Electrocardiography Studies

Prevalence of Male and Female Patterns of Early Ventricular Repolarization in the Normal ECG of Males and Females From Childhood to Old Age

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OBJECTIVES   This study was designed to establish the cause of electrocardiographic (ECG) pattern differences between genders.

BACKGROUND   The male and female patterns of early ventricular repolarization in normal ECGs differ from each other. The male pattern displays a higher J-point amplitude and increased ST angle. The distribution of these patterns between genders has not been studied.

METHODS   Normal ECGs of 529 males and 544 females, age 5 to 96 years, were subdivided into nine age groups in each gender. We designated the pattern as female if the J point was <0.1 mV in each of the leads V_1 to V_4, and as male if the J point was ≥0.1 mV and the ST angle ≥20° in at least one of the V_1 to V_4 leads; the pattern was indeterminate if the J point was ≥0.1 mV and the ST angle was <20°.

RESULTS   Distribution of patterns was significantly different between genders (p < 0.001). In females, the patterns were distributed similarly from puberty to advanced age with about 80% prevalence of the female pattern. In males, the male pattern prevalence increased at puberty, reached 91% in the age group of 17 to 24 years and declined gradually with advancing age to 14% in the oldest males. The prevalence of indeterminate pattern was about 10% in both genders. Patterns were unchanged in 95% of 493 subjects who had ECGs recorded at separate times or at different heart rates.

CONCLUSIONS   Gender differences in early ventricular repolarization were caused by age-dependent changes in prevalence of the male pattern.   (J Am Coll Cardiol 2002;40:1870–6) © 2002 by the American College of Cardiology Foundation

The fact that women have longer QT intervals than men has been known since 1920 (1). Additional differences between ventricular repolarization in the electrocardiograms (ECGs) of males and females were elicited later (2–12).

In 1953, Lepeschkin and Surawicz (3) analyzed the ECGs in 50 normal men and 50 normal women and concluded that the characteristics of the ST-segment and the T-wave make it possible to distinguish the ECG of a woman from that of a man. Until recently, this information has been of no practical interest. This is no longer the case. The interest in the repolarization difference between genders has been awakened by the recognition that ventricular arrhythmias resulting from abnormal ventricular repolarization, i.e., torsades de pointes (TdP), are more prevalent in women than in men (13–17). The investigation into the cause of these gender differences has focused predominantly on the aspects of longer QT interval and greater drug-induced QT prolongation in women. Earlier, Lepeschkin and Surawicz (3) and more recently Lehmann and Yang (12) established that most of the changes contributing to the longer QT duration in women occur during the ST-segment and at the beginning of the T-wave. Recently,

Bidoggia et al. (11) found that the two parameters of early repolarization (i.e., the amplitude of the J point and the angle between the ST-segment and the baseline) were the best discriminators between the ECGs of males and females. Bidoggia et al. (11) computed a score that combined these two measurements with the amplitude of the T-wave and found that about 80% of men had a score with male characteristics and that about 90% of women had a score with female characteristics. They also found that the score with male characteristics declined with age, whereas the score in women remained nearly constant at all ages.

We questioned the specificity of the scores obtained by Bidoggia et al. (11) because they represented the average of all ECGs in a gender. Although it is not emphasized in the literature, it can be readily observed that typical male patterns may occur in females and vice versa. This means that the average male or female patterns have been derived from a mixture of male and female patterns. We hypothesized that we could understand the ECG differences between genders better by examining the distribution of the gender-specific patterns among different age groups of males and females.

METHODS

We retrieved the digitally stored ECGs, interpreted as normal, in the MUSE system (Marquette Medical Systems,

Milwaukee, Wisconsin) at St. Vincent Hospital, Indianapolis, Indiana. We pooled the tracings of both in- and out-patients recorded in the years 1999 and 2000. From this data pool we obtained lists of subjects within specified age categories. The ECG of each adult subject on the list was examined by the first author and that of the child by the second author to determine whether the tracings classified as normal by the MUSE system met our criteria of normalcy established for this study.

