Analysis of the atrial repolarization wave in dogs with third-degree atrioventricular block

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Objective—To characterize the electrocardiographic features of the atrial repolarization (Ta) wave in dogs with third-degree atrioventricular (AV) block.

Sample—ECGs of 36 dogs with third-degree AV block and no identifiable structural heart diseases.

Procedures—Standard 12-lead ECGs were acquired with a digital system, and measurements were manually edited.

Results—A Ta wave was detectable in all dogs for at least 1 ECG lead. The Ta wave had negative polarity in leads I, II, III, and aVF and positive polarity in leads aVL and aVR, with a mean electrical axis of –114.26°. Mean duration and mean amplitude of the Ta wave in lead II were 140.2 milliseconds and –0.09 mV, respectively, with the ratio for the Ta-to-P wave duration of 2.3 and the ratio of Ta-to-P wave amplitude of –0.35. Significant correlations were found between the Ta wave duration and duration of the P-Ta interval, Ta wave amplitude and the ECG lead, Ta wave duration and body weight, and duration of the P-Ta interval and atrial rate. Measurements of the Ta wave were repeatable.

Conclusions and Clinical Relevance—Measurements of the Ta wave in dogs with third-degree AV block were repeatable. The values for the Ta wave reported here can be used as reference values for dogs with AV conduction disturbances and an echocardiographically normal atrial size. Further studies are needed to validate these results in dogs with structural heart diseases. (Am J Vet Res 2014;75:54–58)

Electrical potentials generated during the atrial excitation process are reflected in ECG deflections called P waves. Those generated during the atrial recovery process are projected to the body surface during the PQ segment and QRS complex and are called Ta waves. During physiologically normal conditions, ECG deflection of atrial repolarization is usually hard to recognize because potential amplitudes are small such that the PQ segment is considered to be isoelectric and the onset of ventricular activation abruptly ends the PQ segment before the completion of the Ta wave. Hence, it is usually difficult to evaluate much of the recovery phase during normal sinus rhythm. Studies describing the Ta wave are uncommon in the human and veterinary literature because of ECG features of atrial repolarization deflection. However, during third-degree AV block, the situation is substantially different because the Ta wave and QRS complex are uncoupled.

The Ta wave was first described for an experimental method that involved the use of dogs with induced third-degree AV block paced from the coronary sinus. Analysis of the Ta wave is important as a diagnostic clue for atrial infarction, injuries, or enlargement. Furthermore, analysis of atrial repolarization may reveal important data regarding the arrhythmic propensity of the atrial myocardium, similar to the analysis of the QT segment in the case of ventricular arrhythmias. Analysis of the Ta wave is also important for the clinical determination of the effect of drugs such as atropine, propranolol, disopyramide, and flecainide acetate on the duration of the action potential of the atrial myocardium. The objective of the study reported here was to characterize ECG characteristics of the Ta wave in dogs with third-degree AV block.

Materials and Methods

Sample—Clinical records of dogs in which a pacemaker was implanted as treatment for third-degree AV block at the Clinica Veterinaria Malpensa between January 2008 and December 2010 were included in the study. Physical examination, a standard digital 12-lead ECG, thoracic radiography, and standard transthoracic echocardiography were performed prior to pacemaker implantation. Dogs were excluded if they had ventricu-
lopahsic sinus arrhythmias or right and left atrial enlargement that might have affected measures of the P or Ta waves. Right atrial enlargement was subjectively assessed by 1 author (RAS) and was considered to be more than trivial enlargement. Left atrial dimension was evaluated with echocardiography according to alometric scaling.9

**Procedures**—Standard 12-lead ECGs of 30 seconds’ duration were acquired with a digital systema and subsequent off-line processing. The low-pass filter, high-pass filter, and band-stop filter were set at 70, 0.05, and 50 Hz, respectively. Each ECG was amplified by a factor of 10 to 100 times the gain used for the standard ECG recording, depending on the level of the input signal. A single trained operator (SS) measured each ECG variable and determined the mean value for 3 cardiac cycles. For each 12-lead ECG, atrial cycle duration and ventricular cycle duration preceding the measured P and Ta waves were analyzed. The P wave and Ta wave axes in the frontal plane were calculated by use of the following equation: arctangent (lead Iamp, lead aVFamp) × 180/π, where lead Iamp is the amplitude of the P wave or Ta wave in lead I and lead aVFamp is the amplitude of the P wave or Ta wave in lead aVF. For each lead, the variables analyzed were Ta wave duration, Ta wave amplitude, P wave duration, P wave amplitude, duration of the P-Ta interval, and ratio of the Ta-to-P wave duration. Duration of the Ta wave was the period from the end of the P wave to the end of the Ta wave. Amplitude of the Ta wave was measured from the baseline to the apex of the Ta wave. Duration of the P-Ta interval was the period from the beginning of the P wave to the end of the Ta wave (Figure 1).

