial septal defect; RVET = right ventricular ejection time; VSD = ventricular septal
defect.
transposition were obtained prior to the operative repair. The peak left ventricular systolic pressure in each measured less than 55 mm Hg. No significant left ventricular outflow gradient was measured in any patient. None of the patients in Group 3 had conduction defects or congestive heart failure.

Results

Group 1 (table 2)

The LVET measured simultaneously by carotid pulse tracing and echo differed by less than 3 msec in 10/15 patients and by less than 9 msec in the remaining five. The PEP varied by 5 msec or less in 14 of 15 patients and by 7 msec in one patient.

<table>
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</table>

*Measurement in msec.

Abbreviations: QS = electromechanical systole from carotid pulse tracing; QA = electromechanical systole from echo; LVET = left ventricular ejection time; PEP = pre-ejection period.

Group 2 (table 3)

LVET was shorter than RVET in all patients. The mean LVET/RVET ratio was 0.80 (range 0.75–0.89). However, LPEP was longer than RPEP in 9/10 patients (LPEP/RPEP ratio of 1.25 and range of 0.95 to 1.95) (fig. 6). These results are in accord with data obtained by invasive studies.

Group 3 (table 4)

In each patient with TGA the ratio of the LV to
RVSTI was reversed from that of normal subjects (fig. 6). The ratio of LVET to RVET averaged 1.22 (range 1.10 to 1.33). Similarly, the ratio of LPEP to RPEP was reversed and averaged 0.52 (range 0.38 to 0.69).

Discussion

The accurate measurement of STI in infants has been limited because of the difficulty of obtaining reliable indirect arterial pulse tracings and high quality phonocardiograms. Previous studies in normal children have been confined to the measurement of LVSTI.10-12

The echocardiogram provides a reliable and sensitive method of measuring left ventricular ejection. Data obtained from this study indicated that LVSTI derived from the aortic valve echo were reproducible and demonstrated excellent correlation with simultaneous measurements from arterial pulse tracings. The echocardiogram offered the advantage that it could be performed on critically ill infants in whom the manipulation required to obtain arterial pulse recordings and phonocardiograms was contraindicated. The aortic valve echo permitted direct measurement of the LVSTI and obviated the need to record peripheral arterial pulses.

The LVSTI have been of great clinical value because they afford a rapid noninvasive method of quantitating LV performance.1-3 Myocardial failure produces a characteristic lengthening of PEP and shortening of LVET, while QS2 remains unaltered. The ratio of PEP to LVET has become a popular expression of LV performance and has been closely correlated with other measures of LV performance. Studies in adults with aortic stenosis have demonstrated prolongation of LVET and shortening of PEP which has permitted an estimation of the severity of obstruction.1, 2 Drugs such as digitalis and catecholamines have a predictable influence on STI.1, 2 The ability to easily measure LVSTI by echo promises to extend their usefulness in infants and children.

A noninvasive method for measuring RVSTI has not been described previously. The pulmonary valve echo offers a reliable means of timing the events of right ventricular systole. Although the recording of the pulmonary valve echoes has been technically more difficult than the aortic, in our laboratory it has been possible to record the opening and closure of pulmonary valve cusps in 70-80% of infants and 50-60% of older children. As demonstrated by this study, the variation of RVSTI from cardiac cycle to cardiac cycle was less than 5 msec, when measured in expiration at comparable heart rates.

The effects of the natural reversal of systemic and pulmonic vascular circuits on the right and left ventricle was observed in our patients with TGA. In simple TGA the LV empties into the low resistance pulmonic circuit while the RV ejects into the high resistance systemic circuit. Evaluation of RV function after the Mustard procedure has aroused particular interest because it has been uncertain if the RV can sustain systemic function for a normal life span.

There was a prolonged RPEP and shortened RVET in our patients with TGA. This may have been the result of the increased afterload of systemic pressure, similar to acute animal experiments in which increased afterload is known to prolong PEP and shorten LVET.13 The prolonged RPEP may also be a result of myocardial dysfunction and would indicate that the right ventricle is poorly adapted to assume the function of a systemic ventricle.

The LVSTI in TGA differed in a manner that was appropriate for the decreased afterload, for when the LV emptied into the pulmonic circuit, ejection characteristics were similar to a normal RV (short pre-ejection period and long ejection time).

Table 4

Systolic Time Intervals in Transposition of the Great Arteries*  

<table>
<thead>
<tr>
<th>Sex</th>
<th>Age (yrs)</th>
<th>LVET</th>
<th>RVET</th>
<th>LPEP</th>
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*Measurement in msec.

Abbreviations: LVET = left ventricular ejection time; LPEP = left pre-ejection period; RVET = right ventricular ejection time; RPEP = right pre-ejection period.
Our study has demonstrated that the noninvasive measurement of right, as well as left, ventricular STI can be accomplished with echocardiography. STI of the RV and LV were measured in patients with TGA and it was shown that ventricular STI were reversed when the pulmonic and systemic circuits were transposed. The ability to measure RVSTI echocardiographically should permit the noninvasive assessment of hemodynamic variables on RV function. Further refinement of this technique should allow the evaluation of the hemodynamic effects of elevated pulmonary vascular resistance, volume overload of the right ventricle, and right ventricular obstruction on RVSTI. In addition, it may now be possible to evaluate the results of subsequent surgical or pharmacologic interventions.

References

Measurement of right and left ventricular systolic time intervals by echocardiography.
S Hirschfeld, R Meyer, D C Schwartz, J Korfhagen and S Kaplan

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