Resting and Exercise Systolic Time Intervals

Correlations with Ventricular Performance in Patients with Coronary Artery Disease

By David R. McConahay, Major, MC, Carroll M. Martin, Major, MC, and Melvin D. Cheitlin, Colonel, MC

SUMMARY

Indirect systolic time intervals (STI) corrected for heart rate were compared at rest and immediately following 3 minutes of moderate supine exercise in 33 normal subjects and 32 age- and sex-matched patients with coronary artery disease (CAD). The intervals were correlated with measurements of cardiac index (CI), stroke volume index (SVI), mean pulmonary artery and wedge pressures obtained under identical conditions of rest and exercise, and with resting left ventricular end-diastolic pressure (LVEDP), LV dp/dt, exercise factor, ejection fraction (EF), and extent of CAD.

Total electromechanical systole (Q-A2m) was the same at rest in both normal and CAD groups and did not change with exercise in either group. The CAD group had a significantly longer preejection period $\text{PEP}_r$, shorter left ventricular ejection time ($\text{LVET}_r$), and larger $\text{PEP}/\text{LVET}$ at rest and exercise than the normal group. Both groups responded to exercise with a significant reduction of $\text{PEP}_r$, prolongation of $\text{LVET}_r$, and reduction of $\text{PEP}/\text{LVET}$. Significant correlations were found between these STI and SVI, CI, LV dp/dt, LVEDP, and EF, which explained the differences in STI between the normal and CAD groups. However, exercise did not improve the sensitivities of the STI in detecting disordered hemodynamics in the patients with CAD. Furthermore, the STI failed to predict reliably hemodynamic abnormalities in the individual patient which were not already clinically obvious.

Additional Indexing Words:
Electromechanical systole Preejection period Left ventricular ejection time
Phonocardiography Coronary arteriography

INDIRECT systolic time intervals (STI) are now being measured in a wide variety of cardiac disorders in an attempt to detect changes in ventricular function reflected by alterations in the temporal course of the cardiac contraction cycle. Evidence is rapidly accumulating to suggest that changes in these intervals may provide a noninvasive yet sensitive expression of disordered myocardial performance, particularly when applied serially in the individual patient. Significant correlations have been reported between various STI and stroke volume,$^{1-3}$ cardiac output,$^3$ left ventricular dp/dt,$^4$ left ventricular end-diastolic pressure (LVEDP),$^5$ extent of coronary artery disease (CAD),$^5$ and left ventricular ejection fraction and end-diastolic volume as determined angiographically.$^6,7$ If such externally derived intervals do permit an accurate quantitative estimate of these hemodynamic parameters, they would be a valuable adjunct in the bedside evaluation and outpatient management of cardiac patients. If, however, the STI provide only an imprecise

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measurement of these interdependent variables of left ventricular function, the interpretation of the intervals might actually be misleading or have limited value in the clinical setting.

This study was designed with the following objectives: (1) to establish the normal responses of the STI to moderate supine exercise; (2) to compare these responses with those obtained in patients with angiographically documented coronary artery disease; (3) to relate these alterations in resting and exercise STI to underlying hemodynamic parameters; (4) to assess whether intervals obtained immediately after exercise provide a more discriminating measure of disordered hemodynamics than do resting intervals; and finally (5) to determine if minor abnormalities in ventricular performance can be detected with STI.

Methods

Indirect STI were determined at rest and immediately following exercise in 33 normal subjects and in 32 patients with documented CAD. These STI were then correlated with hemodynamic data obtained at cardiac catheterization in 39 cases (seven normal subjects) (table 1). All patients were in regular sinus rhythm without evidence of left or right bundle-branch block and none had received any cardiac medications for a minimum of 96 hours before study. Patients with aortic valvular disease were excluded. The normal controls were hospital personnel with a normal cardiovascular physical examination, electrocardiogram (ECG), and chest roentgenogram, and no history of cardiac disease. The patients were selected from a series of persons undergoing diagnostic selective coronary arteriography.

