The P Wave, P-R Interval, and Q-T Ratio of the Normal Orthogonal Electrocardiogram

By Hubert V. Pipberger, M.D., and Herbert L. Tanenbaum, M.D.

The shortcomings of electrocardiographic time measurements from single leads have been noted before. With the use of simultaneously recorded corrected, orthogonal leads it is possible to evaluate better the time phase relationships of the electrocardiogram. The present study involves a statistical analysis of measurements of the P-wave duration, P-R interval, P-R segment, Q-T duration, and Q-T ratio of a group of 133 normal subjects.

Electrical signals generated from the heart are more properly defined in magnitude and direction by an orthogonal 3 lead system with constancy in lead direction and strength. The spatial heart vectors are projected on the 3 perpendicular axes of such a Cartesian coordinate system, and are readily available for analysis. With the advent of corrected orthogonal lead systems it appeared appropriate to reevaluate the time-phase relationships of the electrocardiogram in simultaneously recorded tracings of the 3 orthogonal leads. Such an analysis should come very close to the determination of the true beginning and end of electric events as they take place in the heart, as far as these can be ascertained from the body surface.

In previous studies by Blackburn and Simonson and from this laboratory it was found that the QRS duration differs markedly from the commonly accepted, normal standards when simultaneously recorded tracings of orthogonal leads are analyzed. It seemed apparent, therefore, that other intervals used in electrocardiographic interpretations should also be reinvestigated in the same fashion. White and associates and Surawicz have discussed the shortcomings of electrocardiographic time measurements from single leads. More accurate time-phase determinations may yield clinical information hitherto not available.

The present study involves a statistical analysis of measurements of the P-wave duration, P-R interval, P-R segment, corrected Q-T interval, and Q-T ratio in a group of 133 normal subjects. Schmitt’s SVEC III leads were used. A high degree of constancy in lead strength and direction of this system has been demonstrated previously in torso models and in man.

Material and Methods

Tracings were taken from 133 subjects who were admitted to Georgetown University Hospital and the Veterans Administration Hospital, Washington, D.C., for reasons other than heart disease. A complete clinical evaluation including a standard 12 lead electrocardiogram did not reveal any signs or symptoms of past or present cardiac pathology. The age and sex distribution of these patients are shown in Table 1. The mean heart rate of these cases was 77 ± 11 per minute, with a range from 50 to 99.

Recordings from 101 subjects were taken on 5 inch photographic paper with a film speed of 118 mm, per second. The remainder of the tracings were recorded on 35 mm, film with a film speed of 28 mm, per second. A photographic enlarger was used for the analysis of these records with an 8 fold magnification, resulting in an apparent film speed for reading of 224 mm, per second. Such large record sizes and film speeds facilitated the measurements of the data. The electronic characteristics of the high-fidelity recording apparatus have been described previously.

The baseline was established between 2 points on the T-P interval of 2 consecutive complexes.
Fig. 1. Simultaneously recorded tracings of leads X (top), Y (middle) and Z (bottom). The total P-wave duration, P-R interval, P-R segment, and Q-T duration are indicated by the broken lines. Note the discrepancies between the different leads for the onset and end of deflections. The retrograde prolongation of the P-R segment in lead Y shows the method used for the determination of the end of the P waves.

These points were taken just prior to the onset of the P wave. All measurements were made from the lower edge of the tracings.

The total P wave duration was determined as follows: The beginning of the P wave was taken at the point of its earliest departure from the baseline in any one of the 3 leads (fig. 1). Because the P-R segment in most cases does not coincide with the preestablished baseline, a different method had to be used for the determination of the end of the P wave. The P-R segment baseline was extrapolated backward, as illustrated in lead Y of figure 1. The intersection of this line with the preceding P wave wherever it occurred latest in the 3 leads was marked as the end for the measurement of the total P-wave duration. The individual P waves from each lead were measured separately as well.

The amplitude of the P wave was measured between the preestablished baseline (T-P) and the highest point of each P deflection. In some instances, most notably in lead Z, the P amplitude could not be measured accurately because of the biphasic or flat characteristic of the deflections.

The P-R interval was measured from the earliest P deflection to the earliest QRS deflection of the 3 leads. The P-R segment was taken as the difference between the P-R interval and the total P-wave duration.

The Q-T duration was measured from the earliest QRS deflection to the end of the latest T deflection of the leads. The corrected Q-T duration or Q-Tc was calculated by dividing the actual Q-T duration by the square root of the preceding R-R interval. The mean result for Q-Tc was used as a constant K for the calculation of the Q-T ratio, according to the formula:

$$\frac{Q-T \text{ duration}}{K} \times \frac{1}{\sqrt{R-R}}$$

Results

Mean results, standard deviations, standard errors, and ranges of the measured parameters are presented in table 2.

The vertical lead Y was the most reliable of the 3 for the determination of the total P-wave duration. In 35 per cent of the cases, however, P_Y was found shorter than the total P (table 2, 6).

