THESIS

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The application of the 12-lead ECG in healthy dogs

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Abbrevations

CRT : capillary refill time

ECG : electrocadiography

LBBB: left bundle branch block

MEA : mean electrical axis

1. Introduction and aim of the study.

Electrocardiography (ECG) is a medical test that records the electrical activity of the heart over a period of time. It is a common diagnostic tool used to assess the heart's rhythm, rate, and overall electrical function. During an ECG, electrodes are placed on the skin to detect and record the electrical impulses the heart generates as it contracts and relaxes.

The primary components of the surface ECG include the P-wave, QRS complex, and T-wave, which correspond to different phases of the cardiac cycle. By analysing these waveforms and their characteristics, practitioners can diagnose various heart conditions and pathologies or monitor patients during anaesthesia to evaluate the impact of various drugs.

Furthermore, ECG serves as an indispensable tool in the hands of practitioners in the need for supplementary cardiac investigation or in emergency medical situations. The ECG contributes to a comprehensive evaluation of cardiac health, providing insights that can guide ongoing care and interventions. In the fast-paced environment of emergencies, the ECG stands as a rapid and reliable means of swiftly assessing the status of a patient's heart, which is often vital in life-threatening situations.

Extensive literature exists regarding the origin of ECG waves, their cellular basis, disease implications, and diagnostic significance [1]. Due to their indispensable clinical role, ECGs are studied in both human and veterinary medicine. Whether it's for monitoring anaesthesia or diagnosing conditions such as arrhythmias and electrolyte imbalances, it would be highly beneficial for every veterinary practitioner to have a solid foundation in ECG interpretation skills, contributing to a well-rounded expertise in caring for animals. Besides, the traditional and long-used standard limb lead system, six additional chest leads were recently introduced to small animal medicine, adapted from human cardiology. Little data is available about the appearance of different waveforms in these new thoracic leads in healthy dogs.

This study investigates the appearance of PQRS-T waveforms and their relationships using the new 12-lead ECG system in clinically healthy dogs.

By performing this research, the knowledge of how to interpret ECGs in healthy dogs can be expanded, establishing a foundation for future cardiac assessments. The hope is that these findings will not only enhance our understanding of normal canine ECG patterns but also prove valuable for clinical applications and ongoing research in veterinary cardiology.

2. Literature review

2.1. The origin of the electrocardiogram

Tremendous progress and elaborate studies and data have been done and collected on the use of the electrocardiogram. The first book of electrocardiography was published in 1908 by the "Father of Clinical Cardiac Electrophysiology"[2], Thomas Lewis (1881-1945), an English cardiologist and clinical scientist. Based on the work of pioneers like A.D. Waller and W. Einthoven, Lewis could put forward significant contributions to the field of electrocardiography.

Prior to Lewis´ revelations, Augustus D. Waller (1856-1922), an English physician/physiologist found that the electrical activity preceded the contraction of the myocardium, and that this activity could be recorded on the body surface. Waller refined the capillary galvanometer and transferred its use in skeletal muscle to the heart. Through recordings of limb electrodes, he could manifest that the baseline deflections were caused by the apex beats.[3] The apex beat, also termed the apical impulse, is a pulsation generally made by the left ventricle and located near the costochondral junction in the left 5th intercostal space.[4] His work was further developed by Willem Einthoven (1860-1927) by advancing the capillary galvanometers into the string galvanometer in 1887. This advancement improved the recording time and removed the need to convert the tracing mathematically. The deflections were also renamed from ABCD to PQRST to disconcert the slow readings of deflections previously seen on the capillary galvanometer. The advancement made by Einthoven granted him the recognition as "Father of Electrocardiography".

The propulsion of scientific development that has been experienced in the 20th century and now into the 21st, has further given the opportunity for human and veterinary practitioners to provide a rounder overall care based on the principles of these founding fathers in Cardiology[3].

In today´s clinical setting, the principles are the same, based on ECG recordings of the electrical fields produced by the heart on the body's surface. The phases of myocardial depolarization and repolarization represented by specific waveforms can be captured and further analysed to provide better care. Today the ECG should be the primary test when diagnosing cardiac arrhythmias and can provide valuable information in regards to dilation and hypertrophy of the heart, proving to be an indispensable tool[5].

2.2. The basics of electrocardiography

The ECG records the action potential from different angles through the individually located skin electrodes. It makes it possible to follow the cardiac cycle originating from the sinoatrial node. The action potential initiated from the sinoatrial node launches the cardiac cycle. As the potential migrates through the myocytes by cell-to-cell transmission the electrical impulse can be detected. Therefore, by placing the electrodes over the skin, the electrocardiogram is used to produce a readable impulse wave revealing the migration of the action potential. It makes it possible to follow the action potential through the myocytes located in the atria and ventricles.