**Data analysis**—Data analysis was performed manually on all reported measurements. Qualitative variables were expressed as a percentage, and quantitative variables were expressed as mean ± SD as well as the 95% CI for the mean. The Shapiro-Wilk W test was used to assess normality. Significance was established at a value of P < 0.05. Correlation analysis between Ta wave duration, Ta wave amplitude, P wave duration, P wave amplitude, duration of the P-Ta interval, and ratio of the Ta-to-P wave amplitude and ratio of the Ta-to-P wave duration was performed with the parametric Pearson product-moment correlation coefficient. For variables that had a significant strong (r > 0.7) linear correlation, linear regression was performed with a generalized linear equation for repeated measurements. Univariate analysis (t test) was performed to evaluate whether atrial and ventricular rate were homogeneously related to age (median cutoff value, 120 months), sex, and body weight (median cutoff value, 26 kg).

A stepwise multiple regression analysis was then conducted by use of a generalized linear equation for repeated measurements to evaluate the association between Ta wave interval (dependent variable) and atrial rate, ventricular rate, age, sex, and body weight (each of which was adjusted on the basis of ECG lead [covariates]); P wave interval (dependent variable) and atrial rate, ventricular rate, age, sex, and body weight (each of which was adjusted on the basis of ECG lead [covariates]); and P-Ta interval (dependent variable) and atrial rate, ventricular rate, age, sex, and body weight (each of which was adjusted on the basis of ECG lead [covariates]).

Intraobserver reliability was determined by use of measurements obtained by the same observer for each of 3 times, by a random factor ANOVA, and by the ICC. The ICC assesses rating reliability by comparing variation of different ratings of the same subject to the total variation across all ratings and all subjects.10 The ICC values were interpreted as follows: ICC < 0.50 was considered a low level of reliability; ICC between 0.50 and 0.80 was considered a moderate level of reliability, and ICC > 0.80 was considered a high level of reliability.

**Results**

The ECGs of 52 dogs with third-degree AV block undergoing implantation of a pacemaker were analyzed. Ten dogs were excluded because of ventricular-ophasic sinus arrhythmia, and 6 other dogs were excluded because of atrial enlargement. Thus, the ECGs of 36 dogs were used for analysis.

The 36 dogs comprised 21 males and 15 females with a mean ± SD age of 110.9 ± 33.9 months (95% CI, 99.5 to 122.4 months) and mean weight of 29.0 ± 16.1 kg (95% CI, 23.5 to 34 kg). There were 11 mixed-breed dogs, 3 Labrador Retrievers, 3 Great Danes, 2 Chow Chows, 2 Cane Corsos, 2 German Wirehaired Pointers, 2 German Shepherd Dogs, 2 Saint Bernards, and 1 dog each of 9 other breeds.

No significant differences were found between sexes for ventricular rate (P = 0.33) and atrial rate (P = 0.19); males and females had the same mean ventricular and atrial rate. No significant differences were found between age groups for ventricular rate (P = 0.28) and atrial rate (P = 0.36), and no significant differences were found between body weight for atrial rate (P = 0.17) and ventricular rate (P = 0.71). Mean ± SD atrial rate was 157.5 ± 35.7 beats/min (95% CI, 145.4 to 169.6 beats/min), and mean ventricular rate was 56.8 ± 19.6 beats/min (95% CI, 50.2 to 63.4 beats/min).

