Non-Invasive Evaluation by Thermistor Plethysmography of Left Ventricular Performance During Dynamic Exercise Comparison with Echocardiography

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SUMMARY

The purpose of this study was to evaluate the reliability of two non-invasive techniques (STI and echocardiography) in assessing cardiovascular response during exercise.

STI were obtained using a new carotid pulse transducer (thermistor pulse) proved to be reliable in exercise recording. The study population included 12 male rowers (age 15-20 years), who performed supine bicycle exercise; STI and echocardiographic recording of left ventricle were simultaneously obtained at rest and continuously throughout the exercise period. A negative linear correlation ($r = -0.782$; $p < 0.001$) was found between PEP (pre-ejection period) and %LVID (fractional shortening of left ventricle), reliable indexes of cardiac contractility measured by the two techniques. A lower, but significant correlation ($r = 0.643$; $p < 0.001$) was present between ETI (left ventricular ejection time corrected by heart rate) and SV (stroke volume) indexes of pump function.

The present study shows that STI measured with this new technique, can be employed in evaluating left ventricular function in those patients in whom a good echocardiogram is difficult to record during exercise.

Additional Indexing Words:

Myocardial contractility Myocardial pump function Systolic Time Intervals

SYSTOLIC time intervals (STI) and/or echocardiography were successfully employed as reliable and reproducible techniques for assessing left ventricular performance at rest.¹⁾⁻⁶⁾ In previous studies, these techniques were alternatively employed to study left ventricular size and/or performance during isometric stress test and dynamic bicycle exercise in the supine and in the up-

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right position.⁷⁾⁻¹³⁾ However, both techniques pose several technical problems. As an example, during effort, standard STI measurements can be altered for the instability of the carotid pulse trace. Moreover, in-exercise echocardiography in some cases does not allow a quantifiable echocardiographic trace of both sides of the septal endocardium and left ventricular posterior wall.¹⁴⁾⁻¹⁷⁾

This study was undertaken in order to evaluate the reliability of the combination of the two techniques in assessing cardiac response to dynamic exercise. For STI evaluation a new carotid pulse transducer, the so called thermistor pulse transducer, was utilized, since it was proved to be reliable in exercise recording.¹⁸⁾

In order to obtain reliable echocardiographic data, the study population was selected among a group of highly trained athletes, in whom an excellent rest-echocardiogram in the supine position was obtained.

MATERIALS AND METHODS

Twelve competing male rowers ranging in age from 15 to 20 years (mean 18.1) were studied. They performed bicycle ergometer exercise while lying in the supine position; the exercise was started at a work load of 50 watts and was increased by 50 watts every 3 min for 9 min.

Before exercise and during the last 30 sec of each stage, arterial pressure (AP), STI, and echocardiogram were simultaneously recorded. In order to obtain clear echocardiographic recordings, without the influence of hyperpnea, exercise was not strenuous.

The carotid arterial pulse (CTG) was obtained by the thermistor pulse transducer described elsewhere¹⁸⁾ which allowed the clear cut recording of the beginning of the rapid upstroke and of the dicrotic notch in two separate tracings (Fig. 1). The ECG and the carotid pulse were recorded simultaneously at a paper speed of 100 mm/sec on a DR-8 Electronics for Medicine photographic recorder.

The pre-ejection period (PEP) was measured from the onset of the R wave of the ECG to the beginning of the rapid upstroke of the CTG, i.e. to the inscription of the first signal obtained by the thermistor pulse. Left ventricular ejection time (LVET) was measured from the onset of the rapid upstroke of the CTG to the passage through the zero line of the related signal. LVET was corrected (ETI) for heart rate according to the formula: $ETI = LVET / \sqrt{RR}$.

Echocardiograms were obtained by standard method using an ALOKA SSD 110 ultrasonoscope with a 2,25 MHz transducer, and recorded on light-sensitive paper (Kodak Linograph 1895) at a paper speed of 100 mm/sec using a Honeywell 1856 strip chart recorder. The transducer was angled to demonstrate the inter-ventricular septum and the left ventricular posterior wall at the level of the chordae tendineae and held at the same point on the chest wall throughout the examination.

