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“Zone of avoidance”: RR interval distribution in tachograms, histograms, and Poincaré plots of a Boxer dog

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Abstract

The RR intervals of sinus and ventricular beats were determined by analysis of a 24-hour ambulatory electrocardiogram in a Boxer before and after treatment with sotalol. These RR intervals were plotted using tachograms, histograms, and Poincaré plots. The tachogram demonstrated a ‘band’ wherein a range of RR intervals was infrequent, the histogram did not take the form of a single Gaussian distribution of RR intervals, and the Poincaré plot showed nonhomogeneous beat to beat variability. This type of patterning was described as a “zone of avoidance” potentially caused by the clustering of beats within specific ranges. Treatment with sotalol enhanced the “zone of avoidance”. Further investigation is needed to understand the mechanism for this observation as well as any clinical implications.

Keywords

Sinus arrhythmia; Canine; Holter monitoring; Sinus node

The sinus node of the dog does not have a constant discharge rate, but instead sinus arrhythmia is prevalent.^{1,2} While the mechanism behind the variation in sinus rhythm is complex and still disputed, it is probably a composite of influences from the dorsolateral pons, features of breathing (rate, tidal volume, expiratory/inspiratory ratio) and impact of the baroreceptor response.^{3–5} As the heart rate changes from a slow to fast rate and fast to slow rate, it might be expected that the distribution of PP intervals (and thus, RR intervals with 1:1 conduction) would be Gaussian or normally distributed. The PP/RR interval ranges can be examined using the annotated (each beat identified as to its origin, e.g. sinus, ventricular, supraventricular) beat file (measured RR intervals for all beats) from 24-hour electrocardiograms (Holter monitoring). The continuous RR intervals or the frequency density can be displayed through histograms, tachograms and Poincaré plots derived from the Holter beat file.

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Conflict of interest

No conflict of interest.

A beat-to-beat interval tachogram gives the RR interval data over the course of time. The time of day (X-axis) is plotted against the RR interval (Y-axis). As the heart rate increases and decreases throughout the day, the band of RR intervals would theoretically increase and decrease respectively with a full range of RR intervals identified.

A RR interval histogram provides insight into the frequency of RR intervals. Over a given time period a long RR interval series is used to construct the histogram such that the RR interval (X-axis) is plotted against the number or occurrences (Y-axis) of that interval. If the heart rate over the course of a day increases and decreases over the full range of RR interval possibilities, with slowing and speeding of equal probability, the histogram might be expected to have a bell-shaped curve or some degree of skewness, depending on the distribution of the rate.

A Poincaré plot (also known as a Lorenz plot) is a two-dimensional RR interval scattergram of beat-to-beat variability.⁶⁻⁷ By convention, each RR interval is plotted (X-axis, RR_n interval) against the following RR interval (Y-axis, RR_n + 1 interval). Because the heart rhythm and RR interval are not random the resulting structure of this plot has shape.^{8,9} However, if the full range of RR intervals had an equal probability of occurring the shape would have an even distribution of RR intervals represented within this shape.

The images of this report demonstrate the pattern of RR intervals in an 8-year-old, 30-kg female Boxer examined for multiple episodes of syncope before and during treatment with sotalol.^a

Image interpretation: Fig. 1 - Electrocardiograms

Twenty-four hour Holter monitoring^b revealed rapid ventricular tachycardia (Fig. 1A). A modest number of ventricular ectopic beats was documented (n = 1619), representing < 1 % of QRS complexes; however, 1038 of these beats were distributed in runs of ventricular tachycardia (VT), 508 beats were single premature complexes, 17 couplets, and 13 triplets. The longest run of VT had a rate of 451 beats per minute (bpm). The 24-hour average sinus heart rate was 125 bpm. Sinus arrhythmia recorded while the dog slept (owner documented with prospective diary for all comments on behavior/activity) at 0228 hours is shown in Fig. 1B. Note the patterning and beat clustering of sinus arrhythmia in the longer strip below the selected region. The dog was treated with 80 mg sotalol^a given orally twice daily. The dog was monitored for 1 year and did not have further clinical signs. The recheck Holter at 1 year revealed a total of 333 ventricular ectopic beats with 321 single premature complexes, 6 couplets, and no runs of VT. The average heart rate was 80 bpm. Sinus arrhythmia recorded while the dog slept at 0238 hours is evident in Fig. 1C. The heart rates of both the faster and slower beats during sinus arrhythmia are slower when compared to the recording when the dog was not receiving treatment Fig. 1B.

Image interpretation: Fig. 2 - Tachograms

Fig. 2 represents the 24-hour and selected hour (vertical red bars bracket this hour) tachograms corresponding to the ECG recording at each time shown in Fig. 1. In Fig. 2A, the hour with the VT is illustrated and characterized by RR intervals largely less than 500 msec. In the hourly tachogram (lower panel of Fig. 2A) just to the right of the black vertical line the red dots represent the run of VT. Panel B of Fig. 2 shows the tachogram for the hour between 0200 and 0300. A “strip of white” sandwiched between the shorter and longer RR

^aSotalol, Apotex, Toronto, Canada

^bForest Medical Holter Analysis System, Trillium, Syracuse, NY

intervals (conglomeration of blue dots) shows a region with a lower density of the RR intervals (red star). One year later and during treatment with sotalol, the tachogram at the same time (0200-0300) shows RR intervals with a wider range and a broader 'strip of white' (red star) indicating a region or zone with a lower density of RR intervals. For each of the panels the black vertical line corresponds to the ECG recordings in Fig. 1.

