Systolic Time Intervals in Adolescents

Normal Standards for Clinical Use and Comparison with Children and Adults

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SUMMARY Systolic time intervals were measured in 147 healthy 13–19-year-old adolescents to derive regression equations for clinical use in this age group and to determine to what extent they differ from those of children and adults.

Stepwise regression analysis showed that heart rate was the only variable consistently and significantly related to electromechanical systole (QS_2), left ventricular ejection time (LVET) and preejection period (PEP). None of the other variables tested (age, height, weight, body surface area, blood pressure, hemoglobin, hematocrit and serum electrolytes), when used alone, were relevant variables in relation to QS_2, LVET or PEP. The PEP/LVET ratio in adolescents was essentially independent of heart rate, as in children and adults.

The regression lines for QS_2, LVET and PEP in adolescents fall between those for children and adults, indicating that there is a distinct tendency toward lengthening of all the systolic time intervals with age, independent of changes in heart rate. The PEP lengthens proportionately more than the LVET, resulting in a progressive increase in the mean PEP/LVET ratio from childhood (0.30) to adolescence (0.32) and to adulthood (0.345). The precise hemodynamic factors underlying these changes with increasing age remain to be determined.

SYSTOLIC TIME INTERVALS are widely recognized as a reliable method for noninvasive assessment of the systolic performance of the left ventricle. The normal intervals in adults were defined by Weissler et al.,[1] who derived regression equations in relation to heart rate in adults 19–65 years old. These equations, however, are not applicable to children, whose normal systolic time intervals differ significantly from those in adults for any given heart rate. In a recent study on normal children ages 1 month to 13 years, we established regression equations that can be used as normal standards for clinical use in that age group.[2] The present study was undertaken to define the regression equations relating systolic time intervals to heart rate in normal adolescents ages 13–19 years.

Methods

Systolic time intervals were measured in 147 healthy adolescents, 86 males and 61 females. The age distribution is shown in figure 1. A medical history was obtained and a physical examination and ECG were performed before testing. Only healthy subjects with no intercurrent illness were included in the study.

The apparatus and procedure used for recording and measuring the systolic time intervals have been reported,[2] and are the same as used in adults by Weissler et al.[1, 3] The intervals measured were the total electromechanical systole (QS_2) and the left ventricular ejection time (LVET). The preejection period (PEP) was calculated by subtracting the LVET from the QS_2, and the ratio of PEP/LVET was calculated. The heart rate was derived from the RR interval of the electrocardiographic recording. Blood pressure was obtained by sphygmomanometry in all subjects just before testing, and a blood sample was taken for determination of hemoglobin, hematocrit and serum sodium, potassium, calcium and chloride.

The statistical computations were made with the aid of a CDC CYBER 73 computer, using the Statistical Package for the Social Sciences,[4] as previously described.[2] Regression equations for the dependent variables QS_2, LVET, PEP and PEP/LVET were derived for males and females separately. The following independent variables were tested in stepwise fashion for their relevance to each regression equation: heart rate, age, height, weight, body surface area, systolic blood pressure, diastolic blood pressure, hemoglobin, hematocrit and serum sodium, potassium, calcium and chloride. The coefficient of variation (CV%) (standard deviation $\times$ 100/mean) was calculated for the regression line as well as for the mean value of each dependent variable. The t test was used to test the significance of the differences between mean values and between regression lines.

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Received January 3, 1980; revision accepted June 25, 1980.

Circulation 63, No. 1, 1981.