We considered the ECG as normal in the presence of regular sinus rhythm within a rate range from 45 to 96 beats/min in adults and up to 110 beats/min in children younger than 9 years, normal P-wave, PR interval <200 ms, normal QRS complex of <110 ms duration, normal ST-segment, upright T-waves of >0.1 mV amplitude in all leads except III, aV_R, and V_1 (V_2 and V_3 in children), and QTc <440 ms. To obtain numerically equal samples of males and females, we selected alternate ECGs of males and females from the lists. To avoid selection bias, we examined each successive ECG on the list and did not leave out any normal ECG except those in subjects who had earlier abnormal ECGs stored in the computer. The ECGs were recorded at a paper speed of 25 mm/s with standardization of 1 cm = 1 mV. The ECG intervals, including the QTc, were measured by the MUSE system algorithm.

We inspected only the four precordial leads V_1, V_2, V_3, and V_4. In children with negative T-wave in the leads V_1 to V_3, we included lead V_5. We measured the T-wave amplitude in the lead with the tallest T-wave. Guided by the results of the study of Bidoggia et al. (11), we selected the following two variables to define the gender-specific patterns: 1) the amplitude of the J point and 2) the angle between the baseline and the ST-segment (ST angle). The following procedure was used:

1. We selected two successive QRS complexes of identical amplitude in the lead with the largest amplitude of the J point, which in most cases was the lead with the tallest T-wave, and connected the onset of these two QRS complexes by a horizontal line (Q–Q line).
2. We identified the J point visually as a point of sharp transition from the QRS complex to the ST-segment. If the transition point was not clearly defined, we extrapolated the J point as the point at which the ST slope extended backward began to increase (18). The measurement of J-point amplitude was aided by 2× magnification of the ECG complex.
3. The pattern was considered as *female* when the J-point amplitude was <0.1 mV in each of the four leads (Fig. 1A).
4. To measure the ST angle we drew a line that was parallel to the Q–Q line at the level of the J point and a line connecting the J point with a point situated 60 ms after the J point. The angle between these two lines represents the ST angle. The pattern was considered as *male* when the J point was ≥0.1 mV in at least one of the four leads and when the ST angle was ≥20° in at least one of these leads (Fig. 1B). In most cases, both criteria were met in

Figure 1. Method of pattern determination in representative electrocardiogram complexes of lead V_3. The two horizontal lines represent the Q–Q line and the line parallel to the Q–Q line at the level of the J point, respectively. The arrow marks the J point; the short vertical line marks the point 60 ms after the J point; the oblique line connects the J point with the above point (see text). **(A)** Female pattern: the J point is at the level of the Q–Q line, and the ST angle is 19°. **(B)** Male pattern: the J point is >0.1 mV above the Q–Q line, and the ST angle is 36°. **(C)** Variant of the male pattern in which the T-wave ascends at the J point; the J point is >0.1 mV above the Q–Q line, and the angle between the line parallel to the Q–Q line at the level of the J point and the ascent of the T-wave is 29°. **(D)** Indeterminate pattern: the J point is >0.1 mV above the Q–Q line, and the ST angle is 15°.

Table 1. Distribution of Male, Female, and Indeterminate ECG Patterns Among Males and Females of Different Age Groups

Age Group in Years	Males				Females			
	ECGs (n)	Male Pattern n (%)	Female Pattern n (%)	Indet. Pattern n (%)	ECGs (n)	Male Pattern n (%)	Female Pattern n (%)	Indet. Pattern n (%)
5–7	49	31 (63)	16 (33)	2 (4)	60	12 (20)	42 (70)	6 (10)
8–12	55	30 (55)	21 (38)	4 (7)	52	12 (23)	40 (77)	0
13–16	57	46 (80)	9 (16)	2 (4)	57	9 (16)	42 (74)	6 (10)
17–24	46	42 (91)	3 (7)	1 (2)	47	6 (13)	37 (79)	4 (8)
25–35	53	39 (74)	6 (11)	8 (15)	51	5 (10)	40 (78)	6 (12)
36–45	50	29 (58)	12 (24)	9 (18)	50	0	48 (96)	2 (4)
46–54	63	30 (48)	27 (43)	6 (9)	68	4 (6)	57 (84)	7 (10)
55–75	83	25 (30)	45 (54)	13 (16)	83	5 (6)	70 (84)	8 (10)
76–96	73	10 (14)	51 (70)	12 (16)	76	3 (4)	64 (84)	9 (12)
Total	529	282 (53)	190 (36)	57 (11)	544	56 (10)	440 (81)	48 (9)

