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Poincaré plots and tachograms reveal beat patterning in sick sinus syndrome with supraventricular tachycardia and varying AV nodal block

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Abstract

Using 24-hour ambulatory electrocardiography, the RR intervals of all beats were determined in a West Highland white terrier with sick sinus syndrome characterized by sinus arrest, bradycardia, supraventricular tachycardia (SVT) and varying degrees of atrioventricular (AV) heart block and long sinus pauses. Distinctive patterns of bradycardia and 1:1, 2:1, 3:1, 4:1 and 5:1 AV block associated with SVT were evident in the tachogram (RR interval distribution over time) and Poincaré plots (short-term heart rate variability plots of RR_n versus RR_n + 1). These patterns differed from those of abrupt alteration in cycle length during long sinus pauses or bursts of supraventricular tachycardia. Recognition of such patterns may direct attention to time points for which close attention to the cardiac rhythm should be evaluated in the full-disclosure of the 24-hour ECG recording.

Keywords

Canine; Poincaré plots; Lorenz plots; Holter monitoring; 24-hour electrocardiography; sinus node; AV block

Sick sinus syndrome (SSS), which is recognized in humans and dogs,¹⁻⁵ is a primary dysfunction of the sinoatrial node whereby the electrocardiogram (ECG) may show features of sinus bradycardia with or without long sinus pauses.^{1,2} The mechanism for the sinus pauses may be a loss of action potential initiation or exit block from the sinus node.³ Supraventricular tachyarrhythmias also may be a feature of SSS.^{1,2} On its cessation supraventricular tachycardia (SVT) may induce the abrupt sinus pause (arrest or exit block) often referred to as tachycardia-bradycardia syndrome.¹⁻³

Twenty-four hour ECG (Holter) monitoring permits not only the identification of arrhythmias, but the opportunity to understand the patterning, triggers, and timing over the course of the day and night. Tachograms which display the RR intervals over time (24-hour or hourly) provide the opportunity to recognize shifts in heart rate. From the RR interval pattern alone the type of arrhythmia can be distinguished. Poincaré or Lorenz plots can be

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Conflict of Interest

None of the authors have a conflict of interest.

constructed from these RR interval data.⁶⁻¹⁰ Such displays of short-term heart rate variability are evident from the plotting of the RR_n interval (X axis) versus the RR_n + 1 interval (Y axis) (immediate next interval).⁶⁻¹⁰ Studies of the resulting relationships/patterns have been used to understand the restitution curves of repolarization,⁶ effective refractory periods,⁶ and influences of autonomic tone on beat to beat intervals.⁷⁻¹¹

This report details the patterns of RR interval distribution in an 11 year-old male West Highland white terrier (WHWT) examined for numerous episodes of syncope. A diagnosis was made of SSS characterized by SVT with varying degrees of conduction (changing ratios of heart block) through the atrioventricular (AV) node.

Image interpretation: Fig. 1 Twenty-four hour tachograms

Figure 1 compares the 24-hour tachograms recorded from a 14 year-old female WHWT (top frame) that did not have SVT nor any sinus pauses > 4.5 s and that of an 11 year-old male WHWT (bottom frame) with SSS characterized by SVT with varying degrees of conduction (changing ratios of heart block) through the AV node. The data of the dog in the top frame shows a tachogram that typifies a normal dominant sinus arrhythmia with a region of less frequent beats of certain RR interval durations (zone of avoidance¹²). The data of the dog in the bottom frame shows varying patterns of RR intervals. Short RR intervals are seen just before and into the region labeled A (1600-1700 hours) when the RR intervals abruptly increase. In region B (1700-1800 hours) longer RR intervals dominate. In region C (2100-2200 hours) 'bands' of RR intervals are seen suggesting durations that are roughly 'clustered' with minimal variation. In region D (0100-0200 hours) the banding pattern transitions suddenly to longer RR intervals with some RR interval durations 'raining' down from a more densely packed, less variable bradycardia. The 24-hour ECG analysis of this dog revealed an average heart rate of 92 bpm with a heart rate >120 bpm for 9.5 hours and < 50 bpm for 13 hours.

Image interpretation: Fig. 2 Supraventricular tachycardia, sinus arrest, and sinus bradycardia

The hour represented by 'A' in the lower frame of Fig. 1 is shown here as an expanded tachogram to show more detail of the RR intervals. During approximately the first 8 minutes the RR intervals are short (tachycardia) and tightly clustered (very little variation). This pattern of RR interval distribution changes at the first red line (from left). The reason for the transition is shown in the top ECG tracing. Here an SVT with 1:1 AV nodal conduction stops and is followed by a nonsinus beat, then a long pause with no P waves consistent with a tachycardia-bradycardia rhythm. The average of 50 RR intervals (data in figure represented in msec) during the SVT indicated a rate of 207.2 +/- 16.9 bpm. For the majority of the rest of this hour a sinus bradycardia (lower ECG) was the dominant rhythm.

