The Q-T Interval in Normal Infants and Children

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Because of renewed clinical interest in the Q-T interval and because of a need of normal values for an accompanying investigation in rheumatic fever, the Q-T was studied in 517 normal infants and children from birth to 13 years of age. A mean K of 0.404 for Bazett’s formula and of 0.378 for Ashman and Hull’s formula was obtained. With Bazett’s curve approximating the data more closely, a Bazett’s scattergram of the normal Q-T at varying heart rates was constructed. Although no difference in K value was noted between the sexes, significant differences were observed in certain age groups.

A survey of the literature reveals that changes in the Q-T interval of the electrocardiogram have been mentioned in a variety of clinical conditions. Q-T prolongation has been observed in hypertension,1 heart failure,2 spasmophilia,3 hypocalcemia,4 hypopotassemia,5 rheumatic carditis,6 diphtheria,7 quinidine intoxication,8 nephritis,9 and cretinism.10 The Q-T has been used as an aid in differentiating pericardial effusion with heart failure from acute cardiac dilatation and failure, being prolonged in the latter condition.11 It has also been found to be a good index of myocardial improvement during digitalis therapy.12, 13 Since the Q-T interval often regresses towards normal even before significant reduction in heart size occurs. This observation led to the concept that the Q-T reversal is evidence of the direct beneficial action of digitalis on the myocardium and not simply of diminution in heart size.14 Similarly, others have felt that the Q-T interval is a more sensitive index of the state of the myocardium following exercise than is the heart rate.15

Abnormal shortening of the Q-T interval has received less study. It has been reported in hyperparathyroidism16 and also as evidence of digitalis intoxication.17

Although several workers18, 19 have not found the Q-T interval of much clinical value, it is evident that there is a renewed and increasing interest in its clinical applications. This has been particularly true, recently, in rheumatic carditis20, 21 and in electrolyte disturbances.22-24 Obviously, the accuracy of these observations depends upon the knowledge of the normal values of the Q-T interval not only at varying heart rates but also in relation to age and sex.

Several studies have been done on the electrocardiograms of normal infants and children, but only a few included the Q-T interval. Bazett,25 in his original paper in 1920, reported only 5 cases in infancy. In 1937, Hafkesbring, Draw, and Ashman26 published their measurements in 100 normal children. Then, in a more extensive study in 1942, Ashman27 included these same 100 and added 126 more, making a total of 226 children studied. However, he admitted that he did not have enough cases in infancy. Later reports by Savilhati28 and Mannheimer29 were based on 165 and 118 healthy children, respectively. Only a few infants were included in these two reports. The only extensive study of the subject in infancy is that of Nadrai,30 who analyzed the electrocardiograms of 50 premature, 100 newborn, and 250 older infants. This study, however, fails to present the situation in the remaining years of childhood.

A more complete study, which would include both infancy and childhood and which would be done by the same observers, seemed especially warranted in view of the renewed interest in the clinical applications of the Q-T interval in pediatric practice; the present study was therefore undertaken. For an additional
and more specific purpose, it was carried out to provide normal values for an accompanying investigation of the Q-T in rheumatic fever.

**Clinical Material and Method**

This study is based on the electrocardiograms of 517 normal infants and children seen at the Boston Lying-In Hospital, the Department of Maternal and Child Health of the Harvard School of Public Health, and the Children's Hospital of Boston. The study was undertaken in order to determine the normal and more accurate measurements. By means of this device the electrocardiogram was projected on white paper and magnified at least ten times its actual size. In this way, the difficulty in determining the Q wave as well as the end of the T wave was lessened appreciably. Measurements were thus obtained to the nearest 0.005 second. As a rule, no less than three cardiac cycles were analyzed and from these measurements the average Q-T and the average cycle length, R-R interval, were then derived. In instances showing significant sinus arrhythmia, these same measurements were done on more than three cardiac cycles, always including the shortest as well as the longest cycle lengths available.

The measurements were done on Lead II unless there was a significant difference in the Q-T interval between this lead and either Lead I or Lead III due to an isoelectric Q wave in Lead II.