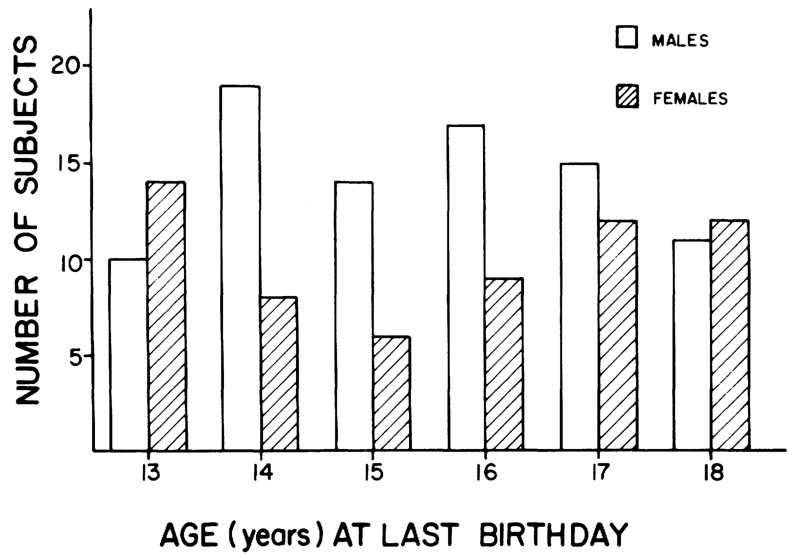

FIGURE 1. *Age distribution of the 147 adolescent subjects.*

Results

Mean Data

The mean values for the independent variables and the systolic time intervals in all 147 adolescents and in males and females separately are given in table 1. No significant differences were found between males and females in the independent variables age, systolic and diastolic blood pressure, serum calcium and serum chloride. The remaining independent variables showed a significant difference between the sexes. The heart rate, which ranged from 44–121 beats/min in the entire group, was significantly higher in females than males. There was no significant difference, however, between the mean values of the systolic time intervals in males and females.

Regression Equations

The stepwise regression analysis showed that heart rate was the only independent variable consistently

TABLE 1. *Independent Variables and Systolic Time Intervals*

	Males (n = 86)	Females (n = 61)	Total (n = 147)
Age (years)	15.8 ± 1.7	15.9 ± 2.0	15.8 ± 2.0
Heart rate (beats/min)	72 ± 14*	82 ± 15	76 ± 15
Height (m)	1.68 ± 0.07*	1.59 ± 0.06	1.64 ± 0.10
Weight (kg)	57 ± 8*	52 ± 7	55 ± 10
Body surface area (m^2)	1.64 ± 0.21*	1.52 ± 0.13	1.59 ± 0.19
Systolic blood pressure (mm Hg)	114 ± 11	113 ± 9	114 ± 11
Diastolic blood pressure (mm Hg)	69 ± 8	69 ± 7	69 ± 8
Hemoglobin (g%)	14.6 ± 1.2*	13.5 ± 0.9	14.1 ± 1.3
Hematocrit (%)	43 ± 3*	41 ± 3	42 ± 4
Serum sodium (mEq/l)	139 ± 6†	137 ± 4	138 ± 6
Serum potassium (mEq/l)	4.4 ± 0.6*	4.0 ± 0.7	4.4 ± 1.1
Serum calcium (mg%)	9.5 ± 0.4	9.4 ± 0.5	9.5 ± 0.3
Serum chloride (mEq/l)	103 ± 3	103 ± 3	103 ± 3
QS_2 (msec)	383 ± 28	377 ± 29	381 ± 29
LVET (msec)	291 ± 19	287 ± 21	290 ± 20
PEP (msec)	92 ± 16	90 ± 13	92 ± 16
PEP/LVET	0.32 ± 0.05	0.31 ± 0.04	0.32 ± 0.05

Values are mean ± SD.
*$p < 0.001$, males vs females.
†$p < 0.05$, males vs females.
Abbreviations: QS_2 = total electromechanical systole; LVET = left ventricular ejection time; PEP = preejection period.