Image interpretation: Fig. 3 Sinus bradycardia

The hour represented by 'B' in the lower frame of Fig. 1 is shown here as an expanded tachogram to show more detail of an hour during which the heart rate was slow. The average of a selected 50 RR intervals (data in figure represented in msec) during the sinus bradycardia indicated a rate of 33.6 +/- 2.4 bpm.

Image interpretation: Fig. 4 Supraventricular tachycardia with 1:1, 2:1, 3:1, 4:1, 5:1 AV nodal block

The expanded tachogram for hour 'C' in the lower frame of Fig. 1 shows the pattern of RR interval bands with differing ratios of AV nodal block during SVT. During this time the patterning is characteristic of sustained SVT because blurring of these bands would have been evident if sinus arrhythmia was interspersed. The RR intervals that resulted from 1:1, 2:1, 3:1, 4:1 and 5:1 AV block form 'bands' during this hour due to the fairly consistent RR intervals for each conduction ratio. Note that the mean RR intervals are approximate multiples of the PP interval or the RR interval during 1:1 conduction. The variation from an exact multiple modestly increases with the block from 3:1 (1%), 4:1 (4.9%), and 5:1 (7.1%). The average RR interval seen with intermittent 1:1 conduction is longer (320 msec) than that observed with sustained 1:1 conduction (291 msec) as illustrated in Fig. 2. The representative ECGs from the time point indicated show examples of the varied AV nodal conduction that has caused this patterning. Occasionally, potential sinus P waves (positive P waves) are seen and this might account for the variability in the 'locked' multiples of AV nodal conduction. The latter of course could contribute to the bands on the tachogram having 'width' rather than being a singular line if the multiples were mathematically exact.

Image interpretation: Fig. 5 Sinus pause and syncope

The expanded tachogram for region 'D' in the lower frame of Fig. 1 shows the RR interval banding of varying AV nodal block during SVT that abruptly stops with a long pause. The dog collapsed during this asystole. Note in the longer ECG recording (below the selected portion indicated by the red arrow) that the long pause is broken by several beats, but severe bradycardia continued. In total the dog had 714 pauses > 2 s with the longest pause reading 15.4 s.

Image interpretation: Fig. 6 Poincaré plots of the changing rhythm

From each of the hours described (A, B, C, D) shown in Fig. 1 the Poincaré plots show the pattern of RR intervals (X axis, RR_n) as each is related to the next RR interval (Y axis, RR_{n+1}). Frame A of Fig. 6 shows primarily two clusters of intervals representing the relationship of short RR intervals (lower left) of the SVT and the long RR intervals (upper right) of the sinus bradycardia. The wide fan distribution of the RR intervals during the period of bradycardia reflects the influence of parasympathetic tone.⁷⁻¹¹ In frame B of Fig. 6 the short RR intervals are absent, with only longer RR intervals distributed above approximately 1200 msec. Parasympathetic influence is again evidenced by the fan shape;⁷⁻¹¹ however, a subpopulation of RR intervals more densely concentrated is seen as an elliptical or 'torpedo or bullet' shape⁷ above 1500 msec (upper right corner). This rhythm would represent a bradycardia that is more constant than the variation seen with sinus arrhythmia. Hypothetically, such a rhythm could be arising from the sinus node or transitional region that is under minimal influence of autonomic tone. Frame C shows multiple clusters that appear as 'islets' of RR interval relationships. Approximately the same islet distribution is noted in Frame D; although the dense clustering of RR intervals associated with bradycardia that was noted in Frame B is seen here as well.

Image Interpretation Fig 7: Poincaré plot of SVT and varied AV nodal block

During the SVT occurring during hour C the AV node did not permit persistent 1:1 conduction, additionally, several other block ratios occurred (2:1, 3:1, 4:1, 5:1 etc). The Poincaré plots of this WHWT during periods of AV nodal block (time regions C and D) showed clustering of RR_n to RR_{n+1} relationships. The number of possible clusters,

referred to as 'islets', is equal to the number of ratios identified. In this dog during this hour, five conduction ratios were identified; therefore, 5^2 , or 25 islets were possible. A comparison of frame A which is the actual Poincaré plot, with frame B illustrates which of the 25 RR_n to $RR_n + 1$ actually occurred during this hour. In this figure we do not show the uncommon longer blocks above 5:1 which caused the long pauses in addition to the periods of sinus arrest.