Image interpretation: Fig. 3 – 24-hour histograms

Fig. 3A is the 24-hour linear histogram of normal RR intervals (ventricular beats not included in histograms) before treatment and Fig. 3B during treatment with sotalol. The distribution of RR intervals is not that of a single gaussian distribution. The distribution could be skewed or have multiple gaussian populations. Each histogram has potentially a hidden distribution indicated by the arrows. Thus, this distribution might indicate one gaussian distribution that is almost completely obscured by the dominant distribution. This hypothesis must be tested by examination of numerous recordings or by interventions that would accentuate or suppress each of the distributions. Note that after sotalol the RR intervals are longer with a greater number at the longer intervals. The logarithmic representations of these 24-hour histograms shown in panels C and D highlight the longer RR intervals and the rightward shift during treatment. Note that a line dropped at the nadir between distributions is approximately stationary despite the shift in heart rate distributions. This line corresponds to the red star and "strip of white" shown in Fig. 2.

Image interpretation: Fig. 4 – Hourly Poincaré Plots and histograms

Figure 4 shows the Poincaré plots and RR interval histograms for the selected hours shown in Fig. 2. The hour with the VT (A) indicates that the RR intervals were shorter (faster heart rate). The Poincaré plot demonstrates a comet shape. The VT is shown as very short RR_n to RR_{n+1} intervals (red dots). The Poincaré plots (Fig. 4 B and C) constructed from the RR intervals between 0200 and 0300 hours before and during treatment demonstrate an area whereby the RR_n and RR_{n+1} relationships are uncommon enough that a central blank area (red stars) is bound by specific ranges of short-short, long-short, short-long, and long-long intervals. The corresponding histograms (Fig. 4B and C) of the same hour show two or possibly three distributions of RR intervals (arrows indicates possible hidden distributions) with longer RR intervals than during the hour of VT. The red star indicates the region of low RR interval density and corresponds to that seen in the Poincaré plots and tachograms of Fig. 2 B and C.

Discussion

These images from a Boxer dog demonstrate that the sinus rhythm may not have a single gaussian distribution of RR intervals. Moreover, there are RR intervals that infrequently occur, possibly because of multiple populations of beat clustering. Such a distribution results in a "zone of avoidance" of RR intervals. This can be documented through the construction of histogram, tachogram, and Poincaré plots. Although the images in this report are from a single animal, we have seen the same 'zone of avoidance' in dogs with and without medication.

We hypothesize that the mechanism for the patterning illustrated is due to the initiation of beats from different cells in the sinus node that have a fixed range of discharge rates or variation in exit block from the sinus node. Isochronic activation mapping of the right atrium in the dog has shown that a shift in the pacemaker location occurs with changes in sympathetic and parasympathetic tone.⁹ Recently, optical mapping of the canine sinus node has demonstrated that discrete exit sites exist through which depolarization from the sinus node reaches the main atrial tissue.¹⁰ These findings may have some bearing on the

observation of the potentially varied populations of beats. From the example in this report, treatment with sotalol increased the 'zone of avoidance' by potentially shifting the RR interval populations so as to alter either the initiation or exit of each beat from the sinus node. An understanding of the influence of the autonomic nervous system and drugs on this phenomenon may have therapeutic impact. These and other questions are currently under investigation.

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Figure 1.

ECGs from a 24-hour Holter recorded from a Boxer with multiple episodes of syncope. A modified X, Y, and Z lead configuration was used. Frames A and B were selected from the initial recording before the dog received treatment. Ventricular tachycardia (A) was recorded during a period of excitement during the afternoon at 1748 hours, while a sinus arrhythmia (B) is evident during sleep between 0200 and 0300 hours. Frame C was recorded one year later during which the dog was receiving treatment with 80 mg sotalol given twice daily. The ECG shows an example of prominent sinus arrhythmia during sleep between 0200 and 0300 hours (same time and behavior as in B). Note the difference in the patterning of the sinus arrhythmia before and during treatment with sotalol such that the faster rate during sinus arrhythmia has slowed with treatment. The time scale on the X-axis is the same in each frame.

Figure 2. Twenty-four hour and hourly tachograms constructed from the Holter recordings of the Boxer before (A and B) and during (C) treatment with sotalol. For each 24-hour frame, the red vertical lines indicate the hour of the expanded hourly tachogram shown below. The black lines in the hourly tachogram indicate the location of the ECG shown in Fig. 1. The red star shows the region of low RR interval density identified as the "zone of avoidance". Note the wider RR interval range and broader "zone of avoidance" in C during treatment with sotalol.

Figure 3.

A (before treatment) and B (during treatment with sotalol) show linear 24-hour histograms and C (before treatment) and D (during treatment) show logarithmic histograms of the RR interval frequency density. The distribution is not a single gaussian distribution, but could be composed of multiple gaussian distributions of RR intervals. The arrows point to potential hidden distributions of beats concealed by the overlapping beat distribution. The vertical red line corresponds to the 'strip of white' seen in the tachogram of Fig. 2 and represents the "zone of avoidance".

Figure 4.

Frames A, B and C show the Poincaré plots and corresponding hourly histogram before (A and B) and during (C) treatment with sotalol. The hour is the same as that represented in the ECGs of Fig. 1 and the tachograms of Fig. 2. The “zone of avoidance” is indicated by the red star. The possible multiple mode RR interval distribution can be seen with potentially hidden distribution indicated by the arrows. After sotalol the RR intervals have shifted to the right and the Poincaré plot covers a broader range of intervals with a larger “zone of avoidance”.