TABLE 2. *Regression Equations for Systolic Time Intervals* in Adolescents*

	Sex	Regression equation	SD	r	CV% of the regression line	CV% of mean value
QS_2	M	498 − 1.60 HR	16.0	0.82	4.2	7.3
	F	522 − 1.77 HR	13.7	0.89	3.6	7.7
LVET	M	366 − 1.04 HR	11.2	0.80	3.8	6.5
		398 − 1.00 HR − 2.41 Hb	11.1	0.83	3.8	6.5
	F	393 − 1.30 HR	9.9	0.89	3.4	7.3
		499 − 1.34 HR − 64.9 Hgt	9.0	0.91	3.1	7.3
PEP	M	132 − 0.56 HR	13.5	0.52	14.7	17.4
		93 − 0.60 HR + 2.95 Hb	13.9	0.54	15.1	17.4
	F	129 − 0.48 HR	11.4	0.52	12.6	14.4
		24 − 0.43 HR + 64.0 Hgt	10.9	0.60	12.0	14.4
		38 − 0.39 HR + 74.0 Hgt − 0.29 SBP	10.7	0.63	11.8	14.4
PEP/LVET	M	0.21 − 0.0011 HR + 0.013 Hb	0.05	0.36	15.7	15.6
	F	−0.094 + 0.34 Hgt − 0.0011 SBP	0.04	0.47	12.3	12.9

*Expressed in milliseconds.
Abbreviations: r = multiple correlation coefficient; CV% = coefficient of variation; HR = heart rate; Hb = hemoglobin; Hgt = height (m); SBP = systolic blood pressure (mm Hg); QS_2 = total electromechanical systole; LVET = left ventricular ejection time; PEP = preejection period.

and significantly related to QS_2, LVET and PEP. These regression equations are given in table 2 and plotted in figures 2 and 3. There is a significant difference between males and females for each of these regression lines ($p < 0.001$).

None of the other independent variables alone was significantly related to QS_2, LVET or PEP. For LVET and PEP, however, regression equations could be derived for hemoglobin, height or systolic blood pressure as additional variables to heart rate (table 2). The equations in which these variables were found to be relevant in addition to heart rate have only a slightly higher correlation (R) than the equations with heart rate alone; further, the addition of these variables does not improve or only slightly improves the coefficient of variation.

Heart rate alone showed no significant relationship to the PEP/LVET ratio. In male subjects, heart rate and hemoglobin together demonstrated a weak, significant correlation with the PEP/LVET ratio. In female subjects, height and systolic blood pressure together were relevant, although the correlation was not strong. These regression equations are shown in table 2. As opposed to the other systolic time intervals, the coefficients of variation for the regression equations for the PEP/LVET ratio differ little from those of the mean values, indicating that the regression equations are no more accurate in predicting this dependent variable than the mean values.

Age was not a relevant variable in any of the regression equations. Regression analysis of the data for each year from ages 13–19 years showed no significant year-to-year differences, validating the use of the data based on the group as a whole.

Discussion

Recently, we confirmed that systolic time intervals in children differ significantly from those in adults, and derived regression equations relating the intervals to heart rate that can serve as reliable normal standards for clinical use in subjects up to the age of 13 years.[2] Compared with the normal standards established by Weissler et al. for adults,[1] QS_2 and PEP were shorter in children at all heart rates, and LVET was shorter at heart rates up to 85 beats/min in males and 105 beats/min in females. The regression lines were not as steep in children as in adults. The present study was undertaken to determine to what extent the

TABLE 3. *Normal Standards for Systolic Time Intervals in Adolescents*

	Equation	Normal value (msec)	SD
QS_2I (males)	= 1.60 HR + QS_2	498	16
QS_2I (females)	= 1.77 HR + QS_2	522	14
LVETI (males)	= 1.04 HR + LVET	366	11
LVETI (females)	= 1.30 HR + LVET	393	10
PEPI (males)	= 0.56 HR + PEP	132	13
PEPI (females)	= 0.48 HR + PEP	129	11
PEP/LVET		0.32	0.05

Abbreviations: HR = heart rate; QS_2 = total electromechanical systole; LVET = left ventricular ejection time; PEP = preejection period; QS_2I, LVETI and PEPI = index values for QS_2, LVET and PEP, respectively.