The action potential is comprised of a depolarization accompanied by a repolarisation, functioning as an activation and a recovery, respectively. Particular ion channels are located on the cell membranes that open and close by the polarization state so that specific ions can flow through them. The action potential is thus the motion of the ions creating an electrical current [1].

The 12-lead system used in human and veterinary ECG includes the bipolar limb leads I-III, the augmented unipolar limb leads and the unipolar precordial leads. The use of the term bipolar means that the ECG recording is taken from two specific electrodes. The right thoracic limb lead (Lead I) is used with the left thoracic limb lead, the right thoracic limb lead (Lead II) with the left pelvic limb and the left thoracic limb lead (Lead III) is used with the left pelvic limb. The augmented unipolar limb leads, however, provide a voltage measurement of one specific limb electrode against the average voltage of the other two limbs' electrodes. In addition to the limb leads, the exploring unipolar positive electrodes placed along the chest wall may provide ancillary information for cardiac enlargement or when limb leads show no clearly visible P waves. These chest leads measure voltages between the given chest electrode serving as the anode against the average of the three limb lead electrodes that serve as the cathode [5]. Thus, all lead systems are bipolar in nature (no voltage measurement is possible without two electrodes, a cathode, and an anode), but when one electrode measure voltages against more than one electrode, the lead systems are called historically unipolar systems.

The depolarization of both atria produces waves on the skin surface ECG that have been termed the P-wave and the depolarisation of the ventricles is called QRS-complex. These electric processes are followed by repolarization producing the so-called T-wave. In veterinary medicine, the use of the P-wave and QRS-complex is emphasized as the repolarization wave shows a greater range of normal variation. A normal T-wave in veterinary medicine can have multiple wave patterns where some leads even may be featureless. The shape of the T-wave can read as a positive or negative deflection, or even biphasic, and still be considered physiological [1].

The production of the waves by the electrocardiogram, their cellular origin, their correlation with disease and their diagnostic value have produced a vast quantity of literature. Since the inception of the ECG, some fundamental concepts have been consistent and overall agreed upon. One is the valuable insight into the electrical events within the heart and body seen by the direction of wave propagation [7]. Moreover, if a depolarization wave is positive, it signifies that the depolarization is travelling towards the anode, which is the positive electrode. Conversely, if a repolarization wave is positive, it implies that the repolarization is moving in the direction of the cathode, the negative electrode. This fundamental concept has remained consistent since the inception of the ECG. An understanding of the direction of electric potentials within the heart and body can therefore be given based on the location of the positive and negative skin electrodes. The anodes are located at the left forelimb in Einthoven I and aVL leads, at the left hind limb in Einthoven II, III and aVF leads, and at the right forelimb in aVR. Additionally, in the chest leads, the actual electrodes V1 to V6 function as anodes [5].

2.3. The normal appearance of the PQRST waves in healthy dogs

The significance of its diagnostic value and the amount of work performed in human medicine with ECG reflects that the veterinary field too, has a great deal of documentation and literature on the subject. This mirrors the vitality of the ECG in the work of the clinician. Today the ECG is used in day-to-day practice for a variety of tasks ranging from monitoring such as during anaesthesia to diagnosing electrolyte imbalance or cardiac arrhythmias. In healthy dogs, the PQRST waveforms observed on an ECG, serve as visual representations of the different phases within the electric cycle of the heart. Each of these waves possesses a characteristic appearance and follows a distinct sequence.

The P-wave corresponds to atrial depolarization, signifying the contraction of the atria as they propel blood into the ventricles. The P-wave is typically small and exhibits a rounded configuration that generally endures for a period of a maximum of 0.045 seconds [5].

The P-wave is followed by the QRS-complex which serves as an indicator of ventricular depolarization, highlighting the contraction of the ventricles responsible for ejecting blood from the heart. The QRS-complex is notably larger and more prominent compared to the P-wave. It is incredibly brief, typically lasting less than 0.06 seconds depending on the size of the breed [5].

PQ-interval is the time needed for the electric impulse to reach the working ventricular cells after sinus node firing, measured from the beginning of the P-wave until the beginning of the QRS-complex. Its typically between 60 and 130 msec in the dog [6].

