The Effect of Exercise on Intrinsic Myocardial Performance

By William G. Winters, M.D., David M. Leaman, M.D., and Richard A. Anderson, M.D.

SUMMARY
Systolic time intervals were performed on 49 male subjects. Twenty-eight subjects were inactive with respect to a continuing exercise program and were classified as a sedentary group. Twenty-one subjects were physically active and were classified as an active group. The active group was composed of 12 members who were moderately active and nine members of a college track team. Using analysis of covariance no significant difference was found in the total duration of electromechanical systole (QS₂), left ventricular ejection time (LVET), or the pre-ejection period (PEP) between the moderately active subgroup and the members of the track team. However, a highly significant difference was found between the sedentary and the active group in the QS₂ and PEP. The LVET was not significantly different.

The results of this study appear to be consistent with the hypothesis that an increase in intrinsic myocardial performance is associated with physical conditioning. In addition, it is suggested that published equations for the QS₂ interval and the PEP may be applicable only to sedentary individuals.

Additional Indexing Words:
Physical conditioning  Left ventricular ejection time  Myocardial contractility
Noninvasive techniques  Pre-ejection period  QS₂ interval

THE PHASES of electromechanical systole have been shown to vary linearly and inversely with heart rate and to be predictable by the use of regression equations. Although separate equations are necessary to define the intervals for men and women,¹ there is little variation in the intervals with variation of blood pressure within the normal range. So far, diurnal variation² and increasing age³ have been shown to be natural, spontaneous influences on the duration of the phases in the normal subject. To date, physical conditioning has not been shown to alter the duration of these intervals.

Physical conditioning is associated with a variety of alterations in the circulation including reduction in resting heart rate, increase in cardiac end-diastolic volume and stroke volume, augmentation of total blood volume and total hemoglobin, and increased arterial-venous oxygen difference.⁴ No evidence has yet been presented, however, to indicate that a primary change in intrinsic myocardial performance may occur with physical conditioning.

The purpose of the study was to answer two questions: 1) Could variation of the regression equations for systolic time intervals occur as a result of a physically trained state? 2) Could any differences be detected between physically active and sedentary individuals which would indicate a difference in intrinsic myocardial performance?

Methods
The subjects of this study were either students or employees of the University of Vermont. No subject was an inpatient or outpatient of the Medical Center Hospital, and no subject had a history of hypertension, heart disease or other systemic illnesses.

Prior to the day of the study, the procedure was explained to all subjects. The subjects usually arrived at the laboratory at 8:00 a.m., never later than 11:00 a.m., and always after at least a 12 hr fast. During a 30 min period of supine rest, the procedure was explained again, age, height and weight were noted, and comments on the subjects’ level of physical exercise for several months prior to the study were recorded. On the basis of these comments the subjects were assigned to one of three groups: 1) sedentary subjects participating rarely in any type of physical activity; 2) active subjects participating in anything from squash to jogging to cross-country skiing so long as these activities occurred a minimum of twice weekly on a regular basis; 3) trained athletes consisting of varsity cross-country runners at the height of the training season.

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Next, blood pressure was recorded, and physical examination of heart and lungs was performed. No subject was included in the study with blood pressure as great as 140/90 or with any murmur except a Grade I/VI systolic ejection murmur which the examiner considered “innocent.” Finally, subjects exhibiting alarm or overt nervousness were excluded from the study.

At the end of the rest period, electrocardiograph leads were attached to the subject, a Cambridge phonocardiograph pick-up was placed in position for optimal identification of heart sounds, and carotid pulse wave was obtained by a small plastic funnel and Cambridge pulse transducer. All wave forms were displayed on the oscilloscope of an Electronics for Medicine DR-8 recorder and were recorded on photographic paper at a paper speed of 100 mm/sec with 0.02 second time lines.

Measurements of QS₂ interval, QS₁ interval, LVET and R-R interval (fig. 1) were performed on 10 to 30 consecutive beats for each subject and averaged to give a mean value. Resolution of intervals was performed to the nearest 5 msec. Pre-ejection period was taken as the difference of QS₂ minus LVET, while the isometric contraction time was calculated by subtracting QS₁ from the PEP. The heart rate was calculated by dividing 60 by the average R-R interval.

Statistical analysis of the data included determination of the mean and the standard deviation for the different systolic time intervals. Regression lines were defined in accordance with the formulae for least squares fit to a straight line where \( Y = A + Bx \). Covariant regression analysis was performed on the intragroup data in accord with the principles of Snedecor and Cochran.\(^5\)

**Figure 1**

Simultaneous recording of the electrocardiogram, phonocardiogram, and carotid arterial pulse tracing. \( Q_1 \) = interval from onset of QRS to the first heart sound; \( Q_2 \) = total electromechanical systole; LVET = left ventricular ejection time. *Paper speed = 100 mm/sec, time lines = 0.02 sec.*