The standard limb lead which inscribed the earliest QRS deflection (usually lead II) was selected for measurement of the onset of ventricular depolarization. Simultaneous indirect carotid artery pulse tracings, external phonocardiograms, and electrocardiograms were recorded on an Elema-Schönander Mingograf-34 recording system at a paper speed of 100 mm/sec with time lines of 10 msec. The carotid pulse was obtained with an Elema-Schönander EMT-510C crystal transducer held manually over the right common carotid artery. Heart sounds were recorded with an Elema-Schönander EMT 25B piezoelectric accelerometer microphone strapped firmly over the third or fourth left parasternal space with the patient's respirations suspended at normal end-expiration. Recordings were made in all subjects in the postabsorptive state at rest in the supine position and immediately (within 15 seconds) following 3 minutes of supine exercise on a bicycle ergometer* at a load of 75 watts (approximately 400 kg-m/min).

Total electromechanical systole (Q-A2) was measured from the onset of the QRS complex on the ECG (Q) to the initial high-frequency vibrations of the aortic component of the second heart sound (A2). The Q-A2 is composed of the pre-ejection period (PEP) and the left ventricular ejection time (LVET). The LVET was measured from the beginning of the rapid upstroke of the indirect carotid artery tracing to the trough of the carotid incisura. The PEP was obtained by subtracting the LVET from the Q-A2. This PEP is in turn composed of the electromechanical lag (EML) and the isovolumic contraction time (IVCT). The EML was measured from the onset of ventricular depolarization (Q) to the first high-frequency vibrations of the mitral component of the first heart sound (M1). The IVCT was obtained by subtracting the LVET from the interval M1-A2. The ratio PEP/LVET was the dividend of PEP divided by LVET, each interval uncorrected for heart rate.

Each STI was calculated from the mean of measurements made with the aid of calipers on five consecutive cardiac cycles, each read to the nearest millisecond. Heart rate (HR) was determined by dividing the average R-R interval into 60. Each interval was then corrected for heart rate by adding the measured interval to the product of the observed heart rate and the appropriate regression slope; these rate-corrected intervals were then designated by the subscript .

\[
\text{Q-A2}_c = \text{Q-A2} + 2.1 \text{ HR (males)}^3 \\
\text{Q-A2}_f = \text{Q-A2} + 2.0 \text{ HR (females)}^3 \\
\text{PEP}_c = \text{PEP} + 0.4 \text{ HR (males, females)}^3 \\
\text{IVCT}_c = \text{IVCT} + 0.2 \text{ HR (males, females)}^3 \\
\text{LVET}_c = \text{LVET} + 1.7 \text{ HR (males)}^3 \\
\text{LVET}_f = \text{LVET} + 1.6 \text{ HR (females)}^3 
\]

Right- and left-heart catheterization with selective coronary arteriography was performed in 39

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**Table 1**

<table>
<thead>
<tr>
<th>No. of patients</th>
<th>Age (years)</th>
<th>Mean ± SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td>Females</td>
<td>Males</td>
<td>Females</td>
</tr>
<tr>
<td>Normal subjects</td>
<td>31</td>
<td>2</td>
<td>35.3 ± 6.4</td>
</tr>
<tr>
<td>CAD* patients</td>
<td>29</td>
<td>3</td>
<td>42.4 ± 8.6</td>
</tr>
</tbody>
</table>

*CAD = coronary artery disease.

*Circulation, Volume XLV, March 1972

*Collins Physiological Development Complex.
subjects, seven of whom were proven to be normal. It was not technically feasible to measure the STI during the cardiac catheterization, so the STI and hemodynamic data were obtained under identical conditions on consecutive days. Each patient was studied in the fasting state with meperidine (50 mg) and diazepam (10 mg) premedication, and all hemodynamic measurements were obtained before the use of contrast medium.