The electrocardiograms were taken with the infant or child lying supine in bed. They were recorded by means of the Sanborn electrocardiograph, generally the direct-writing Viso-Cardiette and in some intervals...
stances the photographic Instomatic Cardiette. That both types of electrocardiographs give essentially identical records and can thus be jointly included in a common study has been recently demonstrated.22

RESULTS
The 517 cases were divided into groups according to their cycle lengths, as measured by the R-R interval. Except for those with an R-R interval greater than 0.82 second, the subjects were grouped together within an increment of 0.04 second in the cycle length, starting from 0.30 second. The cases with slower heart rates were grouped at increments of 0.08 second in the cycle length because of the relatively fewer cases in this range. The average Q-T and R-R intervals for each group were determined. Then the average Q-T value was plotted against the average R-R value, as shown in figure 1. With each point in the graph is also indicated the number of cases from which the average Q-T and R-R figures were derived. It can be seen that except for the three slower rates there is a uniform and adequate distribution of the material throughout the graph.

An attempt was then made to find out whether there is any single formula or curve that can satisfactorily express the pattern of the Q-T and R-R relationship of our entire series. The two most widely accepted formulas, namely, Bazett’s and Ashman and Hull’s, were tested. The constant $K$ was determined for each subject, both with Bazett’s formula as well as with Ashman and Hull’s. This was done by dividing the Q-T interval by $\sqrt{R-R}$ for Bazett’s constant and by $\log[10(C + 0.07)]$ for Ashman and Hull’s constant. The resultant mean $K$ for Bazett’s formula was 0.404 with a standard deviation of 0.026 and a coefficient of variation of 6.4 per cent. With Ashman and Hull’s formula, the mean $K$ value was found to
be 0.378 with a standard deviation of 0.025 and a coefficient of variation of 6.6 per cent. Curves were then constructed, using the mean K values for each formula. It is evident that both curves (fig. 1) approximated satisfactorily the average points, although Bazett’s curve fitted them somewhat more closely than Ashman and Hull’s curve.

With the values for Bazett’s formula as derived from our data, the normal spread of the area of spread includes 95.6 per cent of all cases. Only 4.4 per cent of the entire series fell outside this area; that is, 11 cases above and 12 cases below.

As a corroborative analysis, the frequency distribution of the individual K values was also plotted (fig. 3). As already mentioned, the mean K for Bazett’s formula was 0.404 while that of Ashman and Hull was 0.378. Although the general configuration of these two curves

![Fig. 3.—K Distribution Curves. Continuous line represents the frequency distribution polygon of the individual K values for Bazett’s formula, and broken line presents the same material on the basis of Ashman and Hull’s formula.](http://circ.ahajournals.org/)

entire series was next studied. The result of this analysis is shown in figure 2. Curves above and below the average curve were constructed, using K values of once and twice the standard deviation over and below the mean K. The area covered by the curves close to the average curve includes 73 per cent of our cases, leaving 80 cases below the lower margin and 60 cases above the upper margin of this area. If twice the standard deviation is used, then the wider was very similar in both instances, Bazett’s K distribution curve tends to include a greater number of cases close to or within its standard deviation—this in spite of the fact that the extremes on both sides of the graph belong to Bazett’s K. In any event it is obvious that no single K value is applicable to both formulas.

The next point studied was the possibility of a further differentiation in this general pattern of the Q-T and R-R relationship and K values
through the various ages of infancy and childhood. By plotting the individual Q-T and R-R points along the mean curves according to both Bazett’s and Ashman and Hull’s formulas, it was found that a certain distribution pattern was consistently followed by individuals within a given age group, but that these age groups differed from each other: in some the Q-T and R-R relationship-points uniformly fell close to, in others below, and in still others above the mean curves. The individual K values were then compared to the mean K values in both formulas. Again, the same age group pattern was observed. Table 1 illustrates these results on the basis of the study of the individual K values as related to the mean K, following Bazett’s formula. The other tables and figures showing this entire set of analyses are not included here in view of the identical results obtained. Except for the 1 to 4 month age group, the value for K is shorter in the younger ages and progressively longer in the older age groups. The differences in K values among these age groups are statistically significant as indicated by the coefficient of variation. This would suggest a certain pattern of the Q-T and R-R relationship, hence also of the K value, that is consistently followed and probably peculiar to specific age groups in infancy and childhood.