A normal Gaussian distribution was found for the total P-wave duration, P-R interval, and P-R segment. The distribution curve for the P/P-R segment ratio, however, appeared drawn out toward the higher values (fig. 2). The 8 cases exceeding the confidence limits of the mean plus 2 standard deviations were singled out for further analysis. P-wave durations and P-R intervals of these patients were found inside the established confidence limits. The large values for the P/P-R segment ratio could therefore be attributed solely to short P-R segments.

Results were further analyzed by correlating age and heart rate with the total P-wave duration, P-R interval, and P-R segment, respectively. No significant correlations were found between any of these parameters. However, several interesting factors were noted. Beyond the age of 60, the total P-wave duration was greater than 0.095 second in all cases.

### Table 1.—Age and Sex Distribution of the Subjects Studied

<table>
<thead>
<tr>
<th>Age group</th>
<th>Number of subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td>21—30</td>
<td>5</td>
</tr>
<tr>
<td>31—40</td>
<td>12</td>
</tr>
<tr>
<td>41—50</td>
<td>14</td>
</tr>
<tr>
<td>51—60</td>
<td>11</td>
</tr>
<tr>
<td>61—70</td>
<td>1</td>
</tr>
<tr>
<td>71—83</td>
<td>2</td>
</tr>
</tbody>
</table>
### Table 2.—Mean Results and Ranges for the Normal Orthogonal Electrocardiogram

| 1. Total P-wave duration | 0.102 ± 0.013 sec., SE* 0.001 sec. | Range: 0.068 — 0.141 sec. |
| Lead X | 0.079 ± 0.019 sec., SE 0.002 sec. | Range: 0.038 — 0.127 sec. |
| Lead Y | 0.096 ± 0.018 sec., SE 0.002 sec. | Range: 0.025 — 0.131 sec. |
| Lead Z | 0.072 ± 0.019 sec., SE 0.002 sec. | Range: 0.025 — 0.110 sec. |
| 2. P-wave duration | 0.079 ± 0.019 sec., SE 0.002 sec. | Range: 0.038 — 0.127 sec. |
| Lead X | 0.096 ± 0.018 sec., SE 0.002 sec. | Range: 0.025 — 0.131 sec. |
| Lead Y | 0.072 ± 0.019 sec., SE 0.002 sec. | Range: 0.025 — 0.110 sec. |
| 3. P-wave amplitude (positive deflections) | Lead X | 0.07 ± 0.02 mV, SE 0.002 mV | Range: 0.03 — 0.15 mV |
| Lead Y | 0.11 ± 0.04 mV, SE 0.004 mV | Range: 0.03 — 0.26 mV |
| Lead Z | 0.06 ± 0.03 mV, SE 0.003 mV | Range: 0.02 — 0.12 mV |
| 4. Number of cases with biphasic P waves | Lead X | 0 |
| Lead Y | 2 |
| Lead Z | 55 |
| 5. Amplitude of negative P-wave deflections | Lead Y | 0.03 mV (1) |
| Lead Z | 0.05 ± 0.02 mV, SE 0.006 mV | Range: 0.02 — 0.08 mV |
| 6. Percentage of cases with total P-wave duration equal to P-wave duration | Lead X | 24 |
| Lead Y | 65 |
| Lead Z | 17 |
| 7. P-R interval | 0.135 ± 0.024 sec., SE 0.002 sec. | Range: 0.101 — 0.211 sec. |
| 8. P-R segment | 0.047 ± 0.017 sec., SE 0.001 sec. | Range: 0.010 — 0.093 sec. |
| 9. Ratio between total P-wave duration and P-R segment | 2.56 ± 1.42, SE 0.12 |
| 10. Q-T duration | 0.367 ± 0.028 sec., SE 0.002 sec. | Range: 0.283 — 0.444 sec. |
| 11. Q-Tc (corrected Q-T duration) | 0.41 ± 0.027, SE 0.002 |
| 12. Q-T ratio (calculated on the basis of the mean Q-T of 0.41) | 1.0 ± 0.065, SE 0.006 |

Measurements that appeared unreliable for technical reasons were not included in this tabulation. The number of subjects for each measured item is given in parenthesis. For the methods of measurements see text.

*SE = standard error.
except one, and the P-R interval greater than 0.135 second. In general, smaller P-wave durations and P-R intervals were noted at higher heart rates; however, deviations from this rule were frequent. P-R segments shorter than 0.025 second were found only with heart rates greater than 75 per minute.

The mean corrected Q-T duration (Q-Tc) was also calculated for each sex. It was found to be 0.407 ± 0.025 in males and 0.426 ± 0.026 in females. The difference was not significant (p > 0.05).