All pressures were recorded through fluid-filled catheters with P23Db Statham strain gauges on a photographic recorder, with the measured mid- chest position as the zero reference point. The cardiac index (Fick), stroke volume index (SVI), mean pulmonary artery pressure, and mean pulmonary artery wedge pressure were obtained under the same conditions existing during the measurement of the STI, that is, with the subject in the resting supine position with the legs horizontal and after 3 minutes of supine leg exercise at 75 watts. Mean pressures were derived by electrical integration. The maximal rate of rise of the left ventricular pressure (LV dp/dt) using an electronic differentiator and the left ventricular end-diastolic pressure (LVEDP) at high sensitivity was obtained with subjects in the resting state only. The exercise factor was calculated as the exercise increase in cardiac output in cc/min for each 100 cc/min increase in measured O2 consumption.

Left ventricular cineangiograms were recorded in the 30-degree right anterior oblique projection at 60 frames/second using 40 to 60 cc of meglumine diatrizoate† injected through an 8 F pre-formed pigtail catheter‡ at a pressure of 350 to 450 psi. Left ventricular end-diastolic volumes (EDV) and end-systolic volumes (ESV) were calculated using a modification of the area-length method of Dodge. Ejection fraction (EF) was then derived as follows:

\[ \text{EF} = \frac{\text{EDV} - \text{ESV}}{\text{EDV}} \]

The left ventricular angiogram was also evaluated for localized or generalized disorders of myocardial contraction using frame-by-frame analysis of the internal left ventricular outline.

Coronary arteriograms were then recorded in multiple projections using the Judkins percuta-
neous femoral technique.‡ Both 16-mm cineangiograms and fixed films using a Franklin rapid film changer were obtained in each projection. Disease in a major coronary artery was considered to be functionally significant if its most severe narrow- ing exceeded 50% of the arterial luminal diameter. Each catheterization study was interpreted independently by the authors without knowledge of the patient's clinical status or STI.

The statistical significance of the various parameters was tested by Student's t-test, covariance analysis, and linear regression analysis with the aid of a General Electric 645 digital computer.

Results

Responses of the STI to Exercise (Table 2)

The mean duration of total electromechanical systole (Q-A2e) was the same at rest in the normal and coronary artery disease (CAD) groups and did not change significantly with exercise in either group (fig. 1). The group of patients with CAD had a significantly longer PEPC, shorter LVETC, and larger PEP/LVET at rest (P<0.01) and after exercise (P<0.01) than did the normal group, but both groups responded to exercise with a significant (P<0.01) reduction in PEPC and prolongation of LVETC of nearly identical magnitudes (23 to 25 msec). The PEP/LVET was likewise significantly decreased with exercise by a comparable amount in both subject populations.

The component intervals of the PEP—the EML and IVCT—responded to exercise in the same manner as the PEP. The EML was significantly shorter at rest (P<0.001) in the normal group than in the abnormal group, but decreased significantly with exercise (P<0.01) by a similar amount in both groups. The IVT, s in the normal and CAD groups were statistically indistinguishable at rest and shortened significantly (P<0.001) to the same degree with exercise. Neither EML nor IVCTC was superior to the PEPC alone in discriminating between the normal subjects and the patients with CAD. Furthermore, in no instance did consideration of the EML or IVCTC add to information already available from measurement of the PEPC or PEP/LVET in the assessment of alterations of myocardial function. Therefore, the EML and IVT were not considered further.

*DR-12 recorder, Electronics for Medicine.
†Renografin-76%.
‡Cordis Ducor.
### Table 2

