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Research Article

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# Electrocardiographic Evaluation of Cardiac Electrical Activity in Warmblood Police Horses

**Erly Rizka Adistya[1*], Deni Noviana[2], Gunanti[2], Leni Maylina[3], Eniza Rukisti[4]**

[1]Animal Biomedical Sciences Study Program, Graduate School, IPB University, Bogor, Indonesia
[2]Division of Surgery and Radiology, School of Veterinary Medicine and Biomedical Science, IPB University, Bogor, Indonesia
[3]Division of Internal Medicine, School of Veterinary Medicine and Biomedical Science, IPB University, Bogor, Indonesia
[4]Directorate of Animal Police, Korps Sabhara Baharkam Polri, Kelapa Dua, Depok, Indonesia

*Corresponding author: adistyaerly@gmail.com

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**ABSTRACT**

**Background:** Warmblood police horses undergo regular training and operational activities, such as patrol and crowd control, which place continuous demands on the cardiovascular system and can influence resting electrocardiographic (ECG) parameters. Therefore, baseline ECG data are needed to distinguish normal physiological adaptations from potential cardiac abnormalities during routine health screening.

**Aims:** This study aimed to characterize resting cardiac electrical activity in clinically healthy Warmblood police horses using electrocardiography and to compare the observed values with published reference intervals to support accurate clinical interpretation.

**Methods:** Eight clinically healthy male Warmblood police horses in active service were included. Resting ECG recordings were obtained without sedation while the horses stood quietly using a standard base–apex lead configuration. Evaluated parameters included heart rate (HR), P wave amplitude and duration, PR interval, QRS duration, R wave amplitude, QT interval, and T wave duration and amplitude. Measurements were performed manually from representative sinus complexes using calibrated time and voltage scales and expressed as mean ± standard deviation. The findings were descriptively compared with published reference intervals for adult Warmblood horses.

**Results:** All measured ECG parameters were within published reference intervals for adult Warmblood horses. The mean HR was 40.13 ± 6.18 bpm, consistent with resting vagal predominance typically observed in conditioned horses. Conduction intervals (PR, QRS, and QT) showed minimal inter-individual variation, suggesting stable atrioventricular and ventricular conduction. R and T wave amplitudes displayed greater variability, with no clinically significant arrhythmias or conduction abnormalities identified.

**Conclusion:** Resting ECG evaluation using the base–apex configuration provides practical baseline information for cardiovascular assessment in Warmblood police horses. The results indicate that the observed electrical characteristics reflect physiological adaptation and may assist clinicians in distinguishing normal variation from clinically significant abnormalities in working horses.

## INTRODUCTION

Warmblood police horses are routinely exposed to structured training and operational duties, including patrol and crowd-control activities, that place sustained demands on the cardiovascular system. Although they are not competitive athletes, their workload requires adequate cardiovascular efficiency and autonomic regulation. Long-term conditioning induces physiological cardiovascular adaptation that enhances cardiac performance. However, such adaptation may also influence cardiac electrical activity and modify electrocardiographic (ECG) findings, potentially complicating clinical interpretation if not properly understood (Schwarzwald, 2020; Hinchcliff et al., 2022). Accurate recognition of training-related electrical adaptation is therefore essential to avoid misclassification of normal findings as pathological abnormalities.

Cardiovascular adaptation in conditioned horses is closely associated with modulation of the autonomic nervous system. Increased parasympathetic (vagal) tone at rest commonly results in lower resting heart rate and may influence atrioventricular conduction. Consequently, ECG findings such as sinus arrhythmia, sinus pauses, or mild first-degree atrioventricular block may occur in clinically healthy horses (Physick-Sheard & McGurrin, 2018). Transient arrhythmias without structural heart disease have also been reported in healthy horses and are often vagally mediated (Buhl et al., 2017). Alterations in sympathovagal balance may further affect ventricular repolarization patterns (Verheyen et al., 2019; Decloedt et al., 2021). Warmblood police horses routinely undergo training, patrol, ceremonial, and equestrian sport activities associated with moderate but sustained cardiovascular demands. Standardized exercise testing has demonstrated predictable heart rate and ECG adaptations in conditioned horses, supporting the influence of training status on cardiac electrical modulation (Santamarina et al., 2018).

Electrocardiography is a widely used non-invasive method for assessing cardiac electrical activity in horses. It provides information on heart rate and rhythm, atrial depolarization (P wave), atrioventricular conduction (PR interval), ventricular depolarization (QRS complex), and ventricular repolarization (QT interval and T wave morphology). Interpretation of ECG recordings requires consideration of species-specific anatomical and electrophysiological characteristics. The large myocardial mass and extensive intramural Purkinje fiber network in horses influence waveform configuration and amplitude (Elbrond & Sorensen, 2023). Consequently, variability in R and T wave amplitude may represent physiological variation rather than pathological conduction disturbance.