The Ta wave was visible in 8 (22.2%) ECGs in lead I, 32 (88.9%) ECGs in lead II, 27 (75.0%) ECGs in lead III, 27 (75.0%) ECGs in lead aVR, 16 (44.4%) ECGs in lead aVL, 28 (77.8%) ECGs in lead aVF, 19 (52.8%) ECGs in lead V1, 23 (69.4%) ECGs in lead V2,
found between duration of the P-Ta interval and Ta wave amplitude (95% CI, 13.0° to 20.9°). For all 36 ECGs, the P wave was positive in leads I, II, III, aVF, and aVL and negative in leads aVR and aVR. Mean electrical axis of the P wave in the frontal plane was 95% CI, 131.6° to 106.9°. For all 36 ECGs, the P wave was positive in leads I, II, III, aVF, and aVL and negative in leads aVR and aVR. Mean electrical axis of the P wave in the frontal plane was 70.3° ± 13.0° (95% CI, 65.9° to 74.7°).

Mean amplitude and duration of the Ta wave, mean ratio of the Ta-to-P wave amplitude, mean ratio of the Ta-to-P wave duration, and mean duration of the P-Ta interval were calculated (Table 1). Correlations were determined (Table 2). High linear correlations were found between duration of the P-Ta interval and Ta wave duration (p = 0.93; P < 0.001; Figure 2) and between Ta wave amplitude and P wave amplitude (p = −0.76; P < 0.001; Figure 3). The 2 regression models yielded significant results. The R² was 0.57 (P < 0.001) for the correlation between Ta wave amplitude and P wave amplitude and 0.90 (P < 0.001) for the correlation between duration of the P-Ta interval and Ta wave duration.

Regression equations were determined (Figures 2 and 3). Multivariate analysis revealed a significant positive correlation between Ta wave duration and body weight (P = 0.009), ratio of the Ta-to-P wave duration and age (P < 0.001), Ta wave amplitude and female sex (P = 0.036), and duration of the P-Ta interval and body weight (P < 0.001).

Table 1—Mean ± SD values for several characteristics of 36 ECGs of dogs with third-degree AV block and no identifiable structural heart diseases.

<table>
<thead>
<tr>
<th>Lead</th>
<th>Ta wave amplitude (mV)</th>
<th>Ta wave duration (ms)</th>
<th>P wave amplitude (mV)</th>
<th>P wave duration (ms)</th>
<th>Ratio of Ta-to-P wave duration</th>
<th>Ratio of Ta-to-P wave amplitude</th>
<th>Duration of P-Ta interval (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>0.06 ± 0.03</td>
<td>105.11 ± 47.10</td>
<td>0.08 ± 0.04</td>
<td>42.67 ± 10.35</td>
<td>−0.16 ± 0.32</td>
<td>2.89 ± 0.87</td>
<td>147.97 ± 52.40</td>
</tr>
<tr>
<td>II</td>
<td>0.09 ± 0.04</td>
<td>140.17 ± 35.19</td>
<td>0.27 ± 0.09</td>
<td>47.79 ± 9.33</td>
<td>−0.35 ± 0.27</td>
<td>2.99 ± 0.81</td>
<td>187.99 ± 38.99</td>
</tr>
<tr>
<td>III</td>
<td>0.06 ± 0.03</td>
<td>139.35 ± 30.35</td>
<td>0.31 ± 0.08</td>
<td>45.83 ± 7.49</td>
<td>−0.45 ± 0.31</td>
<td>2.75 ± 0.78</td>
<td>164.23 ± 41.87</td>
</tr>
<tr>
<td>aVR</td>
<td>0.05 ± 0.02</td>
<td>124.63 ± 25.67</td>
<td>−0.17 ± 0.07</td>
<td>47.33 ± 7.83</td>
<td>−0.47 ± 1.07</td>
<td>2.67 ± 0.50</td>
<td>171.93 ± 41.14</td>
</tr>
<tr>
<td>aVL</td>
<td>0.04 ± 0.02</td>
<td>127.01 ± 37.98</td>
<td>−0.10 ± 0.04</td>
<td>45.52 ± 7.27</td>
<td>−0.24 ± 0.36</td>
<td>2.83 ± 0.87</td>
<td>172.52 ± 41.84</td>
</tr>
<tr>
<td>aVF</td>
<td>0.09 ± 0.03</td>
<td>141.14 ± 30.19</td>
<td>0.25 ± 0.09</td>
<td>46.90 ± 7.35</td>
<td>−0.34 ± 0.28</td>
<td>3.00 ± 0.71</td>
<td>198.00 ± 32.08</td>
</tr>
<tr>
<td>V1</td>
<td>0.07 ± 0.02</td>
<td>133.30 ± 45.35</td>
<td>0.08 ± 0.05</td>
<td>48.40 ± 13.29</td>
<td>−0.50 ± 0.38</td>
<td>2.63 ± 0.81</td>
<td>181.70 ± 54.21</td>
</tr>
<tr>
<td>V2</td>
<td>0.07 ± 0.03</td>
<td>135.95 ± 20.52</td>
<td>0.15 ± 0.04</td>
<td>50.99 ± 11.79</td>
<td>−0.45 ± 0.35</td>
<td>2.61 ± 0.57</td>
<td>186.59 ± 24.97</td>
</tr>
<tr>
<td>V3</td>
<td>0.09 ± 0.03</td>
<td>139.29 ± 29.3</td>
<td>0.19 ± 0.07</td>
<td>52.41 ± 9.87</td>
<td>−0.45 ± 0.31</td>
<td>2.65 ± 0.55</td>
<td>191.71 ± 24.08</td>
</tr>
<tr>
<td>V4</td>
<td>0.09 ± 0.04</td>
<td>132.03 ± 22.64</td>
<td>0.20 ± 0.06</td>
<td>50.75 ± 9.75</td>
<td>−0.42 ± 0.22</td>
<td>2.61 ± 0.52</td>
<td>182.75 ± 27.17</td>
</tr>
<tr>
<td>V5</td>
<td>0.08 ± 0.03</td>
<td>135.04 ± 24.78</td>
<td>0.23 ± 0.07</td>
<td>54.40 ± 26.54</td>
<td>−0.34 ± 0.17</td>
<td>2.68 ± 0.68</td>
<td>185.40 ± 42.22</td>
</tr>
<tr>
<td>V6</td>
<td>0.09 ± 0.03</td>
<td>134.97 ± 28.53</td>
<td>0.25 ± 0.08</td>
<td>49.87 ± 10.69</td>
<td>−0.38 ± 0.21</td>
<td>2.73 ± 0.51</td>
<td>194.87 ± 34.47</td>
</tr>
</tbody>
</table>