**Resting and Exercise Systolic Time Intervals in Normal Subjects and in Patients with Coronary Artery Disease**

<table>
<thead>
<tr>
<th></th>
<th>Q-A2ₜ (msec)</th>
<th>PEPₜ (msec)</th>
<th>EML (msec)</th>
<th>IVCTₜ (msec)</th>
<th>LVETₜ (msec)</th>
<th>PEP/LVET</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Resting</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal subjects</td>
<td>548.2 ± 2.9</td>
<td>139.5 ± 1.9</td>
<td>64.6 ± 1.8</td>
<td>60.8 ± 2.2</td>
<td>410.6 ± 2.1</td>
<td>0.376 ± 0.007</td>
</tr>
<tr>
<td>CAD patients</td>
<td>548.7 ± 3.3</td>
<td>152.0 ± 3.8</td>
<td>77.5 ± 2.9</td>
<td>61.9 ± 3.4</td>
<td>396.1 ± 3.2</td>
<td>0.450 ± 0.019</td>
</tr>
<tr>
<td>P (difference between normal and CAD patients)</td>
<td>NS†</td>
<td>&lt;0.01</td>
<td>&lt;0.001</td>
<td>NS</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td><strong>Immediately after exercise</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal subjects</td>
<td>550.3 ± 3.0</td>
<td>115.1 ± 1.8</td>
<td>57.4 ± 1.4</td>
<td>39.4 ± 1.8</td>
<td>434.0 ± 3.0</td>
<td>0.279 ± 0.007</td>
</tr>
<tr>
<td>CAD patients</td>
<td>551.4 ± 3.2</td>
<td>129.1 ± 3.1</td>
<td>67.9 ± 2.7</td>
<td>43.1 ± 2.1</td>
<td>421.6 ± 3.7</td>
<td>0.368 ± 0.019</td>
</tr>
<tr>
<td>P (difference between normal and CAD patients)</td>
<td>NS</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>NS</td>
<td>&lt;0.01</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td><strong>Changes from resting to immediately after exercise</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal subjects</td>
<td>+2.1 ± 2.0</td>
<td>-24.4 ± 2.2</td>
<td>-7.2 ± 1.3</td>
<td>-21.4 ± 2.4</td>
<td>+23.4 ± 2.8</td>
<td>-0.097 ± 0.009</td>
</tr>
<tr>
<td>P</td>
<td>NS</td>
<td>&lt;0.001</td>
<td>&lt;0.01</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>CAD patients</td>
<td>+2.7 ± 2.4</td>
<td>-22.9 ± 2.9</td>
<td>-9.6 ± 2.1</td>
<td>-18.8 ± 2.8</td>
<td>+25.5 ± 3.1</td>
<td>-0.082 ± 0.013</td>
</tr>
<tr>
<td>P</td>
<td>NS</td>
<td>&lt;0.001</td>
<td>&lt;0.02</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

Abbreviations: Q-A2ₜ = total electromechanical systole; PEPₜ = prejection period; EML = electromechanical lag; IVCTₜ = isovolumic contraction time; LVETₜ = left ventricular ejection time; CAD = coronary artery disease.

*Mean ± SEM

†NS = not significant at the 0.05 level of confidence.
Correlations of the STI with Hemodynamic Data

Data from right- and left-heart catheterization, coronary arteriography, and left ventricular cineangiography were available in 39 patients for correlation with the STI obtained under identical conditions of rest and exercise.

Seven patients were free of occlusive lesions that reduced the lumen of a major coronary artery by more than 50%. Seven patients had significant arteriographic disease (>50% occlusion) limited to a single coronary artery, eight had such disease in two major coronary arteries and 17 had significant three-vessel disease. There was no significant difference in Q-A2s, PEPc, or PEP/LVET between the patients with single-, double-, or triple-vessel coronary disease. Although a trend was suggested for the resting and exercise LVETc, to shorten with increasing extent of CAD, the limited number of cases precluded statistical confirmation.

In an attempt to determine the hemodynamic basis for the differences in STI between the normal subjects and the patients with chronic CAD, the group with CAD was further subdivided on the basis of normality or abnormality of each parameter of cardiac function directly measured in this study. Such subgroups were made for each hemodynamic parameter. Those patients with CAD but with a normal SVI, CI, LV dp/dt, or EF had STI which were indistinguishable from the STI of the normal subjects. In contrast, the CAD patients with an abnormally low SVI, CI, LV dp/dt, or EF had a marked prolongation of PEPc, abbreviation of LVETc, and increase in the PEP/LVET ratio at rest (P < 0.01) and immediately after exercise (P < 0.01) compared with the normal subjects and with the hemodynamically normal CAD patients. Q-A2s was similar in all subgroups. Thus, a subgroup of patients within the total CAD group existed composed of those patients with abnormalities of SVI, CI, LV dp/dt, or EF; and the abnormal STI recorded in those patients were responsible for the abnormal deviations in mean STI in the CAD patient group as a whole.