The ST-segment (early repolarisation) is a flat line between the QRS and T-wave in healthy humans, however, can both present as with a mild depression or elevations in the ECG of normal dogs. However, a negative deflection should not exceed 0.2 mV, nor should a positive deflection exceed 0.15 mV in healthy dogs [5]. One should also observe the presence of the J wave, which is characterized by a positive deflection at the J point exceeding 0.1 mV in more than one lead. It's advisable to recognize that this is a normal variation in the dog's ECG and doesn't indicate any disease[7].

T-wave symbolizes the end of ventricular repolarization, reflecting the recovery phase of the heart's electrical cycle as the ventricles prepare for the coming contraction. The T wave may present as both positive or negative, and even as a biphasic wave in healthy canines. Nevertheless, they are generally rounded and sequentially follow the QRS complex. It should not exceed more than one-quarter of the amplitude of the R wave [6].

The QT-interval is the time needed for ventricular depolarisation and repolarisation. Measured from the beginning of the QRS-complex until the end of the T-wave, during normal heart rates may range from 0.15-0.25 seconds [6].

Collectively, these waveforms furnish valuable information about the heart's electrical activity, rhythm, and overall functionality. In healthy individuals, these waveforms and intervals manifest in a consistent pattern and typically do not deviate significantly from the established norm. Nevertheless, it is essential to acknowledge that variations may manifest based on breed-specific characteristics and individual factors [6].

2.4. The ECG leads of the limbs and precordial chest.

The majority of veterinary practitioners use the limb lead system to obtain ECG recordings by using three electrodes. These three electrodes are affixed to the pre-established locations of the right forelimb, the left forelimb, and the left hind limb. Ideally, an additional “earth” electrode should be situated at the right hind limb [8]. Based on this arrangement, six distinct ECG leads can be captured. These encompass the well-known trio of bipolar limb leads, Einthoven I, II, and III, as well as the trio of the augmented unipolar limb leads, aVR, aVL, and aVF.

In the domain of canine electrocardiography, the utilization of precordial leads, including V1, V2, V4, and V10, has been known for more than 70 years. Although more commonly employed in human medicine, these precordial leads hold value in veterinary practice as well [9]. Positioning these leads accurately relies on anatomical landmarks, typically over the right ventricle, left ventricle, and along the dorsal midline. It's important to note that precordial leads offer a higher degree of precision in capturing the heart's dipole compared to limb leads [10]. Furthermore, applying precordial leads improves the clarity in detecting distinct cardiac abnormalities like wide complex arrhythmias or bundle branch blocks. [10]

Already proven, is how the shifts in the dogs´ positioning can alter the captured ECG, especially when limited to the 6-lead ECG of the limbs [11]. This highlights the importance of a standardized and persistent pattern of positioning during the ECG to ensure an accurate representation of the ECG. This should also be done to prevent alteration in the vector of the QRS-complex as both may lead to faulty interpretations of the reading.

When emphasising the uniform body positioning standardized protocols for body positioning have been established for canine ECG. These protocols should be quite straightforward in patients who are compliant and where the handlers have developed skills for restraint. In the field of human ECG, fewer challenges may be present based on thoracic conformation and size, however, in dogs, there is a diverse range of disputes based on breeds that propose alterations in chest conformation, particularly pertaining to the potential fluctuations regarding the electrical axis of the heart [1]. This electrical axis termed the cardiac axis is also known as the mean electrical axis (MEA). This axis usually refers to the QRS-complex which symbolizes the net vector of the ventricular depolarization [6]. The MEA can be determined based on the 6 limb leads or by adding the net amplitude of a horizontal axis seen in the QRS-complex of lead I and the net of the vertical axis seen in the QRS-complex of the augmented lead aVF[6]. The convergence of these values will cater the vector which is equal to MEA. The MEA can also be estimated based on the findings in Lead I and aVF [1]. Due to the heart´s anatomy, with a predominant left ventricle, the MEA is also shifted to the left [1]. Alterations in the ventricular mass, both left or right, can be reflected as alterations in this axis [6]. Based on the directions of the MEA a degree system has been implemented. In normal dogs, the MEA ranges from 40 to 100 degrees [6]. When the MEA is shifted to the left it points less than 40 degrees, whereas the right shift means MEA above 100 degrees.

The main obstacle to establishing a true standardized value in dogs has been based on the alterations in the anatomical conformation of the chest, as the varying axis may hinge on the proximity of the electrodes to the heart. This matter in question was already established based on the early work of Einthoven, showing that waves of the ECG could be altered by the heart's position within the chest [3].