The echocardiographic measurements were made during expiration¹⁹⁾ and represented the average of at least three heart beats. Using the R wave of the simultaneously recorded ECG as reference, we measured end-diastolic dimension (LVIDd) of the left ventricle at the level of the chordae tendineae and end-systolic

Fig. 1. Left panel: Receiver of the thermistor pulse transducer held on the carotid artery by a rubber strip. Right panel: Simultaneous recording performed at rest of (from top to bottom): the standard carotid pulse wave, phonocardiogram, ECG, and the onset of the rapid upstroke (onset) and the dicrotic notch (incisura), recorded by the thermistor pulse transducer. It is also shown how STI are calculated. LVET indicates left ventricular ejection time calculated from standard carotid pulse; PEP_{tp} and $LVET_{tp}$, pre-ejection period and left ventricular ejection time, calculated from thermistor-pulse tracings, respectively.

dimension (LVIDs) considered as the smallest dimension between the left septal endocardium and the posterior wall endocardium during systole.

From these measurements we calculated:

-percent left ventricular dimension shortening: $\%LVID = (LVIDd - LVIDs) / LVIDd \times 100$

-stroke dimension: $SD = LVIDd - LVIDs$

-end-diastolic volume: $EDV = 7 / (2.4 + LVIDd) \times (LVIDd)^3$

-end-systolic volume: $ESV = 7 / (2.4 + LVIDs) \times (LVIDs)^3$ ²⁰

-stroke volume: $SV = EDV - ESV$

-ejection fraction: $EF = SV / EDV$

Statistical analysis was made using the Student's t-test for unpaired samples.

RESULTS

Exercise influenced left ventricular contractility indexes measured by the two techniques to a similar extent: actually, PEP decreased progressively during exercise from the resting value of 107.5 ± 2.6 to 80.0 ± 2.2 msec at peak exercise ($p < 0.001$), and remained significantly lower also in the first minute of the recovery period, returning to the control value only 3 min after the completion of the exercise (Table I, Fig. 2). Similarly $\%LVID$ rose progressively during the stress test from 38.9 ± 1.6 to $52.8 \pm 1.4\%$ at peak exercise ($p < 0.001$), and returned to the resting value only late during the recovery period

Table I. Changes in Heart Rate, Mean Arterial Pressure and STI Values during Dynamic Exercise in 12 Trained Athletes

	HR (beats/min)	APm (mmHg)	LVET (msec)	ETI (msec)	PEP (msec)
Rest	65.3±2.4	92.0±3.5	286.2±7.3	296.3±3.6	107.5±2.6
50 W	90.5±3.8*	102.2±3.2**	268.3±5.7**	317.1±3.4**	97.0±1.8**
100 W	105.6±3.7**	106.4±2.8**	244.0±6.5**	322.0±3.4**	88.0±1.6**
150 W	121.0±6.7**	109.5±3.3**	231.6±8.6**	337.7±4.7**	80.0±2.2**
R ₁	80.5±4.7*	100.1±2.0*	271.0±6.1*	302.1±5.2	97.0±1.5*
R ₃	73.1±3.6	95.0±2.9	277.2±7.5	288.8±5.5	106.4±2.2

* p<0.05, different from rest value

** p<0.001, different from rest value

HR=heart rate; APm=mean arterial pressure; 50,100,150=work load expressed in watt; R₁=1st min of recovery; R₃=3rd min of recovery. See text for abbreviations.

Table II. Echocardiographic Parameters Obtained during Dynamic Supine Exercise in 12 Trained Athletes

	LVIDd (cm)	LVIDs (cm)	% LVID %	SD (cm)	SV (ml)	FF %
Rest	5.14±0.13	3.10±0.14	38.9±1.6	1.91±0.11	83.9±4.1	65.8±2.1
50 W	5.25±0.13	2.94±0.15	44.7±1.4*	2.34±0.63*	92.1±5.4*	70.1±1.9**
100 W	5.43±0.12**	2.74±0.15**	50.1±1.4**	2.66±0.79**	101.6±6.3**	75.6±1.7**
150 W	5.51±0.13**	2.67±0.12**	52.8±1.4**	2.93±0.88**	109.7±8.0**	78.7±1.4**
R ₁	5.37±0.14*	3.07±0.12	44.6±1.5*	2.31±0.67*	92.0±5.9*	69.3±1.3**
R ₃	5.20±0.12	3.10±0.12	40.8±1.2	2.14±0.68	83.2±3.8	66.8±1.3

* p<0.05, different from rest value

** p<0.001, different from rest value

HR=heart rate; 50,100,150=work load expressed in watt; R₁=1st min of recovery; R₃=3rd min of recovery. See text for abbreviations.