ECG = electrocardiograms; Indet. = Indeterminate; n = number.

the same lead. In a variant of a male pattern that was present in 6% of cases, there was no visible transition between the ST-segment and the ascent of the T-wave (Fig. 1C).

5. We considered the pattern as *indeterminate* when the J point was ≥ 0.1 mV but the ST angle was $<20°$ in each of the four leads (Fig. 1D).

For each ECG, the two authors determined jointly the J-point amplitude and the ST-segment angle. The Q–Q line and the two lines defining the ST angle were pencil-marked on each tracing. Before reaching the consensus about the J-point location and the ST-segment angle, inter- and intra-personal differences of pattern definition ranged from 2% to 9% in subgroups of tracings.

After the tabulation of results, we searched the MUSE system records for the remaining ECGs of each study subject. The purpose of this search was to compare in each subject the gender patterns in the ECGs recorded either at intervals ≥ 2 weeks and/or at heart rates differing by ≥ 10 beats. From the ECGs of 1,073 subjects in the study, we excluded from comparison the tracings of 29 (2.7%) subjects in whom an abnormal rhythm or pattern was recorded on an ECG made after the completion of the study. The remaining subjects had no abnormal ECGs recorded before or after completion of the study. In 750 subjects (70%), pattern comparison was not possible, because they had only single ECGs or multiple ECGs recorded at intervals <2 weeks or at heart rates differing by <10 beats/min. We compared the patterns in the ECGs of the remaining 294 subjects (27.3%), designated in the subsequent text as group 1, who had one or more ECGs recorded at intervals ≥ 2 weeks and/or at heart rates differing by ≥ 10 beats/min. In the case of multiple ECGs suitable for comparison, we used the ECG separated by the longest period of time or the one with the heart rate that differed most. When the longest separation period and the heart rate that differed most occurred in two different ECGs, we used for comparison the ECG with the longest separation period.

To test whether the results of pattern comparison in group 1 were reproducible, we compared patterns in the ECGs separated by time of recording or differing in heart rate in another sample of consecutive normal ECGs recorded from November 9, 2001, until February 6, 2002. This cohort included 1,062 subjects in whom all ECGs stored in the computer were normal. Of these, 200 subjects, designated in the subsequent test as group 2, had two or more normal ECGs recorded at intervals ≥ 2 weeks and/or at heart rates differing by ≥ 10 beats/min. These ECGs were compared in the same manner as those in group 1.

Statistical methodology. Data are given as mean $\pm$ SD. Fisher exact test was used to compare the distribution of male, female, and indeterminate patterns in male and female subjects within age groups or between age groups within gender. Continuous variables were compared between genders and age groups using two-way analysis of variance (ANOVA). Comparison within gender used one-way analysis with the Tukey HSD test for multiple comparisons. Comparisons between genders within age group were done using a t test.

RESULTS

We examined 529 ECGs of males and 544 ECGs of females. Eighty-nine percent of subjects were listed as Caucasians, 10.1% as black, and 0.9% as others. Table 1 and Figure 2 show the prevalence of the male, the female, and the indeterminate pattern in nine age groups of males and females. The number of males and females in each group is similar.

