Differentiation of irregular rhythms by frequency distribution analysis

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Summary

Distinctive electrocardiographic patterns for atrial fibrillation, sinus rhythm and atrial extrasystoles, sinus arrhythmia and atrial flutter were found by analysing the frequency distribution of cycle lengths of the electrocardiogram.

Frequency distribution analysis, demonstrated that atrial fibrillation is not completely irregular, but shows more long cycles than expected by chance and often a mode at the lower end of the distribution. Irregular atrial flutter is similar. Sinus arrhythmia has more variable organization, but usually there is a centrally situated mode with decreasing observations to the two extremities, and positive skewing. Examples of sinus rhythm and atrial extrasystoles usually have a mode at the upper end of the distribution with a secondary concentration of observations at the lower extremity.

Ratios derived from the frequency distributions were of value in differentiating these arrhythmias.

It is suggested that such information will improve computer identification of arrhythmia.

Introduction

Before the era of electrocardiography, cardiac arrhythmias were identified by examination of the pulse (Lewis, 1925). If the pulse was irregular it could be described as irregularly irregular, e.g. atrial fibrillation, or regularly irregular, e.g. extrasystoles and many forms of heart block. The advent of electrocardiography permitted further classification of the arrhythmias as supraventricular or ventricular if the shape of the QRS, the P wave and their inter-relationships were identified.

Similar rates and patterns of the pulse can be associated with different electrocardiographic arrhythmias. If P wave identification is impossible the rhythm can be classified only by intra-atrial and His bundle electrograms. The computer identification of arrhythmias is limited by poor P wave analysis (Talbot *et al.*, 1973). This study was therefore performed to see if the frequency distribution of cycle

lengths of atrial fibrillation, sinus arrhythmia, atrial extrasystoles and atrial flutter identify these arrhythmias. Measurements of these patterns may then be of value in describing the pulse, for monitoring arrhythmias and for computer analysis of arrhythmias.

Method

A clear definition of bimodality which is applicable to every frequency distribution has never been established. Two distinct groups of cycle lengths constitute a bimodal rhythm. However, usually the two or more groups merge so that only peaks are shown on a frequency distribution; if there are a limited observations small peaks may be due to measurement and normal variation, and yet they are often interpreted as multimodality (Pickering, 1961). Bimodal rhythms may be more obvious if the range of cycle lengths is much larger than the limits of measurement, but cannot be identified definitely otherwise. In this study, rhythms have been described as bimodal if there were two or more distinct cycle lengths which separately constituted $> 25\%$ of the total number of observations, and which were separated by at least 30% of the range of variation. No electrocardiograms with atrial fibrillation or sinus arrhythmia showed such bimodality, and therefore bimodality clearly identified sinus rhythm and atrial extrasystoles. These recordings have therefore been excluded from further analysis.

Routine 10-sec electrocardiograms of either atrial fibrillation, sinus arrhythmia or atrial extrasystoles in which there were 15-25 cycles, were examined. Cycle lengths were measured and compared to the normal distribution using Fisher's 'g' statistic (Snedecor, 1967). From this analysis, a subsequent smaller sample with more QRS complexes in each instance was found to be representative of these arrhythmias. For this sample, longer electrocardiographic recordings lasting 20 sec and 1 min were obtained, because these samples are the longest that are practicable for routine computer analysis. The cycle lengths were measured, the range of cycle lengths was divided into ten equal parts and intervals

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histograms were constructed. The mean and median were determined. If there was one class interval with $> 25\%$ of the observations this constituted the mode.

Arrhythmias are identified by the departure of any parameter from its most frequent measurement, and therefore either the mode (if any class interval fulfilled the conditions) or the mean has been used as the 'centre' of the frequency distribution. This divided the distribution into two sectors (Fig. 1) and each half was then bisected to give four 'quadrants'. This enabled the different types of frequency distribution for each arrhythmia to be compared. The sectors and quadrants were then expressed as percentages of the range so that results at different heart rates could be compared. The authors also determined the percentage variation of the cycle lengths in relation to either the mode or mean and the average variation for each group.

FIG. 1. A diagram of the usual frequency distribution of atrial fibrillation. The sectors and quadrants are shown and the situation of the mean, mode and median.

Results

The 'g' statistics were applied to 201 (10-sec) electrocardiograms.