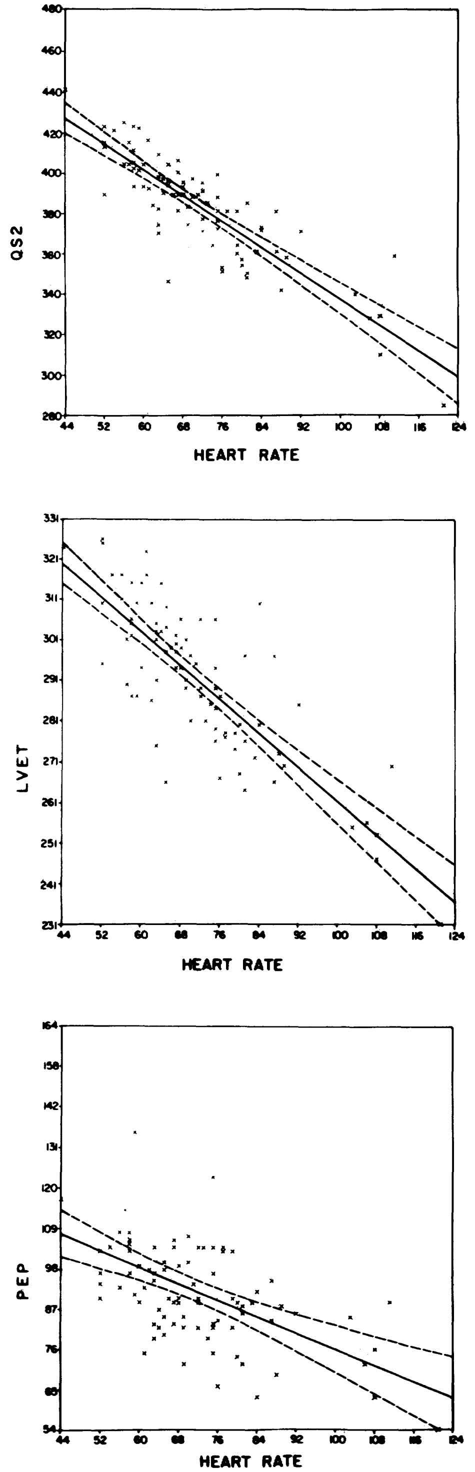

FIGURE 2. *Regression data in male adolescents for total electromechanical systole (QS_2) (top), left ventricular ejection time (LVET) (middle), and preejection period (PEP) (bottom).*