Figure 2 shows that in females the three patterns are similarly distributed in all age groups except for children, in whom the prevalence of the male pattern is higher and that of the female pattern is lower than in the remaining age groups ($p < 0.001$). The prevalence of the male pattern increased in male adolescents and young adults, reaching 91% in the age group 17 to 24 years of age. With further increase in age, prevalence of the male pattern gradually declined and was accompanied by a corresponding increase
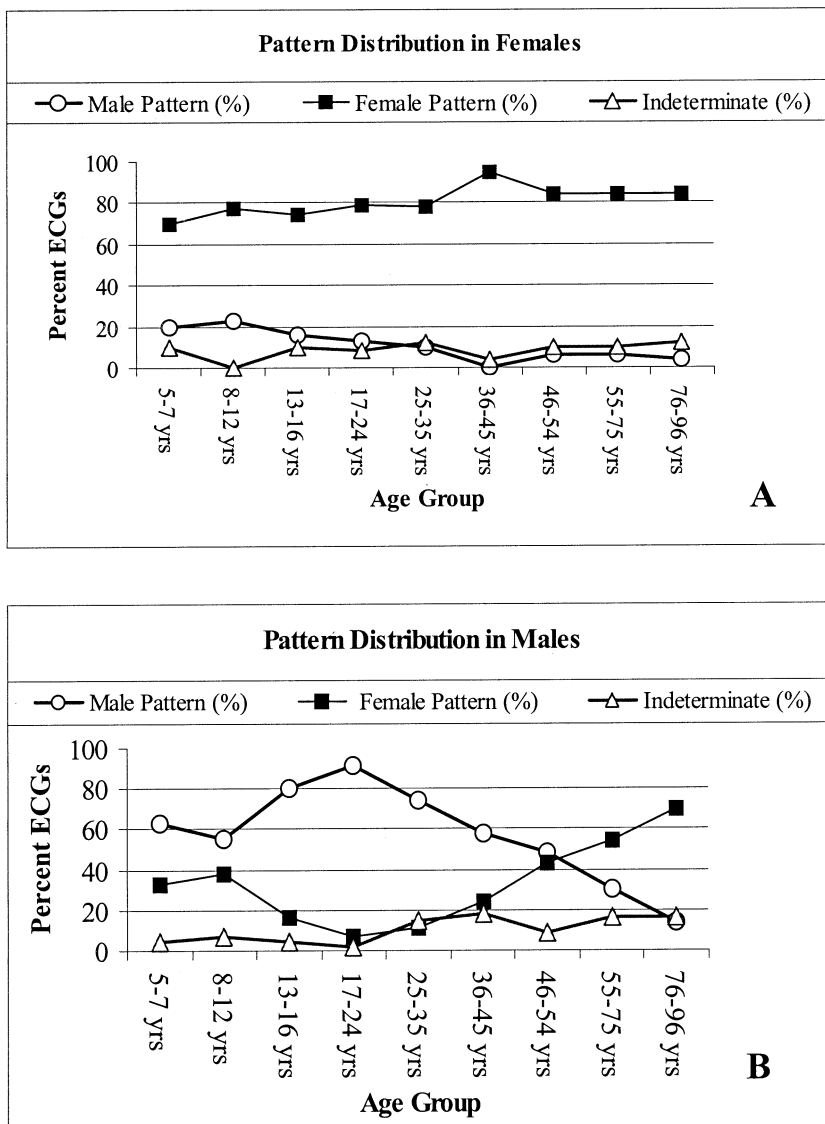
Figure 2. Pattern distribution in different age groups of females and males. See text. ECG = electrocardiograms.

in the prevalence of the female pattern. At more advanced ages, the female pattern became predominant.

Comparison between age groups in males showed a significant difference in the overall distribution of patterns (p < 0.001). The differences between the distribution of patterns in males versus females were significant in all age groups (p < 0.001) except for the oldest, in which the differences were borderline (p = 0.059). The significance of the differences was not affected by the inclusion of subjects with indeterminate patterns into the cohort with either the male or female pattern (p < 0.001 for both comparisons). The distribution of patterns among black subjects appeared to be the same as among Caucasians, but the numbers of black subjects in the individual groups were too small to test the statistical significance of differences.

Table 2 shows the distribution of heart rate, QTc interval, and T-wave amplitude among different age groups in both genders. The heart rate was significantly faster in

females than in males in four of nine age groups and was not significantly different in the other five age groups. In the individual age groups of males and females, there were no significant differences between the heart rates of subjects with male patterns compared with subjects with female patterns.