Positive skewing (an excess of long cycles) often accompanied by positive kurtosis (an excess of central cycles) was the most characteristic feature of atrial fibrillation (Fig. 1). However, this kurtosis was less than that observed with sinus rhythm and was similar to that observed with sinus rhythm and atrial extrasystoles and sinus arrhythmia. Sinus rhythm and atrial extrasystoles were associated with a tendency to negative skewing; sinus arrhythmia was more often associated with positive than negative

skewing, but the distributions were more symmetrical than those of the other arrhythmias.

The cumulative results for the frequency distributions of the one minute electrocardiograms are shown in Table 1. These were essentially similar to those of 20-sec tracings (25–35 cycle measurements) on 57 patients with atrial fibrillation, 37 patients with sinus rhythm and atrial extrasystoles, and 38 patients with sinus arrhythmia. Discrepancies were probably due to differences in the number of observations. Thus, there may be frequent sinus suppression with atrial extrasystoles and this suppression cycle may be so constant and frequent, when extrasystoles have variable coupling, that this cycle becomes the mode.

The authors have not observed bimodal or trimodal rhythms in cases of atrial fibrillation but sinus arrhythmia occasionally is bimodal.

There was a long upper quadrant in atrial fibrillation due to the greater scatter of observations longer than the mode compared to those below the mode (Fig. 2). This scattering could be found in tracings showing sinus arrhythmia and sinus rhythm and atrial extrasystoles, but in these cases the third and fourth quadrants were of equal breadth in the upper sector of the range. In addition, cycles in atrial fibrillation clustered close to the centre of the distribution and these cycles were mostly shorter than the mode so that the second quadrant was small (Fig. 2).

Sinus arrhythmia (Fig. 3) was slightly asymmetrical and often showed positive skewing associated with relatively equal third and fourth quadrants and first and second quadrants. Sinus rhythm and atrial extrasystoles (Fig. 4) was the most variable of the three arrhythmias (Table 1). Usually there was a reduction in width of the first quadrant with compensatory expansion of the second, but the distribution was asymmetrical with negative skewing. Peaks were frequent and were probably evidence of insignificant bimodality or trimodality. There was usually a marked mode (positive kurtosis).

All but one of the total number of distributions departed significantly from a binomial distribution ($P < 0.01$). The situation of the mode in the different arrhythmias is shown in Table 2. Sinus arrhythmia showed either a central mode or a mode situated towards the lower end of the distribution although occasionally it was situated towards the upper end of the distribution. Four recordings of sinus arrhythmia did not show distinct modes. The mode, median and mean were generally close together and there was usually a dearth of cycles just longer than the mode with an excess of cycles at the upper extremity of the range. The flanks of the distribution contained few cycles and most were situated at the mode and extremities. The mode in atrial fibrillation was usually situated towards the lower end of the distribution, whereas the mode in sinus rhythm and

TABLE 1. Quantitative description of the frequency distribution of supraventricular arrhythmias*

	The average width of each quadrant of the frequency distribution†				Total No. of recordings
	Lower (first) quadrant	Second quadrant	Third quadrant	Upper (fourth) quadrant	
Sinus arrhythmia	22.4	20.0	27.1	30.5	17
	42.4		57.6		
Sinus rhythm and atrial extrasystoles	29.5	25.2	22.4	22.9	18
	54.7		45.3		
Atrial fibrillation	15.7	16.6	24.3	43.4	32
	32.3		67.7		

* One-min samples.
† Expressed as percentages of the range.

FIG. 2. An interval histogram of atrial fibrillation divided into ten class intervals, which shows evidence of positive skewing.

FIG. 4. An interval histogram of sinus rhythm and atrial extrasystoles, divided into ten class intervals, which shows negative skewing and a small secondary peak of short cycles.