Although resting ECG evaluation is routinely performed in equine clinical practice, published data describing ECG characteristics in actively working Warmblood police horses in Indonesia remain limited. The absence of locally derived baseline values may hinder accurate differentiation between physiological adaptation and clinically relevant electrophysiological abnormalities. Therefore, this study aimed to evaluate resting cardiac electrical activity in clinically healthy Warmblood police horses using electrocardiography in order to provide baseline data to support cardiovascular screening and clinical assessment.

## MATERIALS AND METHODS

### Study Design and Ethical Approval

This study was conducted in November 2025 as a prospective observational investigation. Electrocardiographic recordings were obtained at the Directorate of Animal Police, Korps Sabhara Baharkam Polri, Kelapa Dua, Depok, Indonesia, and subsequently analyzed at the Veterinary Teaching Hospital, School of Veterinary Medicine and Biomedical Sciences, IPB University. All procedures involving animals were reviewed and approved by the Animal Ethics Committee of IPB University (Approval No. 387/KEH/SKE/X/2025). The study adhered to institutional standards for animal welfare and ethical research practice.

### Study Animals

Eight male Warmblood police horses were enrolled to obtain a more homogeneous study population and reduce physiological variation related to sex and reproductive status. All horses were actively participating in routine training and operational activities and underwent clinical assessment prior to inclusion. Only clinically healthy horses free of cardiovascular disease were included. The horses remained under their usual management and training conditions throughout the study, and no medications known to affect cardiac electrical activity were administered before ECG evaluation.

### Electrocardiographic Examination

Electrocardiography (ECG) was performed under resting conditions with the horses standing calmly in a quiet environment without sedation. Recordings were obtained using a portable veterinary ECG device (Medi ECG-II06L Vet) with a standard base–apex lead configuration at a paper speed of 50 mm/s and calibration of 10 mm/mV. The negative electrode was positioned on the right side of the neck near the cardiac base, while the positive electrode was placed on the left thoracic wall at the level of the cardiac apex. A reference electrode was attached according to standard procedures to ensure stable signal acquisition. Recording continued until a consistent tracing with minimal motion artifact was obtained. All tracings were digitally stored for further analysis. For each horse, several representative sinus cycles with clearly defined waveforms were selected for measurement.

**Electrocardiographic Parameters**

The evaluated ECG parameters included heart rate, P wave amplitude and duration, PR interval, QRS duration, R wave amplitude, QT interval, and T wave duration and amplitude. These variables were selected to represent atrial depolarization, atrioventricular conduction, ventricular depolarization, and ventricular repolarization. Measurements were performed manually using calibrated time and voltage scales displayed on the ECG recordings. To improve reliability, each parameter was calculated as the mean of multiple representative sinus complexes from each horse, thereby minimizing the influence of transient variation or minor recording artifacts.

**Data Analysis**

ECG data were analyzed using descriptive and quantitative approaches. Continuous variables were expressed as mean ± standard deviation (mean ± SD). Waveform morphology, including P wave configuration, QRS complex pattern, T wave morphology, and PR and QT intervals, was assessed descriptively. Inter-individual variability within the study population was evaluated quantitatively. Statistical analysis was limited to descriptive evaluation given the exploratory nature of the study and the small sample size.

## RESULTS AND DISCUSSION

Electrocardiographic (ECG) examinations were successfully completed in all Warmblood police horses under resting conditions using the standard base–apex lead configuration. Recordings were obtained in a calm and controlled environment to minimize sympathetic stimulation, as transient stress responses may influence resting cardiac electrical parameters (Hinchcliff, 2021). All tracings displayed stable baselines with clearly identifiable waveforms and minimal motion artifacts, allowing reliable evaluation of atrial and ventricular electrical activity. The horses tolerated the procedure well, and no recording required repetition, indicating good feasibility of resting ECG assessment in this working population.

A representative electrocardiographic tracing from one of the examined horses is shown in Figure 1. The tracing demonstrates a regular sinus rhythm, with each QRS complex preceded by a distinct P wave and followed by a clearly defined T wave. The PR intervals appear consistent throughout the recording, and the QRS complexes are narrow and uniform in morphology. No abnormal complexes, conduction pauses, or rhythm irregularities are evident. The orderly sequence of atrial depolarization, atrioventricular conduction, ventricular depolarization, and ventricular repolarization reflects preserved electrical coordination under resting conditions. These qualitative observations are supported by the quantitative measurements summarized in Table 1.