No significant correlations existed between any resting or exercise STI and the resting or exercise.

Figure 1

Comparison of the effects of moderate supine exercise on the mean systolic time intervals corrected for heart rate in the group of normal subjects (solid lines) and the group of patients with coronary artery disease (broken lines). 

See text for other abbreviations.
exercise mean pulmonary artery or pulmonary artery wedge pressures, exercise factor, or evidence of left ventricular asynergy on cineangiography.

The relationships between resting and exercise PEP, LVET, and PEP/LVET and the directly measured parameters of left ventricular function were further explored with linear regression equations. The results of the analyses are presented in Table 3.

Both the PEP and the PEP/LVET were better correlated with the SVI than with the CI, and both intervals were more closely related to the SVI and CI when measured under resting conditions than when measured immediately after exercise. In contrast, the correlations between the PEP and PEP/LVET and LVEDP, LV dp/dt, and EF were better when intervals obtained immediately after exercise were used.

The LVET correlated with SVI, LV dp/dt, and EF, but less closely and in an opposite direction than the PEP correlated with these parameters. No significant relationships could be established in this study between LVET and CI or LVEDP.

To access the potential clinical application of the STI as indirect measures of various parameters of left ventricular function in the individual patient, each STI was plotted against the corresponding hemodynamic measurement obtained under identical conditions. An example of such a presentation is illustrated in figure 2, in which the exercise PEP/LVET is related to the left ventricular ejection fraction. Despite the significant inverse correlation (r = -0.67, P < 0.0005), it is apparent that the considerable overlap of data prevents any confident prediction of EF from the PEP/LVET. Although a marked elevation of PEP/LVET after exercise predicts a marked reduction in EF, less obvious alterations in EF cannot be reliably detected with the ratio of PEP/LVET in the individual patient. Similar difficulties are encountered

### Table 3

**Correlation Matrix: Hemodynamic Parameters versus Systolic Time Intervals**

<table>
<thead>
<tr>
<th>Cardiac index</th>
<th>Stroke volume index</th>
<th>LVEDP</th>
<th>LV dp/dt</th>
<th>EF</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R</td>
<td>E</td>
<td>R</td>
<td>E</td>
</tr>
<tr>
<td>PEP_e (R)</td>
<td>-0.46†</td>
<td>-0.60†</td>
<td>0.15</td>
<td>-0.42†</td>
</tr>
<tr>
<td>(E)</td>
<td></td>
<td></td>
<td>-0.20</td>
<td>-0.39†</td>
</tr>
<tr>
<td>LVET_e (R)</td>
<td>0.26</td>
<td>0.41†</td>
<td>-0.05</td>
<td>0.39†</td>
</tr>
<tr>
<td>(E)</td>
<td>0.04</td>
<td>-0.03</td>
<td>-0.25</td>
<td>0.35†</td>
</tr>
<tr>
<td>PEP/LVET (R)</td>
<td>-0.45†</td>
<td>-0.62†</td>
<td>0.29†</td>
<td>-0.42†</td>
</tr>
<tr>
<td>(E)</td>
<td>-0.36†</td>
<td>-0.37†</td>
<td>0.49†</td>
<td>-0.50†</td>
</tr>
</tbody>
</table>

Abbreviations: R = rest; E = exercise; LVEDP = left ventricular end-diastolic pressure; EF = ejection fraction; PEP_e = preejection period; LVET_e = left ventricular ejection time.

*All figures represent correlation coefficients (r values).

†P < 0.01.