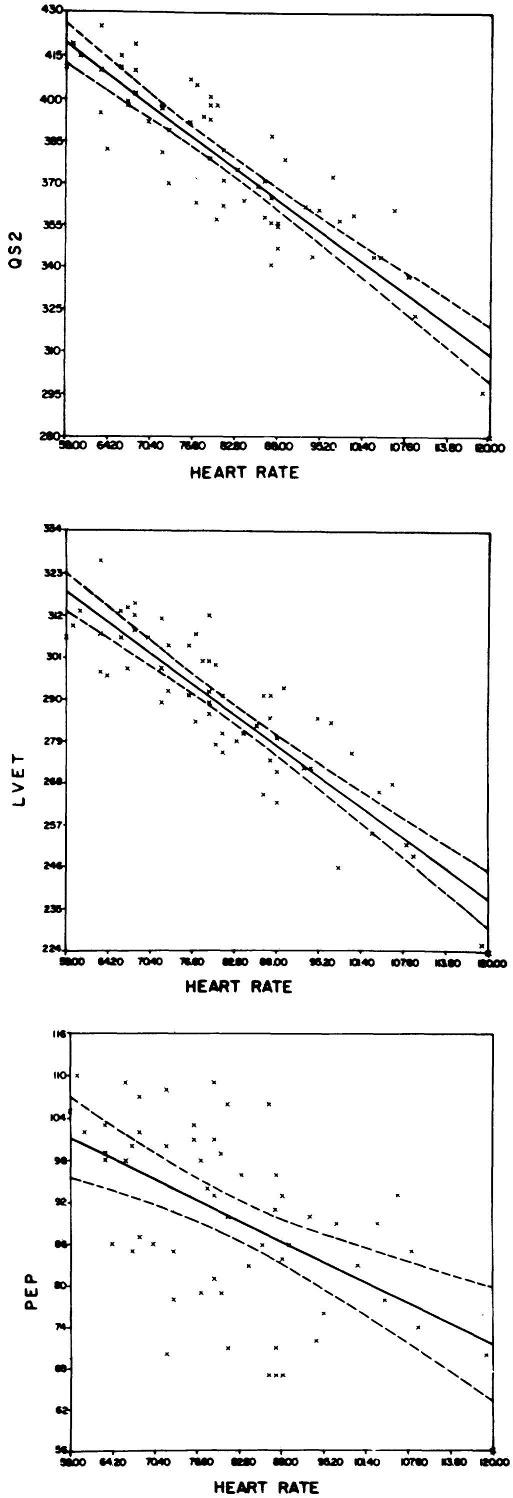

FIGURE 3. *Regression data in female adolescents. Format and abbreviations as in figure 2.*

regression equations relating systolic time intervals to heart rate in normal adolescents ages 13–19 years differ from those of children and adults and thereby define normal standards for clinical use in that age group.

In adolescents, heart rate was the only variable that was consistently significantly related to QS_2, LVET and PEP, as in children. Age was not a relevant variable in the regression equations, nor were any of the other variables tested when used alone. Hemoglobin, height or systolic blood pressure, when used together with heart rate, did, however, have a significant relationship to some of the systolic time intervals, but the influence of these variables in addition to heart rate was small, and the use of the regression equations in which these variables appear would add little accuracy when compared with the use of the regression equations with heart rate alone as normal standards.

For clinical use, the regression equations relating QS_2, LVET and PEP to heart rate alone are satisfactory. The index values of these systolic time intervals (QS_2I, LVETI and PEPI) obtained by transposing the terms of each regression equation are shown in table 3 with the normal values for each of the indexes. Because the PEP/LVET ratio in this study was essentially independent of heart rate, as it is in children and adults, the mean value and its standard deviation are shown in the table. Table 3 provides, therefore, the normal standards of systolic time intervals for clinical use in adolescents.

Although age was not a relevant variable in the regression equations in adolescents and there were no significant year-to-year differences, there were significant differences between adolescents and the other two age groups, children and adults. The regression lines for QS_2, LVET and PEP in adolescents fall between the regression lines for children and adults (figs. 4 and 5). The slopes of the lines for adolescents are almost the same as those for children; all the systolic time intervals, however, are longer in adolescents than in children, at all heart rates, and the regression lines are significantly different from each other ($p < 0.001$). Compared with adults, the PEP at all heart rates is shorter in adolescents, and QS_2 and LVET are shorter at the low or normal heart rates present in most of the adolescents. The mean PEP/LVET ratio for adolescents (0.32) is also midway between the ratios for children (0.30) and adults (0.345).

Comparison of children, adolescents and adults shows a distinct tendency toward lengthening of all the systolic time intervals with increasing age, independent of changes in heart rate. This tendency seems to continue in the elderly, who have been shown to have longer LVET and QS_2 than young adults.[5, 6] Further, there is a change in the relationship of the systolic time intervals to each other, the PEP lengthening proportionately more than the LVET, resulting in a progressively higher PEP/LVET ratio with development from childhood to adolescence and to adulthood. The factors determining these changes with increasing age are not obvious. The small but significant influence of changes in such factors as hemoglobin and blood pressure may play a role. Other possible factors, such as decreasing sympathetic nervous tonus and increasing aortic impedance, and a decline in myocardial contractility with increasing age, are speculative.