Outcome

This dog had a pacemaker implanted and treatment with atenolol. The dog is doing well 3 years after this initial examination.

Discussion

The RR interval images from the 24-hour ECG of a WHWT with SSS showed the hourly and beat to beat relationship patterns for supraventricular tachycardia, bradycardia with and without variation, changing AV nodal block, and sinus arrest. Through these illustrations phenomena are documented that are not appreciated from routine electrocardiography. For example, this dog clearly was afflicted with SSS as demonstrated by long pauses without P waves; however it also had long pauses associated with AV nodal block during sustained SVT. It cannot be determined whether the atrial asystole was due to sinus arrest or sinus node exit block. During sustained SVT the clustering of RR intervals suggested that during these many hours the dog did not have a normal rhythm of sinus arrhythmia as evidenced by the clarity of the distinct bands without the more diffuse spread of intervals normally seen with high parasympathetic tone.¹² Another example of patterning seen in this case provokes questions about the mechanism responsible for periods of bradycardia that were tightly clustered, compared to those periods of bradycardia with a more blurred distribution of RR intervals giving the appearance of RR intervals 'raining down'. The former pattern suggests a more fixed bradycardia, and the latter pattern suggests a vulnerability to autonomic influence. Therefore, the methods of heart rhythm representation provide a view of the importance of autonomic influence, but also how the absence of this signature of variation can highlight time points. The Poincaré plot can reveal not only the more global autonomic influence, but the short-term beat to beat impact on rhythm.¹³ Although these methods show the influences on the heart rhythm of autonomic tone and circadian effects, specific changes in both ion channel function and conduction demand consideration too as suggested by the patterning of beats that seem to be independent of the forces of sympathetic and parasympathetic tone (e.g. closely clustered RR intervals of SVT and AV nodal block). Chronobiology of cardiac rhythm in disease and health is now known to provide markers for the mechanisms that trigger an arrhythmia that can provide greater understanding than routine short electrocardiograms.¹⁵ The case presented here illustrates the need to look beyond the practice of only recording the heart rate at one moment and identifying individual beat types.

References

1. Dobrzynski H, Boyett MR, Anderson RH. New insights into pacemaker activity: promoting understanding of sick sinus syndrome. *Circulation*. 2007; 115:1921–1932. [PubMed: 17420362]
2. Yeh YH, Burstein B, Qi XY, Sakabe M, Chartier D, Comtois P, Wang Z, Kuo CT, Nattel S. Funny current downregulation and sinus node dysfunction associated with atrial tachyarrhythmia: A molecular basis for tachycardia-bradycardia syndrome. *Circulation*. 2009; 119:1576–1585. [PubMed: 19289641]
3. Efimov IR, Fedorov VV, Joung B, Lin SF. Mapping cardiac pacemaker circuits: methodological puzzles of the sinoatrial node optical mapping. *Circ Res*. 2010; 106(2):255–271. [PubMed: 20133911]