Finally, table 2 shows that there is no significant difference in K values between the sexes. This situation is unlike that in adults where women have a higher K value than men, indicating that women tend to have a longer Q-T interval than men for the same heart rate. This lack of significant difference between the sexes in our series is evident not only from the over-

Table 1.—Bazett’s K in Different Age Groups

<table>
<thead>
<tr>
<th>Ages</th>
<th>Mean “K”</th>
<th>Standard Deviation</th>
<th>Coefficient of Variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–Below 1 month</td>
<td>0.386</td>
<td>0.019</td>
<td>4.9%</td>
</tr>
<tr>
<td>1–4 months</td>
<td>0.410</td>
<td>0.024</td>
<td>5.9%</td>
</tr>
<tr>
<td>5 months–1 year</td>
<td>0.391</td>
<td>0.022</td>
<td>5.6%</td>
</tr>
<tr>
<td>2–5 years</td>
<td>0.401</td>
<td>0.023</td>
<td>5.7%</td>
</tr>
<tr>
<td>6–13 years</td>
<td>0.416</td>
<td>0.025</td>
<td>6.0%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
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<th>Mean “K”</th>
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<th>Coefficient of Variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–13 years</td>
<td>0.404</td>
<td>0.026</td>
<td>6.4%</td>
</tr>
</tbody>
</table>

all figures but also from the mean figures for the various age groups. There is an almost equal distribution of cases between the sexes in our series in the total number as well as in the different age groups.

As far as individual cases are concerned, 8 had Q-T intervals longer than 0.40 second, 2 of which were 0.44 second. These cases were found in the older ages with longer cycle lengths. The slowest heart rate among these 8 subjects was that of a 12 year old child who had a cycle length of 1.18 second and a Q-T interval of 0.415 second. At the other extreme, 5 cases had Q-T intervals of 0.22 second or less. The shortest was 0.21 second and was found in a 4 month old infant with a cycle length of 0.39 second. This was not the fastest heart rate in the entire series, however, the shortest cycle length being 0.326 second in a 1 month old infant with a Q-T interval of 0.225 second.

On the basis of Bazett’s formula, the largest K value was that of 0.50 in a 9 year old child with a cycle length of 0.52 second and a Q-T interval of 0.36 second. The smallest K was 0.289 in a 6 month old infant with a cycle length of 0.465 second and a Q-T interval of 0.225 second.

Discussion

The value of the measurement of the time duration of ventricular systole as a criterion of myocardial efficiency is agreed upon by physiologists,25, 33 Garrod24 was the first to point out the relationship between heart rate and the duration of ventricular systole. Although several other factors have since then been found to affect the duration of systole, all workers
agree that the cardiac cycle length is the most important one.\textsuperscript{34} To express this relationship in terms of the Q-T and R-R intervals of the electrocardiogram, several empiric formulas have been proposed. The most widely used are those of Bazett and of Ashman and Hull. Bazett’s formula, similar to many others, is a somewhat linear or curvilinear formula, while that of Ashman and Hull is the only logarithmic one. The latter workers feel that a logarithmic formula should be a better one because of the closer relationship between logarithmic formulas in general and many biologic processes.\textsuperscript{26} On the other hand, if a linear or curvilinear formula can be just as satisfactory as a logarithmic one, the former is certainly a much simpler and more practical guide.

Among the various simple formulas, Bazett’s is probably the simplest. Using the cube root rather than the square root of the cycle length, Fridericia\textsuperscript{34} proposed an almost identical formula to that of Bazett: $Q-T = K \sqrt[3]{C}$. These two formulas have been found to be substantially correct by several other workers,\textsuperscript{37–42} except for some changes in the absolute value for $K$ to suit the actual data of individual series. However, a few observers have introduced completely different formulas. Adams,\textsuperscript{43} for instance, proposed the formula, $Q-T = 0.1536 \times R-R + 0.2462$, for men and $0.1259 \times R-R + 0.2789$ for women. More recently, Schlamowitz\textsuperscript{44} introduced the formula, $Q-T = 0.205 C + 0.167$, while Lung\textsuperscript{45} favors the formula, $Q-T = 0.2 R-R + 0.12 \pm 0.04$.