Overall, the electrocardiographic values obtained in this study correspond closely with published reference intervals for clinically healthy adult Warmblood horses. All measured parameters—including heart rate, atrial depolarization indices, atrioventricular conduction intervals, ventricular depolarization duration, and repolarization characteristics—remained within expected physiological limits. This consistent pattern supports the interpretation that the findings represent normal cardiovascular adaptation associated with regular conditioning rather than evidence of structural or electrophysiological pathology. In working horses such as police mounts, which are routinely exposed to structured training and operational duties, distinguishing adaptive electrical patterns from clinically significant abnormalities is essential for accurate cardiovascular assessment.

The mean heart rate (HR) was 40.13 ± 6.18 bpm, which falls within the reported resting reference interval of 28–44 bpm for adult Warmblood horses (Hinchcliff et al., 2022; Schwarzwald, 2020). A relatively low resting HR is a well-recognized feature of conditioned horses and primarily reflects enhanced parasympathetic tone together with increased stroke volume. Long-term conditioning improves myocardial efficiency, enabling adequate cardiac output to be maintained at lower heart rates. Increased vagal predominance at rest is widely regarded as a hallmark of cardiovascular fitness in equine athletes and working horses. Heart rate variability studies in trained horses have further demonstrated enhanced vagal modulation and improved autonomic balance compared with untrained individuals, supporting the concept of conditioning-related electrical adaptation (Broux et al., 2018). The HR values observed in this population are therefore consistent with physiological bradycardia rather than pathological sinoatrial dysfunction.

Importantly, no sinus pauses, atrial premature complexes, or irregular rhythm patterns were detected in any of the recordings. Although vagally mediated arrhythmias may occasionally occur in healthy horses at rest, particularly in highly conditioned individuals, none were identified in this cohort. The absence of rhythm disturbances reinforces the interpretation that autonomic regulation in these horses is stable and well balanced. While arrhythmias may be more readily detected during exercise or early recovery (Navas de Solis, 2016), the resting findings demonstrate preserved baseline electrical stability.

Atrial depolarization parameters were similarly consistent with physiological expectations. The mean P wave amplitude was 0.221 ± 0.033 mV, remaining below the commonly accepted upper limit of 0.30 mV. The mean P wave duration was 0.115 ± 0.018 s, within the reference range of 0.08–0.14 s. Inter-individual variability was limited, suggesting relatively uniform atrial conduction characteristics across the study population. In conditioned horses, adaptive enlargement of cardiac chambers may occur as part of physiological remodeling (de Oliveira et al., 2019). However, such structural changes do not necessarily produce abnormal P wave morphology unless atrial dilation becomes pathological. Previous investigations have shown that cardiac dimensions and ECG parameters may vary within physiological limits in athletic horses without indicating structural disease (Hesselkilde et al., 2021). The normal amplitude and duration values observed here indicate preserved atrial electrical integrity and support the interpretation that the observed findings represent physiological adaptation rather than structural abnormality.

The PR interval averaged 0.344 ± 0.040 s, which lies within the established reference interval of 0.28–0.44 s. In horses, relatively prolonged PR intervals at rest are considered physiologically normal due to strong parasympathetic influence on the atrioventricular (AV)

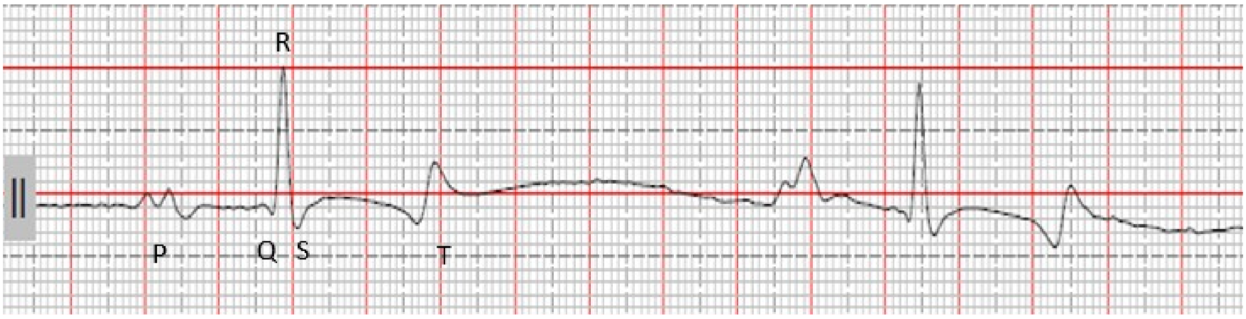


**Figure 1.** Representative resting ECG tracing from one Warmblood police horse recorded using the standard base–apex lead configuration.