‡P < 0.05.
when one attempts to predict the presence of minor abnormalities in SVI, CI, LV dp/dt, or LVEDP using measurements of STI.

Comment

Any noninvasive technique that could provide a sensitive yet practical measure of cardiac performance would deserve widespread application. A number of authors have suggested that an analysis of indirectly obtained cardiac systolic time intervals, in particular the PEP or IVCT, the LVET, and the ratio of PEP/LVET, may fulfill this need.15-17

Comparison of STI in Normal Subjects and in Patients with Coronary Artery Disease

In this study, normal subjects were compared with a group of patients with chronic coronary artery disease who were clinically but not hemodynamically homogeneous (table 2). Despite individual variation, the mean total electromechanical systole (Q-A2c) was the same at rest in both normal and CAD groups, and was unchanged by exercise in either group. This interval is markedly responsive to changes in heart rate, but the tendency of the Q-A2 to shorten with exercise-induced tachycardia was neutralized by the use of rate-corrected intervals.3 The Q-A2c was unaffected by changes in either SVI or CI.

Total electromechanical systole was further evaluated in terms of its two components, the PEPc and the LVETc. The PEP represents that period from the onset of electrical systole to the onset of actual left ventricular ejection and incorporates both the time required for excitation-contraction coupling (the EML) and the period of isovolumic contraction (the IVCT). The duration of the PEP is most dependent on the velocity of isovolumic contraction.18 The PEP thus provides an indirect measure of the maximal velocity of myocardial fiber shortening ("contractility"), which in turn is directly related to the rate of left ventricular pressure rise during isovolumic contraction (LV dp/dt). Patients with chronic coronary artery disease as a group would be expected to have a reduced rate of myocardial force development resulting in an increased time necessary for intraventricular pressure to attain aortic diastolic levels. In this study such patients did, in fact, have a longer PEPc at rest and following exercise than did a normal group (P < 0.001). Other factors tending to prolong the PEPc, such as a higher aortic diastolic pressure, are rarely of clinical significance within the physiologic ranges of blood pressures.4 None of our patients had resting aortic diastolic pressures exceeding 100 mm Hg.

In the face of a constant Q-A2 and a prolonged PEP, the isotonic phase of left ventricular systole represented by the LVET would be expected to be abbreviated by impaired myocardial function with the associated reduction in SVI and CI. As predicted, the LVETc in the CAD group was shorter at rest and following exercise than in the normal subjects (P < 0.001). The duration of LVETc is also strongly and inversely related to changes in heart rate, but such influences were eliminated by appropriate heart rate correction factors.3

Response of the STI to Supine Exercise

Since the duration of total electromechanical systole (Q-A2c) was not significantly changed by exercise in either the normal or CAD groups in this study, any reduction in PEPc due to the exercise-related increase in SVI and CI and the enhanced inotropic stimulation should be balanced by a prolongation in LVETc of comparable magnitude. Such was the case. However, both normal and abnormal groups responded to exercise with a significant (P < 0.001) reduction in PEPc and prolongation of LVETc of nearly identical magnitudes (23 to 25 msec). It would have been predicted that the patient with CAD might be less able than the normal subject to translate the inotropic stimulation of an exercise-induced catecholamine release into improved myocardial fiber shortening and a reduction in PEPc. It is possible that the hemodynamically abnormal patient may experience a much greater beta-adrenergic

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stimulation with the stress of exercise than the normal patient so that myocardial function would be enhanced by a proportionately similar degree in both groups.

With the reduction in PEP, with exercise, a greater proportion of electromechanical systole is then available for isotonic contraction as measured by the LVETc. The tendency for the LVETc to lengthen in response to an exercise-induced increase in SVI and CI apparently effectively overbalances the tendency for the LVETc to shorten in response to the associated increased inotropism.