The actual Q-T duration was correlated with the heart rate. Although an apparent correlation was noted on a scattergram (fig. 3), the correlation coefficient was found to be low (-0.17). The marked scatter noted in relating the Q-T interval to heart rate, especially in individuals over 50 years of age, has been commented on by Klakeg et al.12

**Discussion**

**P-Wave Duration.** The total P-wave duration as determined from the simultaneously recorded orthogonal leads was considerably larger than the generally accepted normal standards of the conventional electrocardiogram.13 Caceres and Kelsey,14 who analyzed recently standard electrocardiographic leads of a smaller group of normal persons, have also noted larger limits for the normal range of P duration. Some of their results exceeded those of the present study. The discrepancies may be partially due to differences in the recording technic. Enlarged tracings from a direct-writing electrocardiograph were analyzed. The thickness of the tracings relative to oscillographic records may conceivably add to the length of measured waves.

No single lead was sufficiently reliable to indicate the total P-wave duration. With lead Y taken as the most reliable of the 3 leads, the total P duration would have been missed in 35 per cent of the present series. This finding indicates the need of the use of multichannel recorders in electrocardiography for greater accuracy in time-phase analysis.5-9

**P-R Interval.** Stewart and Manning15 reported a higher mean value for the P-R interval in conventional electrocardiograms than found in the present study. This, in part, can be explained by the difference in time for the onset of the QRS deflection recorded in different leads.6-9 A lead with an isoelectric interval at the beginning of QRS may point to an apparent P-R interval prolongation. Likewise, discrepancies in the apparent onset of the P and QRS deflections in different leads can account for the larger range of P-R intervals noted.

**P-R Segment.** The range for this parameter was relatively large. This limits the diagnostic usefulness of this criterion.

**Total P/P-R Segment Ratio.** With the recent attention directed to the use of the ratio between P-wave duration and P-R segment as a means of evaluating left, right, or combined atrial enlargement,16 it was of interest to
study this ratio from the available data. As is noted on table 2, 9, the range of this ratio was found to vary from 0.97 to 10.17. This variability would also limit the diagnostic significance of this ratio insofar as values have to be extremely large or small to exceed the normal range.

Q-Tc and Q-T Ratio. The mean corrected Q-T duration (Q-Tc) of 0.41 and the Q-T ratio did not differ markedly from results obtained by other investigators. It was surprising to note that a correlation between the Q-T duration and heart rate resulted in a very low correlation coefficient, −0.17. Such a result, however, does not necessarily rule out a relationship between the 2 parameters as more than one factor can conceivably influence the Q-T duration. Mainland has pointed out again recently that the significance of such statistical correlations can be obscured by additional factors that are not under test in the correlation.

SUMMARY AND CONCLUSIONS

Measurements of the P wave, P-R interval, and Q-T ratio were made in a group of 133 normal subjects from simultaneously recorded orthogonal electrocardiograms (Schmitt’s SVEC III system). Most results differed from generally accepted normal limits. The discrepancies were essentially due to the recorded differences in the onset and termination of the electric cardiac events as measured from separately recorded leads. There was no single lead that reliably indicated the true duration of these events. These findings indicate a need for the use of simultaneously recorded leads for greater accuracy of time measurements from the electrocardiogram.

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SUMMARIO IN INTERLINGUA

Esseva effectuate mesuraciones del unda P, del intervallo P-R, e del proportion Q/T in le simultaneemente registrate electrocardiogrammas (systema SVEC III de Schmitt) de un gruppo de 133 subjectos normal. Le majoritate del resultatos differeva ab le generalmente acceptate limites normal. Le discrepantias resultava essentialmente ab le registrate diferentias in le declaration e terminacion del evenimentos electro-cardiac in comparation con mesuraciones super le base de separate-mente registrate derivationes. Nulle del der-ivationes presentava per se un indication fidel del ver duration de ille evenimentos. Le constatationes del presente studio indica le necessitate del uso de derivationes a registracion simultane pro augmentar le accuratias del mesuraciones in le electrocardiogramma.

REFERENCES


The present report considers the incidence of streptococcal infections and recurrences of rheumatic fever observed during the first 2 years of a large-scale, carefully controlled 5-year study of children with unequivocal histories of rheumatic fever maintained on prophylaxis against streptococcal infection. The clinical material consisted of 405 children, all of whom had had a definite attack of rheumatic fever within the preceding 28-month period. The prophylactic regimens used were as follows: a single daily oral 1-Gm. dose of sulfadiazine, a single oral dose of 200,000 units of penicillin half an hour before breakfast, and an intramuscular injection of 1,000,000 units of benzathine penicillin G every 4 weeks. The data obtained indicated that 1,200,000 units of benzathine penicillin G, given intramuscularly every 4 weeks, was more effective in preventing both streptococcal infections and rheumatic recurrences than either of the other 2 methods of prophylaxis. Probable reasons for this superiority are that the benzathine penicillin is injected, thus giving assurance that prophylaxis is received, and that each monthly injection also provides a probable eradicating dose of penicillin for group A streptococci, a property not present in the dose schedule used for the other 2 agents.

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