(Table II, Fig. 2).

Also left ventricular pump function indexes calculated by systolic time intervals and by echocardiography were affected similarly. In fact, ETI rose significantly in the early phases of the exercise, increasing from 296.3±3.6 to 317.1±3.4 msec during the first 3 min of exercise (p<0.001), indicating that cardiac output rose promptly at lower level of exercise (Table I, Fig. 3); to a comparable extent were modified the echocardiography-derived indexes of ventricular pump function, SV and EF, which showed a significant increase in the early period of the stress and remained high not only during the remaining part of the exercise, but also in the first minute of the recovery period (Table II, Fig. 3).

Finally, echocardiographic and polygraphic indexes of myocardial perfor-

Fig. 2. Changes induced by bicycle exercise on left ventricular fractional shortening (%LVID) and pre-ejection period (PEP). Note that to a progressive fall in PEP during exercise and in the initial part of the recovery period corresponds a simultaneous increase in %LVID. R=rest value; 50,100,150=work load expressed in watts; R₁=1st min of recovery; R₃=3rd min of recovery.

* difference from R, $p < 0.05$ ** difference from R, $p < 0.001$
All numbers are expressed as mean $\pm$ standard error of the mean.

Fig. 3. Changes induced by bicycle exercise on stroke volume assessed by echocardiography (SV) and ejection time index (ETI). R=rest value; 50,100,150=work load expressed in watts; R₁=1st min of recovery; R₃=3rd min of recovery.

* difference from R, $p < 0.05$ ** difference from R, $p < 0.001$
All numbers are expressed as mean $\pm$ standard error of the mean.

mance were linked by a good correlation, since a negative linear correlation was found between PEP and %LVID ($\%LVID = 88.79 - 0.455PEP$; $r = -0.782$; $p < 0.001$) (Fig. 4) and a positive linear correlation was present between ETI and SV ($SV = -60.22 + 0.536ETI$; $r = 0.643$; $p < 0.001$) (Fig. 5).

Fig. 4. Correlation between indexes of myocardial contractility assessed either by echocardiography or by STI. %LVID=left ventricular fractional shortening; PEP=pre-ejection period. A highly significant linear correlation was found ($p < 0.001$).

Fig. 5. Correlation between indexes of myocardial pump function assessed either by echocardiography or by STI. SV=stroke volume; ETI=ejection time index. A highly significant linear correlation was found ($p < 0.001$).

DISCUSSION

Our data confirm that the overall response to dynamic exercise consists of an increase in heart rate, blood pressure, and cardiac output, as previously reported.^{11)–13)}

In the hope to increase the accuracy of left ventricular performance measurement, we decided to evaluate it during exercise by two different techniques, i.e. STI and echocardiographic recordings. The simultaneous use of these two combined techniques actually improves greatly the accuracy of the evaluation of cardiac function during exercise, provided that satisfactory recordings of STI and echocardiograms can be obtained.

An interesting result of this study is that changes in PEP and %LVID values, reliable indexes of cardiac performance, and in ETI and SV values, indexes of pump function, measured by the two techniques, are comparable in size and take place simultaneously.

In fact, PEP and %LVID are affected similarly at lower levels of exercise, reach respectively the maximum decrease or increase at peak exercise, and show a progressive and comparable restoration of the rest values during recovery.

The tight correlation found between PEP and %LVID, despite a dispersion of data from the regression line, confirms that STI measured by the previously described technique can be successfully used as a reliable index of the inotropic condition of the myocardium during exercise.

In contrast, ETI and SV, indexes of left ventricular pump function, are less closely correlated, the correlation coefficient being 0.643, as compared to 0.782, which is the correlation coefficient found between the two indexes of left ventricular contractility (PEP and %LVID). This is probably related to the minor reliability of echocardiography in measuring left ventricular volumes.^{20), 21)}

In conclusion, this investigation suggests that the combination of STI and echocardiography may improve greatly the accuracy and the sensitivity of the evaluation of left ventricular pump and contractility functions, and that this goal can be achieved not only in the rest condition, but also during dynamic exercise, when the reliability of each of the two techniques is severely impaired.

Finally, since good echocardiographic tracings are not always obtainable during exercise, STI recording by the thermistor pulse transducer may represent a possible reliable means to assess left ventricular performance under this dynamic condition.

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