4. Fedorov VV, Schuessler RB, Hemphill M, Ambrosi CM, Chang R, Voloshina AS, Brown K, Hucker WJ, Efimov IR. Structural and functional evidence for discrete exit pathways that connect the canine sinoatrial node and atria. *Circ Res.* 2009; 104:915–923. [PubMed: 19246679]
5. Moneva-Jordan A, Corcoran BM, French A, Dukes-McEwan J, Martin MWS, Luis Fuentes V, Hitchcock LS, Bonagura JD. Sick sinus syndrome in nine West Highland white terriers. *Vet Rec.* 2001; 148:142–147. [PubMed: 11271916]
6. Taggart P, Labb M. Cardiac mechano-electric feedback and electrical restitution in humans. *Prog Biophys Mol Bio.* 2008; 97:452–460. [PubMed: 18407323]
7. Esperer HD, Esperer C, Cohen RJ. Cardiac arrhythmias imprint specific signatures on Lorenz plots. *Ann Noninvasive Electrocardiol.* 2008; 13(1):44–60. [PubMed: 18234006]
8. Esperer HD, Esperer C. Mechanisms of asymmetric Poincaré' plots obtained by means of 24-hour Holter monitoring in athletes. *Comput Cardiol.* 2008; 35:473–476.
9. Esperer HD, Oehler M. Automatic quantification of the Poincaré plot asymmetry of NN-interval recordings. *Physiol Meas.* 2010; 31:395–413. [PubMed: 20147774]
10. Woo MA, Stevenson WG, Moser DK, Trelease RB, Harper RM. Patterns of beat-to-beat heart rate variability in advanced heart failure. *Am Heart J Heart Circ Physiol.* 1992; 123:704–710.
11. Esperer HD, Esperer C, Chernyak YB. Risk stratification in advanced heart failure using Lorenz plot indices of heart rate variability. *Comput Cardiol.* 2004; 31:209–212.
12. Moïse SN, Gladuli A, Hemsley SA, Otani NF. 'Zone of avoidance': RR interval distribution in tachograms, histograms, and Poincaré plots in a Boxer dog. *J Vet Cardiol.* 2010; 12:191–196. [PubMed: 21036115]
13. Portaluppi F, Hermida RC. Circadian rhythms in cardiac arrhythmias and opportunities for their chronotherapy. *Adv Drug Deliv Rev.* 2007; 59:940–951. [PubMed: 17659808]
14. Climent AM, Salud Guillem M, Husser D, Castells F, Millet J, Bollmann A. Poincare surface profiles of RR intervals: A novel noninvasive method for the evaluation of preferential av nodal conduction during atrial fibrillation. *IEEE Transactions on Biomed Engin.* 2009; 56:433–442.
15. Yue-Chun L, Li-Sha G, Xue-Qiang G, Peng C, Lian-Pin W, Peng-Lin Y, Ji-Fei T, Jia-Feng L. Establishment of a canine model of cardiac memory using endocardial pacing via internal jugular vein. *BMC Cardiovasc Disord.* 2010; 10 e-pub.

Figure 1.

24-hour tachograms of the RR intervals from two West Highland white terriers (WHWT). The top frame is data from a WHWT with a prominent sinus arrhythmia. The bottom frame is data from a WHWT with sick sinus syndrome (SSS). The time regions (A, B, C, and D) illustrate the varied pattern of RR interval clustering associated with the different cardiac rhythms. Each example region is expanded in Figs. 2-5 to further examine the patterning and a selected ECG from each hour.

Figure 2.

Tachogram for hour A from a WHWT with SSS. A supraventricular tachycardia is the cause for the narrow band of shorter RR intervals that is followed by atrial asystole. Sinus bradycardia follows with one interruption occurring at approximately 1650 hours when the owner reported that the dog was eating.

Figure 3. Tachogram for hour B from a WHWT with SSS. During this hour of sleep a bradycardia predominates.

Figure 4.

Tachogram for hour C from a WHWT with SSS. The RR interval bands correspond to the intervals for 1:1 to 5:1 conduction. Note the mean +/- standard deviation (SD) of RR interval durations in msec for each ratio of P wave number to R wave number (data in table). The RR intervals are approximate multiples of the 1:1 interval of 300 msec. The ECGs show examples of the AV nodal block that occurred during the long periods of supraventricular tachycardia. The P waves are identified to demonstrate the countdown to the conducted P wave (P_1). Note the positive $T_{sub a}$ waves for each of the ectopic negative P waves. Numbers between RR waves are in msec.

Figure 5. Tachogram for hour D from a WHWT with SSS. The bands continue as shown in hour C; however, a long pause without atrial depolarization follows a blocked P wave (note the negative T_{sub a} wave that follows the blocked P wave before the atrial asystole).

Figure 6.

Poincaré plots from each of the 4 hours (A, B, C, D) show the relationship of the RR intervals versus the next RR interval. Frame A shows the RR interval clustering associated with the supraventricular tachycardia and the sinus bradycardia shown in Fig. 2. Frame B shows the sinus bradycardia with a wide variation in the short term variability, but with a region of more constant RR intervals (upper right corner) above 1500 msec shown in Fig. 3. Frame C shows the clustering associated with varying degrees of AV nodal block shown in Fig 4. Frame D shows the appearance of the varying degrees of AV nodal block and the more constant RR intervals during the very slow heart rate shown in Fig. 5.

Figure 7. Actual (A) and theoretical (B) Poincaré plots for hour C shown in Fig. 5 of a WHWT with SSS. The RRn to RRn + 1 relationship clusters in islets that are related to the number of interval populations. In this dog during this hour AV nodal block most frequently occurred with 5 potential ratios (1:1, 2:1, 3:1, 4:1, 5:1). The potential number of islets of cluster RR interval relationships would be 25. In this dog 3 islets did not have RR intervals (indicated by the open circles). The RRn and RRn + 1 relationship for each islet is shown in the theoretical Poincaré plot.