The QTc interval was significantly longer in women than in men in the age groups from 17 to 75 years and was not significantly different in children up to age 16 and in the age group 76 to 98 years. The T-wave amplitude was significantly greater in males than in females in all age groups except for the age group 5 to 7 years.

Table 3 shows the average ST angles in all males (n = 282) and all females (n = 56) with male patterns. The ST angle among males in the age group 17 to 24 years was significantly greater than that in age groups 5 to 7 years, 8 to 12 years, 36 to 45 years, 46 to 54 years, and 78 to 96 years (ANOVA p < 0.001). There were no differences in ST

Table 2. Distribution of Heart Rate, QTc Duration, and T-Wave Amplitude

Age Group in Years	Male Mean HR (SD)	Female Mean HR (SD)	p Value	Male Mean QTc (SD)	Female Mean QTc (SD)	p Value	Male Mean T (SD)	Female Mean T (SD)	p Value
5–7	89.6 (11.7)	87.2 (12.9)	0.334	403.2 (16.4)	402.6 (10.0)	0.84	5.3 (2.1)	4.9 (2.3)	0.297
8–12	77.5 (11.9)	82.6 (11.1)	0.023	408.8 (11.9)	409.7 (14.9)	0.725	5.2 (2.2)	4.2 (1.6)	0.005
13–16	71.8 (13.6)	75.8 (14.7)	0.134	407.7 (13.6)	411.9 (14.9)	0.118	4.5 (2.3)	3.7 (1.5)	0.037
17–24	70.3 (11.2)	73.0 (10.4)	0.23	401.8 (14.6)	408.6 (15.5)	0.033	5.3 (2.1)	3.0 (1.2)	< 0.001
25–35	70.3 (12.0)	74.5 (9.3)	0.046	405.7 (15.8)	411.9 (14.6)	0.042	3.7 (1.8)	3.0 (1.4)	0.024
36–45	70.1 (10.8)	73.5 (9.6)	0.11	403.6 (11.3)	411.4 (13.1)	0.003	4.2 (1.6)	2.5 (1.3)	< 0.001
46–54	70.1 (13.9)	74.3 (11.8)	0.061	409.4 (14.4)	417.3 (14.5)	0.002	4.0 (1.9)	2.8 (1.3)	< 0.001
55–75	64.1 (10.4)	70.5 (12.4)	0.001	408.0 (11.8)	412.6 (10.2)	0.004	4.3 (1.7)	2.6 (1.1)	< 0.001
76–98	67.5 (14.8)	72.2 (11.7)	0.032	415.1 (15.6)	415.5 (14.4)	0.98	4.2 (2.1)	3.4 (1.4)	0.007

HR = heart rate; QTc = corrected QT interval; mean T = mean T-wave voltage (×0.1 mV).

angle between age groups among women with male patterns (ANOVA p = 0.112), but sample sizes are small.

Among subjects with female patterns, an ST angle of >20° was present in 40 of 440 females and in 33 of 190 males. In the former group, the ST angle averaged 25.4 ± 5.1° (21° to 36°), and in the latter group, the ST angle averaged 25.3 ± 3.7° (21° to 33°) (NS).

Table 4 shows that in 280 of 294 subjects (95.2%) in group 1, patterns were not changed by differences in the time of recording or differences in the heart rate. In five males the change from male to female or to indeterminate pattern could be explained by an increase in age. No such speculative explanation of pattern change could be applied to four other males and females in whom the following pattern changes took place: male to female (n = 1); female to male (n = 2); male to indeterminate (n = 1); female to indeterminate (n = 2); and indeterminate to female (n = 3).

In group 2, patterns were not changed by differences in the time of recording or differences in the heart rate in 190 of 200 subjects. The findings in group 1 and group 2 were nearly identical (p = 0.95; Fisher exact test).