Values reported are p (P value). Values were considered significant at P < 0.05.

*Represents a strong linear association between the variables.
— = Not applicable.

Table 2—Linear correlation (calculated by use of the Pearson correlation coefficient) between variables for 36 ECGs of dogs with third-degree AV block.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Ta wave duration (ms)</th>
<th>P wave duration (ms)</th>
<th>Ratio of Ta-to-P wave duration</th>
<th>Ratio of Ta-to-P wave amplitude</th>
<th>Duration of P-Ta interval (ms)</th>
<th>Ratio of Ta-to-P wave amplitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ta wave duration</td>
<td>—</td>
<td>0.32 (&lt; 0.001)</td>
<td>0.56 (&lt; 0.001)</td>
<td>−0.20 (&lt; 0.001)</td>
<td>0.14 (&lt; 0.015)</td>
<td>0.95 (&lt; 0.001)*</td>
</tr>
<tr>
<td>Ratio of Ta-to-P wave duration</td>
<td>0.32 (&lt; 0.001)</td>
<td>0.56 (&lt; 0.001)</td>
<td>0.01 (0.903)</td>
<td>−0.07 (0.212)</td>
<td>0.11 (0.040)</td>
<td>0.53 (&lt; 0.001)</td>
</tr>
<tr>
<td>Ratio of Ta-to-P wave amplitude</td>
<td>−0.20 (&lt; 0.001)</td>
<td>−0.07 (0.212)</td>
<td>−0.12 (0.037)</td>
<td>−0.76 (&lt; 0.001)*</td>
<td>−0.19 (0.001)</td>
<td>0.07 (0.228)</td>
</tr>
<tr>
<td>Duration of P-Ta interval</td>
<td>0.95 (&lt; 0.001)*</td>
<td>0.53 (&lt; 0.001)</td>
<td>0.40 (&lt; 0.001)</td>
<td>−0.19 (0.001)</td>
<td>0.15 (0.010)</td>
<td>0.07 (0.142)</td>
</tr>
<tr>
<td>Ratio of Ta-to-P wave voltage</td>
<td>−0.12 (0.036)</td>
<td>−0.04 (0.501)</td>
<td>−0.44 (&lt; 0.001)</td>
<td>0.07 (0.228)</td>
<td>0.02 (0.714)</td>
<td>−0.08 (0.142)</td>
</tr>
</tbody>
</table>