In the present study, only Bazett’s and Ashman and Hull’s formulas were tested chiefly for two reasons: first, because they are the two most widely used, and second, because such an analysis would tell us whether a more complicated logarithmic formula is needed rather than a simpler linear or curvilinear one. From the results in figure 1 it is evident that there is no real need for a logarithmic formula and that Bazett’s simple formula actually gives a slightly more satisfactory approximation of our actual measurements. The validity of this analysis is confirmed by the fact that the mean value of 0.378 for Ashman and Hull’s $K$, as derived from our data, fits exactly Ashman’s more recent observation\textsuperscript{46}; namely, that the mean $K$ value for children is closer to 0.38 than to the original Ashman and Hull’s figure of 0.375 for both men and children. With Bazett’s formula giving a closer approximation, it becomes imperative to know the true value for Bazett’s constant in these younger ages. We believe that the present study, derived from a series that is large and evenly distributed throughout the entire span of infancy and childhood, furnishes this data for the first time. Our figure is significantly different from those that Bazett found in adults (men, 0.37; women, 0.40).

It is equally important to know the normal spread of individual cases around this normal mean value or curve. Ashman and Hull furnished figures for their upper limits of normal, using their formula and considering identical $K$ values for men and children. Bazett, on the other hand, did not furnish similar figures for adults, nor could he do so for children because of an insufficient number of cases. Our figure for Bazett’s mean $K$ differs significantly from various figures in the literature that have been employed for the upper limits of normal in evaluating individual cases on the basis of Bazett’s formula. Our results also demonstrate that the $K$ values in the younger ages differ from those generally accepted for adult men.

Other investigators\textsuperscript{4, 18, 47} have preferred to approximate the normal spread from scattergrams of their normal figures, the mean curve being constructed by simple inspection of these figures. This is probably an easier procedure but is less accurate than one in which curves are derived through a mathematical appraisal of the actual measurements. In any event such a graph for the normal spread is obviously a more practical guide for the evaluation of individual Q-T intervals than tabulated figures and prediction tables which may set too rigid criteria for individual cases. For this reason figure 2 was constructed. Such a diagram not only relates an individual case, indicated by its Q-T and R-R relationship-point, to the mean normal curve but also to the areas of normal spread. The fact that such areas are wide in young children is an important point to be considered. In fact, even with the wider area of spread, 4.4 per cent of our cases still fell beyond it. These findings emphasize the need for a less rigid
attitude in evaluating the Q-T interval in infancy and childhood as perhaps in contrast to adults. This is even more important when the Q-T interval may be the only apparent abnormality in an individual case.

Finally, the differences in K values observed for the arbitrary age groupings in table I are of special interest. While statistically significant, they may not be exclusively due to a peculiar and specific pattern for certain ages of infancy and childhood. These age groupings were arrived at on the basis of the relationship of the Q-T and R-R points as well as the individual K values to the mean curves and mean K values, respectively, of Bazett and of Ashman and Hull. Evidently, while both curves are satisfactory approximations of our actual figures, neither of them is identical with our data. This technical factor may partly explain the resulting age group deviations. How much deviations are due to real age peculiarities and how much to incidental apparent differences as a result of the method herein followed can be ascertained only by constructing a new formula derived from our figures.

Obviously, a new formula for this purpose alone is not indicated, especially when the two formulas tested proved to be satisfactory. Furthermore, another formula added to the many already found in the literature cannot possibly clarify, much less simplify, the Q-T problem. From our observations, therefore, we may suggest that evaluation of individual Q-T intervals in infancy and childhood can be satisfactorily done on the basis of the over-all figures for Bazett’s K and the diagram for the normal spread in figure 2. Only in instances where greater accuracy is needed and in studies involving certain age groups of infants or children may the age group figures in table I have to be followed.

Summary and Conclusions

The Q-T interval was measured in 517 normal infants and children from birth to 13 years of age inclusive. Its relationship to the cardiac cycle length was studied on the basis of both Bazett’s and Ashman and Hull’s formulas. Although curves from both of these two formulas approximated the data well, Bazett’s curve fitted them somewhat more closely. The values for the mean K in these two curves were 0.404 with a standard deviation of 0.026 for Bazett’s formula and 0.378 with a standard deviation of 0.025 for Ashman and Hull’s formula.

The spread of the normal Q-T, as related to the heart rate, can be expressed by the diagram with areas bounded by curves constructed with K values of the mean K plus and minus once and twice the standard deviation. In such a diagram, 73 per cent of all cases fell within the narrower area of spread and 95.6 per cent within the wider area.

Differences in the K values were noted in certain age groups, suggesting the possibility of some age peculiarities of the Q-T and R-R relationship. These variations may have to be considered for purposes of greater accuracy as well as for studies involving specific age groups in infancy and childhood.

There was no significant difference in K values between the sexes.

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