FIG. 3. An interval histogram of sinus arrhythmia, divided into ten class intervals, which shows slight positive skewing, but a relatively symmetrical distribution. A 90-sec recording is shown for clarity.

atrial extrasystoles was usually towards the upper end of the distribution. In six out of 57 examples of atrial fibrillation (1-min tracings) the distribution resembled that characteristic of atrial extrasystoles and in three it was symmetrical. In two out of 18 recordings with atrial extrasystoles and in five recordings of sinus arrhythmia the distribution resembled that characteristic of atrial fibrillation. Variation of cycle lengths was greater in examples of atrial fibrillation than in sinus rhythm and atrial extrasystoles, but there was considerable overlap between these arrhythmias. The longer 1-min electrocardiograms of sinus arrhythmia did not show significantly greater percentage variation than the 20-sec tracings, but the variation of both atrial extrasystoles and atrial fibrillation was greater in the longer tracings (Fig. 5). Therefore percentage variation becomes of greater diagnostic value with increasing sample size (Table 3). The authors have not seen less than 10% variation of cycle lengths in atrial fibrillation. At faster heart rates there was less beat

TABLE 2. Situation of the mode

	Upper* mode		Lower† mode		No mode		Central‡ mode	
	1-min ECG	20-sec ECG	1-min ECG	20-sec ECG	1-min ECG	20-sec ECG	1-min ECG	20-sec ECG
Sinus arrhythmia	1	1	5	5(2)	4	15	7	17
Sinus rhythm and atrial extrasystoles	0	4(2)	2	3(3)	5	14	11	16
Atrial fibrillation	0	1	13(3)	24(2)	12	21	7	11

Parentheses include modes that were at either extremity of the frequency distribution.

* Upper mode occurred in the upper two class intervals.

† Lower mode occurred in the lower two class intervals.

‡ Central mode occurred in the 3rd–7th class intervals.

The remaining recordings did not show distinct modes.

FIG. 5. The average percentage variation of recordings of atrial fibrillation, sinus arrhythmia and sinus rhythm and atrial extrasystoles in the different lengths of electrocardiogram.

TABLE 3. Significance of percentage variation of cycle length

	Atrial fibrillation		Sinus arrhythmia		Sinus rhythm and atrial extrasystoles	
	20-sec ECG	1-min ECG	20-sec ECG	1-min ECG	20-sec ECG	1-min ECG
> 80% variation	25 (43.9)	30 (93.8)	2 (5.3)	1 (2.6)	7 (18.9)	3 (16.6)
> 100% variation	8 (14.0)	23 (71.9)	1 (2.6)	0	4 (10.8)	1 (5.6)
Mean cycle length	0.60 (0.18 s.d.)	0.66 (0.20 s.d.)	0.82 (0.18 s.d.)	0.80 (0.21 s.d.)	0.71 (0.17 s.d.)	0.74 (0.21 s.d.)

Number of electrocardiograms which could have been considered atrial fibrillation if either > 80% variation or > 100% variation were taken as criteria for diagnosis of atrial fibrillation. The mean cycle length and s.d. of the cycle lengths are also presented. Percentages in parentheses.

to beat variation, but since there were more observations the total variation of the samples was similar. The average heart rates of the three arrhythmias were slightly different (Table 3) and in particular all cases of sinus arrhythmia showed heart rates < 120 beats/min.

Similar principles may be applied to the analysis of atrial flutter. Regular atrial flutter is a difficult diagnosis. In a study of forty-seven 20-sec ECGs showing atrial flutter, twenty-two had less than 15% variation of cycle length and were considered regular. The characteristic heart rates of 75, 100 and 150 beats/min. may suggest this diagnosis (although 3 : 1 block was not observed in this study). In the remaining irregular rhythms (twenty-five) the range of variation (74·8%) was slightly less than atrial fibrillation, but the frequency distribution curves were similar. However, thirteen showed bimodality and could thus be clearly differentiated from atrial fibrillation although not from sinus rhythm and atrial extrasystoles.

Information from the frequency distributions (by means of the ratios derived from the upper and lower quadrants) has correctly identified 93 (70·5%) of these supraventricular arrhythmias on 20-sec recordings and 49 (73·1%) of one-min electrocardiograms, and this is significantly more than could be identified by percentage variation and routine computer analysis (58·4% – Talbot *et al.*, 1973). Accuracy of positive identification of atrial fibrillation was greater than that of atrial extrasystoles.