Figure 2—Scatterplot depicting the correlation between the Ta wave amplitude and P wave amplitude for 36 ECGs obtained from dogs with third-degree AV block. The dashed line represents the line of best fit.
A negative correlation was found between duration of the P-Ta interval and atrial rate (P < 0.001). The ICC was calculated with the Shrout-Fleiss reliability test. The ICC was 0.76 for the Ta wave amplitude, 0.94 for the Ta wave duration, 0.97 for the P wave amplitude, and 0.88 for the P wave duration.

Discussion

To the authors’ knowledge, the study reported here was the first in which ECG features of the Ta wave have been characterized in dogs in a clinical setting. The P wave and Ta wave were analyzed with amplified ECGs, as previously reported, to obtain reliable results because it is hard to recognize the Ta wave if the trace is a typical ECG. In this study, 6 dogs were excluded from the statistical analysis because of atrial enlargement, and 10 dogs were excluded because of ventriculoaphasic sinus arrhythmia. The dogs with atrial enlargement, which was diagnosed by radiographic and echocardiographic examinations, were excluded because atrial enlargement can cause an abnormal duration and amplitude of the P wave as well as alterations of the ECG features of the Ta wave. Dogs with ventriculoaphasic sinus arrhythmia were excluded because vagal stimulation, such as happens during ventriculoaphasic sinus arrhythmia, can lead to the temporary appearance of an extremely pronounced Ta wave in standard leads, particularly in lead II. In the present study, the P wave was followed by a dome-shaped Ta wave in all dogs.

In agreement with results of a previous study, P wave deflections were always positive in leads I, II, III, and aVF and all precordial leads (V1 through V6) and always negative in leads aVR and aVL. The Ta wave deflections were always negative in leads I, II, III, and aVF and all precordial leads (V1 through V6). As reported in previous studies in humans and other animals in experimental conditions, the P wave and Ta wave always have opposite polarity. This is explained by the following mechanism. Although the depolarization process of the ventricular myocardium spreads from the endocardial surface to the epicardial surface, the repolarization process spreads from the epicardial surface to the endocardial surface because of the pressure gradient and the difference in temperature between the inside and outside of the ventricular cavity. Thus, as happens in a single cardiac fiber, the atrial myocardium depolarization and repolarization have a similar direction because the intra-atrial pressure is not as high as the intraventricular pressure and there is almost no difference in temperature between the endocardial and epicardial surfaces because the atrial muscle is extremely thin.

In agreement with previous studies in humans and other animals in experimental conditions, the Ta wave in the present study was found to be substantially longer in duration and smaller in amplitude than the P wave. In the study reported here, the mean amplitude and duration of the Ta wave, ratio of the Ta-to-P wave amplitude, and ratio of the Ta-to-P wave duration differed, compared with results of a previous study. The discrepancy of these results is probably attributable to the fact that in the present study, atrial depolarization and repolarization phases were analyzed during sinus rhythm, whereas in previous studies, analysis of the Ta wave was conducted during atrial pacing with the electrical stimulus originating from the coronary sinus ostium or from both the right and left atrium. The different site of origin of the atrial impulse can explain the different values reported for both the P wave and Ta wave.

In agreement with results of a previous study, the P-Ta segment was not taken into consideration because the segment does not exist between the end of the P wave and the beginning of the Ta wave. This was previously described in human studies and a study of other animals under experimental conditions and was confirmed in the present study. The absence of the P-Ta segment is probably attributable to the fact that the duration of the action potential of the atrial fibers is short when compared with that of the ventricular fibers, and the plateau of the atrial action potential is almost zero or, if present, extremely short. In the present study, the reported mean duration of the P-Ta interval was 187.99 milliseconds (95% CI, 172.13 to 203.84 milliseconds). This value is in contrast to that in previous studies (mean duration of the P-Ta interval of 210 milliseconds and mean ± SD of 248.0 ± 25.3 milliseconds in a dog with right atrial pacing and 256.0 ± 38.4 milliseconds in a dog with left atrial pacing). As was explained for the Ta wave duration and amplitude, the shorter duration of the P-Ta interval reported in the present study was attributable to different activation modalities of the atrial myocardium.