DISCUSSION

Analysis of the ECG. Without measurements, the typical male and the typical female patterns are readily recognizable visually in most normal ECGs. For separation of patterns we used a 0.1 mV J-point amplitude and an ST angle of 20°.

In all ECGs with male patterns, J-point amplitude was ≥0.1 mV, and ST angle was ≥20°. In the ECGs with female patterns, the J point was <0.1 mV in all cases, and the ST angle was <20° in 88.4% of cases. The two variables were distributed similarly. Thus, the male pattern was present in 76.3% of subjects with a J point ≥0.1 mV and in 82.2% of all subjects with an ST angle ≥20°. Conversely, the female pattern was present in 85.7% of all subjects with a J point <0.1 mV and in 89.6% of all subjects with an ST angle <20°. If we used J-point criterion alone the indeterminate pattern would become male, which would not change the statistical significance of the differences. Similarly, the statistical difference would remain unchanged if we used the criterion of ST angle alone.

Hormonal hypothesis. Our findings support the hypothesis that the physiologic differences between ventricular repolarization in males and females are strongly influenced by changes in the availability or activity of the male sex hormones. The age-dependent changes in prevalence of the male pattern in males appear to parallel the rise of testosterone blood level in males during puberty and the decline of testosterone level in elderly males (19,20).

In support of the androgen hypothesis, Bidoggia et al. (21) found that repolarization in castrated males was slower than in normal males, whereas the repolarization in virilized women was faster than that in normal women. A study of isolated ventricular endocardium from control and castrated

Table 3. ST Segment Angle >20° in Males and Females With Male Pattern

Age in Years	Males Total Number	Males Angle ≥20°	Males Mean	Males SD	Females Total Number	Females Angle ≥20°	Females Mean	Females SD
5–7	49	31	29.6	6.6	60	12	29.3	7.2
8–12	55	30	29.6	6.7	52	12	28.7	4.8
13–16	57	46	31	8.3	57	9	23.3	2.1
17–24	46	42	37.6	12.4	47	6	24.8	4.2
25–35	53	39	33.5	8.1	51	5	26.3	3.8
36–45	50	29	29.8	7.4	50	0		
46–54	63	30	29.6	6.2	68	4	24.3	3.1
55–75	83	25	31.1	7.1	83	5	26	4.5
76–96	73	10	26.1	6.4	76	3	28.3	1.5
Total	529	282			544	56		

Table 4. Comparison of ECG Patterns Recorded at Different Times and at Different Heart Rates (Group I)

	Subjects (n)	Age at First ECG Mean ± SD	HR Diff (beats/min)	Time Diff (years)	Pattern 1 (m,f,i)	Pattern 2 (m,f,i)	Pattern 1 & 2 Comparison Same	Pattern 1 & 2 Comparison Not Same
Males:								
Time between ECGs <2 weeks, HR difference ≥10 beats/min								
	22	50 ± 18 (15–81)	26.7 ± 14.6 (11–58)	<0.04	12,8,2	11,9,2	21	1
Time between ECGs >2 weeks, HR difference <10 beats/min								
	70	57 ± 20 (8–86)	<10	1.4 ± 1 (0.04–3.4)	31,35,4	26,38,6	65	5
Time between ECGs >2 weeks, HR difference ≥10 beats/min								
	60	53 ± 24 (7–90)	22.1 ± 13.1 (10–65)	1.1 ± 0.9 (0.07–3.8)	24,33,3	23,34,3	57	3
Total	152						143	9
Females:								
Time between ECGs <2 weeks, HR difference ≥10 beats/min								
	7	49 ± 26 (15–76)	28.4 ± 15 (12–49)	<0.04	1,5,1	2,5,0	6	1
Time between ECGs >2 weeks, HR difference <10 beats/min								
	63	58 ± 21 (10–91)	<10	1.4 ± 0.9 (0.08–3.6)	6,49,8	7,48,8	60	3
Time between ECGs >2 weeks, HR difference ≥10 beats/min								
	72	53 ± 20 (15–94)	21.2 ± 12.4 (10–62)	1.4 ± 1 (0.14–3.5)	2,69,1	2,70,0	71	1
Total	142						137	5
Total Males & Females:								
	294						280	14

Numbers in parentheses represent range. Age of subjects is in years.
diff = difference; HR = heart rate; m,f,i = male, female, and indeterminate patterns.

male and female rabbits showed that testosterone protected from excessive drug-induced action potential prolongation in males (22). As a clinical corollary, intramuscular testosterone administration restored male ECG pattern of repolarization in three castrated males (21).