**Table 1**

<table>
<thead>
<tr>
<th>Phase of systole: regression equation</th>
<th>Regression coefficient</th>
<th>( P ) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>QS₂ = (0.521) - (0.0018 \times HR) = 0.014</td>
<td>- 0.760</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>LVET = (0.300) - (0.0012 \times HR) = 0.012</td>
<td>- 0.710</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Q₁ = (0.894) - (0.0005 \times HR) = 0.017</td>
<td>- 0.270</td>
<td>.1 &gt; ( P ) &gt; .05</td>
</tr>
<tr>
<td>PEP = (0.131) - (0.0005 \times HR) = 0.011</td>
<td>- 0.410</td>
<td>.01 &gt; ( P ) &gt; .001</td>
</tr>
<tr>
<td>ICT = 0.033 \times 10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Age: 18–58; heart rate: 60 \( \pm \) 10; systolic blood pressure \( \pm \) sd: 116 \( \pm \) 9; diastolic blood pressure \( \pm \) sd: 72 \( \pm \) 7.

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Table 2

**Sedentary***

<table>
<thead>
<tr>
<th>Phase of systole: regression equation</th>
<th>Regression coefficient</th>
<th>( P ) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( Q_S = (0.538) - (0.0020 \times HR) \pm 0.010 )</td>
<td>-0.810</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>( LVET = (0.494) - (0.0015 \times HR) \pm 0.008 )</td>
<td>-0.770</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>( Q-1 = (0.093) - (0.0004 \times HR) \pm 0.012 )</td>
<td>-0.310</td>
<td>NS</td>
</tr>
<tr>
<td>( PEP = (0.133) - (0.0005 \times HR) \pm 0.006 )</td>
<td>-0.420</td>
<td>.05 &gt; ( P &gt; .01 )</td>
</tr>
<tr>
<td>( ICT = 0.038 \neq 0.013 )</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Weissler's Normal Subjects†

<table>
<thead>
<tr>
<th>Phase of systole: regression equation</th>
<th>Regression coefficient</th>
<th>( P ) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( Q_S = (0.546) - (0.0021 \times HR) \pm 0.014 )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( LVET = (0.413) - (0.0017 \times HR) \pm 0.010 )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( Q-1 = (0.090) - (0.0004 \times HR) \pm 0.011 )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( PEP = (0.131) - (0.0004 \times HR) \pm 0.013 )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( ICT = 0.038 \neq 0.010 )</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Age: 25-58; heart rate: 59 ± 9; systolic blood pressure ± 1 sd: 115 ± 7; diastolic blood pressure ± 1 sd: 72 ± 7.

†Age: 19-65; blood pressure: normal.

Table 3

**Active***

<table>
<thead>
<tr>
<th>Phase of systole: regression equation</th>
<th>Regression coefficient</th>
<th>( P ) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( Q_S = (0.501) - (0.0015 \times HR) \pm 0.009 )</td>
<td>-0.750</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>( LVET = (0.379) - (0.0010 \times HR) \pm 0.008 )</td>
<td>-0.670</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>( Q-1 = (0.075) - (0.0002 \times HR) \pm 0.008 )</td>
<td>-0.230</td>
<td>NS</td>
</tr>
<tr>
<td>( PEP = (0.124) - (0.0005 \times HR) \pm 0.007 )</td>
<td>-0.510</td>
<td>.05 &gt; ( P &gt; .01 )</td>
</tr>
<tr>
<td>( ICT = 0.027 \neq 0.010 )</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Age: 18-45; heart rate: 60 ± 11; systolic blood pressure: 118 ± 11; diastolic blood pressure: 72 ± 5.

\( PEP \), was much the same in our total group and in Weissler's material.

Twenty-eight members of our total group were then identified as being almost entirely inactive with respect to a continuing exercise program. The equations developed for the phases of systole of this group were so close to the equations presented by Weissler that they are presented together in table 2.

The procedure for separating the data and deriving equations was applied to a group of 12 males identified as being physically active prior to the study and, separately, to a group of nine members of the track team. The intra-group comparison of the data for each interval of systole was performed by analysis of covariance, and no significant difference between these two groups could be identified for any interval.

Subsequently, the data from the physically active group and the track group were combined and referred to as the active group. Equations were developed to describe the data of this combined group, and these are presented in table 3. Covariant analysis revealed that significant differences existed between the sedentary and the active group. At a

given heart rate, \( QS_2 \) in the active group was different from the sedentary group, with a crossover at a heart rate of 74 beats/min. The \( y \) intercept for the sedentary group was 538 msec and for the active group 501 msec (\( P < .05 \)). No significant dif-

![Figure 2](https://example.com/figure2)

**Figure 2**

Relationship between the \( QS_2 \) and heart rate. The derived regression equation for each group is given and the equation for the sedentary group compared with the equation given by Weissler et al. for normal males; \( r = \) correlation coefficient, \( \text{see} = \) standard error of the estimate.
Relationship between the LVET and heart rate. The derived regression equation for each group is given and the equation for the sedentary group compared with the equation given by Weissler et al. for normal males; \( r \) = correlation coefficient, \( \text{SEE} \) = standard error of the estimate.