In agreement with results of a previous experimental study in which the amplitude of the Ta wave was 24% that of the P wave, we detected a correlation between the Ta wave amplitude and P wave amplitude but no correlation between the Ta wave duration and P wave duration. In this study, we found a correlation between the amplitude of the Ta wave and the ECG lead. The correlation can be explained by the mean electrical axis of the Ta wave in the frontal plane (~114.26°). From a vector point of view, this value can explain the higher amplitude of the Ta wave in lead II and lead aVF and the lower amplitude in lead I and lead aVL.

In agreement with results of a previous study, we detected a correlation between the duration of the P-Ta interval and the Ta wave duration. The duration of the...
P-Ta interval, similar to the QT interval for the ventricle, represents the duration of atrial electrical excitation. The duration of this interval, similar to that for the ventricle, is related to the duration of the repolarization phase and not to the duration of the depolarization phase.

In agreement with results of a previous study, we also found that the duration of the P-Ta interval was correlated with the duration of the atrial cycle. An increase in the duration of the atrial cycle induces an increase in the duration of the P-Ta interval, and conversely, a decrease in the duration of the atrial cycle induces a decrease in the duration of the P-Ta interval. This was also reported in another study in which investigators found that increasing the pacing rate decreases the P-Ta interval mainly by reducing the duration of repolarization. In human medicine, there is a relationship between atrial vulnerability to arrhythmias and failure of the atrial refractory period to shorten with an increase in atrial rate.

The duration of the P-Ta interval can also be influenced by drugs. Propranolol, disopyramide, and flecainide all increase the P-Ta interval, whereas atropine decreases it. Propranolol prolongs the interval by slowing the atrial rate, whereas disopyramide and flecainide prolong the repolarization interval without modifying the atrial rate. The effect of atropine on the interval duration is explained by its effect on the atrial rate because the drug has no independent effects.

The present study had several limitations. The sample included a small number of dogs because 16 dogs were excluded. Furthermore, the end of the Ta wave and peak of the Ta wave were manually determined, and the ECG points were hard to recognize in some of the recordings. Despite this limitation, the measurements had good reproducibility, although interobserver variation was not tested. The presence of third-degree AV block was a prerequisite to enable us to perform analysis of the Ta wave. Consequently, the study population was older than the general population. Because patients with third-degree AV block were analyzed, the impact of the Ta wave on the ST segment was not assessed, although it was reported in a previous study (in which the Ta wave was analyzed during sinus rhythm) that the Ta wave extended to the ST segment over the QRS complex for a mean of 0.06 milliseconds.

Further studies are needed to evaluate Ta wave features in pathological conditions. When atria of dogs were experimentally injured, the magnitude of the spatial atrial gradient increased markedly, and its direction changed systematically in accordance with the site of the injury. In human medicine, the Ta loop may be useful in separating healthy from diseased atria in individuals with third-degree AV block. Additional studies are also needed to evaluate Ta wave features in cases of ectopic atrial depolarization. In human medicine, Ta waves with maximum amplitude originate from the caudal portion of the atria as a result of retrograde conduction or an ectopic rhythm originating in the caudal portion of the atrium.

Analysis of the Ta wave is also important during the postfibrillation period. Postfibrillation atrial remodeling is important because it determines, in part, whether fibrillation will return. On the basis of the extreme decrease of the atrial action potential during atrial fibrillation and the fact the duration of the P-Ta interval does not immediately increase after the restoration of a sinus rhythm with normal sinus rate, analysis of the duration of the P-Ta interval can be used to indicate subjects prone to paroxysmal atrial fibrillation.

In the present study, we provided a detailed ECG characterization of the Ta wave in dogs with third-degree AV block with good reproducibility of the measurements. These results for the Ta wave can be used as reference values for dogs with AV conduction disturbances and an echocardiographically normal cardiac size. Further studies are needed to validate these results in dogs with structural heart diseases.

References