Discussion

The description of the frequency distribution of atrial fibrillation, sinus arrhythmia and atrial extrasystoles is of value. This may be performed by computer (Bootsma *et al.*, 1970) and has been used to identify junctional tachycardia in the presence of atrial fibrillation. This analysis of small samples

showed that similar distributions are found in large and small samples of atrial fibrillation (Urbach, 1973). Bimodal rhythms have been found in larger samples of atrial fibrillation, particularly at slow heart rates (Urbach, Grauman and Straus, 1969), but in small samples there is no evidence of bimodality and this is an important point of differentiation between atrial fibrillation and extrasystoles. A distinct second mode in such small samples of atrial fibrillation can be considered evidence of junctional rhythm if the samples are standardized. Differences in the shape of the frequency distribution have been described at different heart rates (Urbach *et al.*, 1969), but there are probably no differences of allowance is made for the limited range of cycle lengths at faster heart rates. Long samples of sinus arrhythmia appear to show an upper mode and negative skewing (if anything) probably because of expiration, with lengthening of the sinus cycles, last longer than inspiration (Urbach, personal communication). The positive skewing in short electrocardiograms is probably due to breath holding, anxiety, and more rapid respiration but the frequency distributions of small samples have important implications in the differential diagnosis of arrhythmias.

Almost none of the frequency distributions showed a binomial distribution: even atrial fibrillation, which is usually considered a totally irregular rhythm, shows partial organization. The degree of variation cannot be considered an absolute differentiating point between the arrhythmias, but strict definitions of bimodality may be used to differentiate atrial extrasystoles in small samples. Atrial fibrillation and sinus arrhythmia may show bimodal or multi-modal features (Soderstrohm, 1950), but the authors found the definition presented in this article was the most satisfactory definition of bimodality for diagnostic purposes. Larger samples (as by electrocardiographic monitoring) would permit fewer stipulations

TABLE 4. Alternating rhythms (QRS similar)

1. 3 : 2 Sino-atrial block (Mobitz II)	Differences between (1) and (3) can only be determined by P waves.
2. Atrial bigeminy	Short cycle length, usually <0·5 sec.
3. 3 : 2 Atrioventricular block (Mobitz II)	(See 1.)
4. Sinus arrhythmia	Rare, usually two cycles not integral multiples.
5. Atrial flutter with ventricular response not integral divisor of atrial rate, e.g. 3:2, 5:2, 7:2 block. (Can be considered regular alteration of block, e.g. 3:1 to 2:1 block.)	Usually rapid > 100/mm.
6. Atrioventricular dissociation with sinus capture only in supernormal period of AV conduction	This is really retrograde block and 1 sinus capture for each junctional beat.
7. Reciprocal rhythm	Similar to atrial bigeminy – only differences by P wave analysis.

of bimodality because intermediate cycle lengths in atrial fibrillation and sinus arrhythmia would produce a continuous distribution. A list of obvious bimodal rhythms producing alternating rhythms is shown in Table 4.

There was never a mode comprising more than 50% of the observations in atrial fibrillation although this was seen in some of the other arrhythmias; conversely, an even distribution of cycle lengths was only seen in one example of atrial fibrillation.

Digitalis appears to increase positive skewing of fibrillation but since this is more obvious at slower heart rates (Urbach, 1973), this effect of digitalis may only be secondary to the effect on heart rate. The long cycles are probably due to concealed conduction. Excess of digitalis may regularize the rhythm producing less variation of cycle length although skewing persists; a subsidiary mode may appear.

Whatever mechanisms produce the frequency distributions of atrial fibrillation and flutter, sinus arrhythmia and atrial extrasystoles, measurements derived from the quadrants of these distributions are of value in differentiating these arrhythmias and can be used in the absence of *P* wave identification and to supplement arrhythmia diagnosis based on *P* wave identification.

Conclusions for each rhythm

Atrial fibrillation

1. The frequency distribution shows positive skewing.

Those cycle lengths that lie close to the mode are predominantly shorter than the mode. If there is a mode it is usually towards the lower end of the frequency distribution.

2. In small samples there is no evidence of bimodality.

3. Percentage variation is often $> 100\%$.

Sinus rhythm and atrial premature systoles

This arrhythmia usually shows bimodality but occasionally it appears totally irregular.

1. There is positive kurtosis, sometimes with negative skewing.

2. The curve may be bi- or trimodal (the latter is due to sinus suppression cycles).

3. There may be absent class intervals – a significant finding on longer recordings (if there is sinus arrhythmia these factors are disturbed and these rhythms resemble atrial fibrillation. Only detection of atrial activity will distinguish).

Sinus arrhythmia

1. Usually of limited variation ($< 30\%$)

2. A frequency distribution with positive skewing, and positive kurtosis.

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