After puberty in females, we found no significant age-dependent differences in the distribution of patterns. Earlier studies showed no difference in the corrected QT intervals in women among the three phases of menstrual cycle (23) and no significant effect of hormonal replacement on the duration of the QT interval (24). In a more recent study, the drug-induced QT prolongation in women was greater during menses and ovulatory cycles than during the luteal phase (25).

Relationship to previous studies. In agreement with Rautaharaju et al. (26), we found no significant difference between the QTc intervals of boys and girls below the age of 16 years. A significant difference between males and females appeared in the 17-to-24-year age group, probably as a result of QTc shortening in males (26). The significantly shorter QTc in males than in females persisted in all age groups up to age of 75 years. In the age groups in which QTc was significantly longer in females than in males, differences in the distribution of male and female patterns were present. The absence of QTc differences between males and females in the oldest subjects was associated with the near absence of difference in the distribution of male and female patterns. The absence of QTc differences in children up to age 12 could be explained by a relatively high prevalence of female patterns in boys and a greater prevalence of male patterns in girls, compared with adult females.

The T-wave amplitude was higher in all age groups in males than in females except for 5-to-7-year-old children.

The observed differences in the T-wave amplitude corroborated the results of several previous studies (3,5,9,27).

The characteristics of male and female patterns in our study were based on the findings of Bidoggia et al. (11). In this study (11), all average ST-angle values in males in age groups 20 to 60 years were above 20°, and all average values in females in all age groups were below 15° (Fig. 2 in reference 11). In the same study, the average J-point amplitude was <0.3 mm in all age groups in females and above 0.8 mm in 20- to 49-year-old males. Also, the illustrated results of the Lehmann and Yang study (12) support our choice of the 20° ST angle for separating male and female repolarization patterns.

Possible practical significance. Women are known to be at higher risk of TdP in various conditions associated with prolonged QT (13–17). Also, drugs that prolong repolarization cause a greater increase in QT duration in women than in men (28). It will be of interest to examine whether these gender differences are caused by differences in prevalence of the male and female patterns among genders, that is, whether females with male patterns enjoy the benefits of males and males with female patterns share the risks of females.

Limitations. The arbitrary choice of 0.1 mV J-point amplitude as the criterion of the male pattern in the normal ECG fails to take into account the influence of QRS amplitude on J-point amplitude. An appropriate correction for this factor may be desirable to increase the accuracy of pattern separation. Of similar benefit may be the substitution of ST angle by a computed slope of the ST-segment. Our results apply only to subjects with normal ECGs at normal heart rates.

We do not know the physical and clinical characteristics

of the subjects. The time of the hour and of the season of the ECG recording was beyond our control. Circadian rhythms may affect the duration of QT intervals (29–31) and the QT rate dependence (29,30). Similarly, both the time of the day and the season of the year may affect blood testosterone levels in males (31,32). We are unable to estimate the influence of these and other unrecognized uncontrolled factors that may affect the ECG both directly and indirectly, but it appears unlikely that such factors could challenge the validity of our results. Our finding that in 95% of subjects the pattern remained unchanged in the normal ECGs recorded at different times or at different heart rates argues against random variability caused by undisclosed factors, such as variations in the autonomic tone. Other evidences favoring the validity of our results include the high level of statistical significance and the fact that our results are in complete agreement with the findings elicited in healthy population groups in all aspects of previously studied gender- and rate-dependent ECG comparisons (3,5,9,11,12,26,27). We propose that our findings define conditions prevailing in a population with normal ECGs, but we acknowledge the need for confirmation and further studies of gender-dependent electrophysiologic differences.

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