**Table 1.** Electrocardiographic parameters in Warmblood police horses (mean ± standard deviation)

| Parameter | Mean ± SD | Warmblood Reference |
|---|---|---|
| HR (bpm) | 40.13 ± 6.18 | 28 – 44 [1)2)] |
| P amp (mV) | 0.221 ± 0.033 | ≤ 0.30 [3)] |
| P dur (s) | 0.115 ± 0.018 | 0.08 - 0.14 [3)] |
| PR (s) | 0.344 ± 0.040 | 0.28 - 0.44 [1)2)] |
| QRS (s) | 0.085 ± 0.018 | 0.08 - 0.12 [3)] |
| R amp (mV) | 0.720 ± 0.332 | 0.3 - 1.5 [3)] |
| QT(s) | 0.499 ± 0.042 | 0.40 - 0.55 [1)2)] |
| T dur (s) | 0.111 ± 0.029 | 0.08 - 0.16 [3)] |
| T amp (mV) | 0.096 ± 0.268 | 0.1 - 1.0 (polarity dependent) [3)4)] |

Sources [1)]Hinchcliff et al., 2022; [2)]Schwarzwald, 2020; [3)]Physick-Sheard & McGurrin, 2018; [4)]Pedersen et al., 2018
*HR = heart rate; P amp = P wave amplitude; P dur = P wave duration; PR = PR interval; QRS = QRS complex duration; R amp = R wave amplitude; QT = QT interval; T dur = T wave duration; T amp = T wave amplitude; SD = standard deviation.

node (Physick-Sheard & McGurrin, 2018). Vagal tone slows AV nodal conduction, resulting in modest PR prolongation without pathological significance. During exercise, sympathetic activation shortens AV conduction time, reflecting dynamic autonomic modulation (Verheyen et al., 2019). Subtle modulation of conduction intervals in response to training intensity has also been described, reflecting electrophysiological plasticity rather than pathological alteration (Decloedt et al., 2022). In the present study, no second-degree AV block or higher-grade conduction disturbances were identified, further supporting the interpretation of physiologically regulated AV conduction.

Ventricular depolarization, represented by QRS duration, averaged 0.085 ± 0.018 s and remained within the reference interval of 0.08–0.12 s. The equine heart possesses an extensive intramural Purkinje fiber network that facilitates rapid and nearly simultaneous activation of ventricular myocardium (Elbrond & Sorensen, 2023). As a result, QRS complexes are typically narrow even in large-bodied horses. Conditioning-related increases in myocardial mass do not necessarily prolong QRS duration in the absence of conduction system abnormalities. The preserved QRS morphology and duration in this study indicate intact intraventricular conduction and coordinated ventricular activation.

The mean R wave amplitude was 0.720 ± 0.332 mV, within the reported physiological range of approximately 0.3–1.5 mV. Compared with conduction intervals, amplitude measurements showed greater inter-individual variability, which is expected because R wave amplitude in horses is influenced by thoracic conformation, cardiac axis orientation, electrode placement, and body condition (Schwarzwald, 2020). In this study, variation in body weight (475–615 kg) despite relatively uniform BCS (5–6/9) may have affected thoracic musculature and the spatial relationship between the heart and recording electrodes, contributing to waveform variability. Therefore, the observed amplitude dispersion most likely reflects normal anatomical variation rather than pathological ventricular remodeling.

The QT interval averaged 0.499 ± 0.042 s and remained within the reference interval of 0.40–0.55 s. QT duration represents the total time required for ventricular depolarization and repolarization and is influenced by heart rate and autonomic tone (Slack et al., 2020). Excessive QT prolongation has been associated with increased susceptibility to ventricular arrhythmias; however, no abnormal prolongation was observed in this population. Inter-individual variability was relatively small, indicating stable ventricular electrical recovery at rest.

T wave duration (0.111 ± 0.029 s) remained within the expected physiological range of 0.08–0.16 s. T wave amplitude (0.096 ± 0.268 mV) showed greater variability but remained within reported physiological limits, typically described as approximately 0.1–1.0 mV depending on polarity. Variations in T wave polarity and amplitude are well recognized in clinically healthy horses and are strongly influenced by autonomic modulation (Schwarzwald, 2015; Pedersen et al., 2018). Variability in repolarization patterns, including T-wave morphology, has been documented in performance horses and is generally considered a physiological phenomenon in the absence of concurrent conduction abnormalities (Borowicz et al., 2022). In the present study, variability in T wave amplitude was not accompanied by arrhythmia, QT prolongation, or conduction disturbance, supporting a physiological interpretation of repolarization variability.