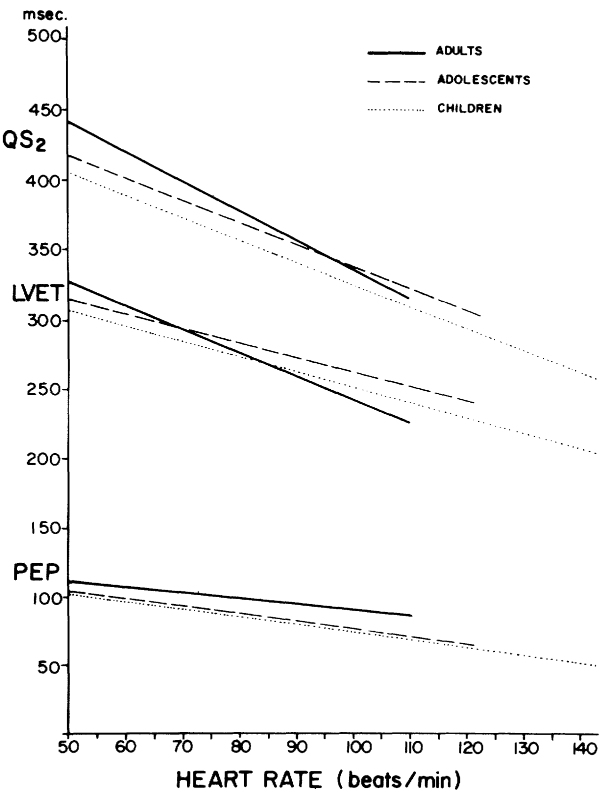

FIGURE 4. *Regression lines for total electromechanical systole (QS_2), left ventricular ejection time (LVET) and preejection period (PEP) in male adults, adolescents and children.*

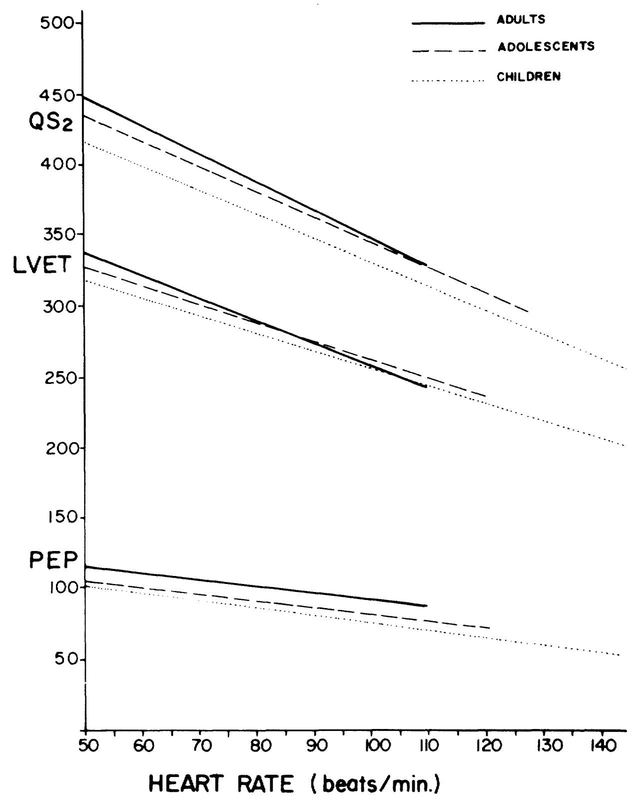

FIGURE 5. *Regression lines for total electromechanical systole (QS_2), left ventricular ejection time (LVET) and preejection period (PEP) in female adults, adolescents and children.*

The precise definitions of the underlying mechanisms, however, must await studies designed to correlate changes in hemodynamic factors with the changes in systolic time intervals with increasing age.

Acknowledgment

The authors thank A. M. Weissler, M.D., for his critical review of the manuscript, and Eliyahu Gertsbach, Ph.D., for his helpful suggestions in the statistical analysis of the data.

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