Comparison of the QS\(_1\) subdivision of the pre-ejection period between groups showed that group differences in this interval were not significant. The isometric contraction time (ICT) has not been shown to vary linearly with heart rate but rather to be constant within a narrow range.

Comparison of this interval in the sedentary and active groups was therefore accomplished by the \( t \) test of unequal groups and the difference found to be highly significant (\( P < .001 \)). The mean ICT of the active group—27 msec—was markedly shorter than the sedentary group—38 msec.

The individual pre-ejection period index (PEP-I) was calculated using the appropriate regression equation. This is shown in figure 5. The mean index for the sedentary group was 134.6 ± 1.7 msec and for the active group was 120.5 ± 2.7 msec. While
there is some overlap between the two groups the PEP-I was significantly shorter in the active group ($P < .001$).

Garrard, Weissler and Dodge\textsuperscript{7} have shown that the ratio of PEP/LVET correlates closely with the ejection fraction. As this ratio decreases the ejection fraction increases. The individual value for each subject is shown in figure 6. The mean value for the sedentary group was $0.332 \pm 0.007$ while the mean value for the active group was $0.287 \pm 0.007$. While there is overlap between the groups, the PEP/LVET is significantly shorter in the active group ($P < .001$).

Discussion

The similarity of the regression equations of our sedentary group (table 2) and Weissler's equations for males leads us to the conclusion that our methods of recording and analyzing the data are similar. The differences found in the athletic group might well have arisen on the basis of physical training.

The present study clearly indicates that the exercise habits of adult males are an important determinant of the duration of systolic time intervals. Thus, habits of exercise prior to study or onset of disease state could cause confusion in interpretation of duration of these phases in a given individual. This study strongly suggests that published equations for the prediction of systolic intervals in normal men are applicable only to normal sedentary men. Although we have no information on these intervals in sedentary or active females, the probability is great that physical training affects women in much the same way.

In regard to any difference in intrinsic myocardial performance between the sedentary and the active groups, an important finding is a decreased PEP/LVET ratio in the active group compared with the sedentary group. Since this ratio correlates well with ejection fraction this would indicate an increased ejection fraction with physical conditioning.

A second important finding is a shorter than predicted PEP in the active group. Metzger et al.\textsuperscript{8} have shown that the PEP is a reflection of dp/dt in that as dp/dt increases the PEP decreases. The PEP is also a reflection of the isometric contraction time in that changes in the PEP reflect changes in the same direction in the isometric contraction time. Both the PEP-I and the derived ICT were significantly shorter in the active group.

![Figure 6](https://example.com/figure6.png)

The individual values for the PEP/LVET of each group. The crossbar is the mean for the group.

Preload, afterload, and myocardial contractility are known to alter dp/dt. The diastolic arterial pressure is virtually identical in the two groups, averaging $72 \pm 7$ mm Hg in the sedentary group.
and 72 ± 5 mm Hg in the active group. Thus, differences in afterload cannot account for the differences found between the two groups.

Athletes are known to have an increased left ventricular end-diastolic volume. Based on the Starling mechanism the increased end-diastolic volume may then lead to an increased dp/dt. This may, at least in part, account for the shortened PEP found in the athletic group.

The third factor, increased intrinsic myocardial contractility, most likely accounts for most of the observed changes. Without knowing the actual left ventricular end-diastolic volumes it is impossible to determine exactly how much changes in the intrinsic myocardial contractility versus changes in the left ventricular end-diastolic volume are responsible for the alterations observed. However, the findings of a shortened PEP and ICT along with a decreased PEP/LVET ratio strongly suggests an increased intrinsic myocardial contractility.

While it has not been previously shown that physically conditioned males have intrinsically better myocardial performance, it is not surprising to find this to be the case. What is surprising is that adult males in a moderate exercise program did not evidence any difference in intrinsic myocardial performance when compared with a group of highly trained athletes. This would suggest that a moderate exercise program is as beneficial to intrinsic myocardial performance as a strenuous exercise program.

The possibility was considered that the difference in the systolic time intervals might be related in part to a significant age variation between the two groups. The sedentary subjects ranged in age from 28 to 58 years with a mean of 40.6 years, and the active subjects ranged in age from 18 to 45 years with a mean of 27.0 years. However, no variation in the derived indices for the QS₂, LVET, or PEP were observed in either group as a function of age.

The present study is in disagreement with those of Rabb and Whitsett and Naughton concerning the effects of training on the pre-ejection period. On the basis of averages of the Tension Period (the equivalent of PEP) in subjects before and after training, the conclusion was drawn that exercise lengthens the TP, i.e., PEP. Again, on the basis of the mean pre-ejection period no difference was found between active and sedentary subjects. However, neither of these studies derived the equation for linear regression so characteristic of the systolic intervals in the pre- or post-trained state. Rather, since training led to a reduction in heart rate and thus a relative prolongation of the tension period or pre-ejection period, this overall effect was noted and no attempt was made to compare measured versus expected interval for the given heart rate.

The future application of the phases of systole in the estimation and treatment of disease of the cardiovascular system will improve as other variables which affect the "normal" are recognized.

References


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