In a recent report by Pouget and associates, mild upright exercise for 4 minutes resulted in a shortening of the PEP (uncorrected for heart rate) by 26 msec in normal subjects and 35 msec in patients with angina pectoris. The LVETc, lengthened by 23 msec in their angina patients but was unchanged by exercise in their normal subjects, a finding that is difficult to reconcile with our data and those of Levine et al. It is doubtful whether different activity habits in the control populations could explain these contradictory findings.

The differences could be related in part to the different mode, position, and extent of exercise, as suggested by Agress and co-workers. These authors examined the relationship of indirectly obtained ejection times in normal subjects at rest and immediately after completing various types of upright exercise. If their data are corrected for heart rate using Weissler’s regression factor, the mean changes in corrected ejection times with exercise varied between −22.9 msec with a double Master’s two-step test, −2.5 msec with treadmill exercise (1.73 mph on a 10% grade for 10 minutes), and +10.0 msec with moderate exercise on an upright bicycle ergometer (3 kiloponds for 3 minutes). No hemodynamic data were obtained in their study, but it is known that a normal untrained individual maintains a relatively stable SVI during mild exercise and augments his cardiac output primarily via heart rate acceleration (hence the relatively stable LVETc). With more strenuous exercise, the SVI increases (as it did in the normal subjects in our study, from a mean of 40 cc/min/m² at rest to 51 cc/min/m² with exercise) and the LVETc is progressively prolonged.

Correlations between STI and Direct Measurements of Ventricular Performance

Several previous studies have established associations between PEP prolongation and LVET shortening and such interdependent abnormalities as reduced SVI and CI, increased left ventricular end-diastolic pressure and volume, reduced left ventricular ejection fraction, and increasing extent of coronary arteriographic disease. These direct measurements of ventricular performance and the indirect STI should be related by virtue of their common dependence on the rate and extent of myocardial contractile element shortening. Such significant correlations were confirmed in the present study between the PEPc, LVETc, and PEP/LVETc and the LVEDP, LV dp/dt, resting and exercise SVI and CI, and EF as determined angiographically (table 3). Within the CAD group, the abnormal STI existed predominantly in those patients with an abnormally low SVI, CI, LV dp/dt, or EF. Those CAD patients with normal hemodynamics had STI that were generally indistinguishable from those of the control population.

Recording STI immediately after exercise improved the correlations only between PEPc and PEP/LVETc and LVEDP, LV dp/dt, and EF. In all other instances the resting correlations were superior. Furthermore, an analysis of the changes in STI from rest to exercise, using each patient as his own control, did not improve the separation of patients with normal from those with abnormal hemodynamics.

Despite the correlations listed in table 3, minor abnormalities of ventricular function could not be predicted reliably in the individual patient with coronary artery disease. As exemplified in figure 2, the STI failed to detect hemodynamic alterations that were not already clinically obvious. A similar conclusion may be drawn from the study of Garrard et al., in which the correlations
between PEP/LVET and EF in their patients with ischemic heart disease were significant \((r = -0.72, P < 0.01)\) but inferior to the close correlations obtained in their patients with other kinds of heart disease.

Aronow and co-workers\(^7\) were recently able to predict the presence of a normal or abnormal EF in 21 of 21 patients by the ratio of LVET to external isovolumic contraction time measured immediately after upright exercise \((r = 0.71, P < 0.0002)\). However, the abnormal EF ranged from 2 to 35% \((\text{mean} = 20\%)\); no patients with minor reductions in EF were included in their comparison. It is doubtful whether such a perfect separation of normal and abnormal EF by these indirect measurements would be confirmed with less critically ill patients.

The present study suggests that one must be cautious when attempting to extrapolate from STI measurements to the actual underlying hemodynamic variables in patients with chronic CAD. Such caution is particularly urged when STI are used in the individual patient for the purpose of detecting functional abnormalities that are not already clinically apparent. So many diverse factors may affect each STI that it would be surprising if one could relate these derived intervals directly and precisely to single hemodynamic events. However, their application in the serial assessment of an acutely ill patient may offer more promise and deserves further study.\(^{12, 24, 25}\)

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