When the electrocardiographic parameters are considered collectively, a consistent pattern becomes evident. Conduction-related parameters (PR, QRS, and QT) demonstrate relative stability across individuals, whereas amplitude-related parameters (R and T waves) exhibit broader dispersion. This distribution reflects the intrinsic electrophysiological organization of the equine heart, in which activation timing is tightly regulated by the specialized conduction system, while electrical vector magnitude is more susceptible to anatomical configuration and autonomic influences. Such coordinated regulation is characteristic of balanced cardiovascular adaptation in conditioned horses.

From a broader physiological perspective, cardiovascular adaptation in working horses involves integrated structural, hemodynamic, and autonomic adjustments. Improved myocardial efficiency, increased stroke volume, and enhanced parasympathetic predominance collectively support sustained workload while maintaining electrical stability at rest. Exercise-induced cardiac adaptation in horses has been described as a balanced process involving structural remodeling and electrophysiological stability without pathological conduction delay (van Loon & Decloedt, 2020). Despite regular exposure to patrol and operational duties, these Warmblood police horses maintained stable conduction parameters and absence of clinically significant arrhythmias, suggesting that their workload remained within adaptive limits.

In addition to the stability of individual electrocardiographic parameters, the overall ECG profile observed in this study reflects effective coordination between electrical activation and autonomic regulation. Electrical stability at rest is particularly important in working horses that are routinely exposed to unpredictable operational environments, where rapid transitions between sympathetic activation and parasympathetic recovery may occur. A well-regulated baseline rhythm provides physiological reserve, enabling appropriate cardiovascular responses during sudden physical exertion or environmental stress. The absence of conduction delay, pathological arrhythmia, or excessive interval variability indicates that adaptive remodeling has occurred within functional limits.

Clinically, the availability of baseline ECG data in this specific working population has practical implications. Police horses are frequently exposed to variable physical and environmental stressors. Accurate interpretation of electrocardiographic findings requires differentiation between physiological adaptation and clinically significant abnormalities. Recommendations for cardiovascular screening in equine athletes emphasize the importance of distinguishing physiological adaptation from clinically significant cardiac abnormalities (Reef et al., 2014). The present results provide locally derived baseline data that may assist veterinarians in routine cardiovascular screening and longitudinal monitoring.

A limitation of this study is the relatively small sample size and the absence of exercise ECG monitoring. Certain arrhythmias may only manifest during high-intensity exertion or early recovery (Navas de Solis, 2016). Exercise electrocardiography may reveal transient rhythm disturbances not detectable during resting recordings, highlighting the value of dynamic assessment in certain clinical scenarios (Ryan et al., 2021). Additionally, structural cardiac assessment was not performed concurrently, limiting correlation between morphological and electrical findings. Future studies incorporating dynamic ECG evaluation and multimodal cardiovascular assessment would provide a more comprehensive understanding of adaptation in working equine populations.

In summary, all measured electrocardiographic parameters in these Warmblood police horses were consistent with established physiological reference values for adult Warmblood horses. The stability of conduction intervals, combined with controlled variability in amplitude parameters and absence of arrhythmia, supports the interpretation of regulated electrical adaptation rather than pathological alteration. These findings provide clinically relevant baseline information to support cardiovascular evaluation and routine screening in working horses.

## CONCLUSION

The electrocardiographic evaluation of these Warmblood police horses demonstrated that all assessed parameters were consistent with established physiological reference values for adult Warmblood horses. The observed electrical profile supports the presence of regulated cardiovascular adaptation associated with routine training and operational duties rather than evidence of pathological electrical disturbance. Resting electrocardiography using the standard base–apex configuration provides practical baseline information for cardiovascular screening in working horses. Interpretation of ECG findings in this population should consider conditioning status and workload to ensure appropriate differentiation between physiological adaptation and clinically significant abnormalities.


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## AUTHORS CONTRIBUTION

E.R.A. designed the study, collected and analyzed the data, and drafted the manuscript. D.N. supervised the electrocardiography examinations and contributed to data interpretation. G. participated in data interpretation and scientific discussion. L.M. and E.R. contributed to the clinical interpretation of the findings. All authors revised and approved the final version of the manuscript.

*"The author declares that there is no conflict of interest with the parties involved in this research".*

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