In the scope of human studies, the exploration of the relationship between in vivo cardiac orientation, the cardiac electric field, and the ensuing electrical activity of the surface, has already been performed [12, 13]. These studies found that establishing a straightforward correlation between the anatomical cardiac axis and the pattern of the ECG waves was difficult. However, this cannot be easily transposed to the field of veterinary medicine as the consistency in thoracic confirmation of humans varies significantly for that of abundant dog breeds.

The use of precordial chest leads can further complement and in some cases reveal changes in the electric work of the heart. The values of the chest leads are obtained by exploring unipolar anodes along the margins of the chest. Several protocols for the placement of these leads have been proposed, however, few have been able to provide a set value for standardized measures [10, 14]. If so, the leads have been altering on which to provide the confirmational data to support or exclude the diagnosis [14].

2.5. The newly introduced chest-lead system on healthy dogs.

During the accelerated evolvements in cardiology, seen in the latter half of the 20th century, various precordial systems have been suggested for veterinary use [15]. Some have been attempted with modifications to mirror the human application of the 12 lead ECG, whereas others have ventured to generate placements based on the dogs' anatomy itself. By alterations in the positioning of the leads in different locations on the thorax, the lead responsible for monitoring the ventricular depolarization has typically been positioned in the 3^{rd} or 5^{th} intercostal space on the right.

The challenge, however, with transposing the human application of the chest leads to dogs, have been the alterations in chest conformation seen among the different breeds compared to humans. The chest confirmations in dogs have typically been described as brachymorphic, mesomorphic and doliomorphic, commonly known as barrel-chested, oval and deep-chested, respectively. Studies have proposed that the chest conformation alters the consistency, especially for the atrial and ventricular depolarization of the right heart. This inconsistency in findings has made evaluation difficult, with possibilities of misdiagnosis of cardiac anomalies or missing diagnoses altogether.

Research has been done to evaluate the effects of chest conformation with various means. Ranging from thoracic X-rays, vertebral heart scores and external body measurements to body positioning and altering the placement of leads, studies have shown variations of the cardiac axis due to the dorsoventral diameter of the chest as well as its effect on the horizontal plane of the heart [13, 15]. These variations may contribute to the interpretation of the waves and their polarity on the ECG. Simultaneously, some studies find that it's not the conformation of the chest wall itself that contributes to the changes seen on the ECG, but more the orientation of the heart itself within the thoracic chamber[13].

Nevertheless, the alteration of the placement for the precordial lead V1 to the costochondral junction of the 1st intercostal space on the right side of the thorax instead of the 5th intercostal space, has provided promising results [14]. This placement has been demonstrated to provide a consistent assessment in the majority of dogs when evaluating the right atrial and ventricular repolarization [15]. Locating the V1 lead in this anatomical position has also been shown to produce a negative deflection of the P wave as it is located over the right atrial epicardium. The pattern of the QRS complex was also deemed relatively constant regardless of the chest conformation [14]. This location also shows indications of trends noted in the R and S waves, being small and deep, respectively. Other consistencies were also found to be evident and showed trends of polarity in several leads. This is due to the collective vector of the directed impulse originating from the SA node located in the atrium to the AV node, located within the triangle of Koch, as well as the depolarization of the right ventricle [15].

Our study aimed to perform 12 lead standard ECG examinations on healthy dogs by using the newly introduced chest lead system. We aimed to describe the appearance and polarity of the ECG waves and the direction of the cardiac vector in normal canines.

3. Materials and methods

This study involved the ECG evaluation of 70 clinically healthy dogs. All but five of the ECG exams were performed in standard right lateral recumbent position with the 12-lead CARDIAX PC-ECG machine. The remaining five dogs were examined while standing as the dogs were trained for cardiac ultrasound practice and had found this as the least stressful position.

***Figure 1** Owner fixating patient during reading.*

This ECG monitoring device provides a user-friendly software with multiple functions that are simple to use. Up to 12 leads can be monitored at the same time and the ECG vector can be documented as a 2D or 3D vector by using the FRANK leads.

In all the recordings the owners were present to minimize the stress of the animal as displayed in **Figure 1**.

The study was approved by the Norwegian Food Safety Authority and carried out in Norway and Hungary in 2023.

Prior to every measurement, overall health and vital parameters were assessed. A brief history was obtained to exclude previous health issues, as well as the documentation of sex and breed together with the weight of the animal. In addition to obtaining the history, cardiac auscultation, capillary refill time (CRT) of oral mucous membranes and palpation of the femoral pulse was done all individuals. These measures were taken to eliminate diseased or cardiovascular-compromised dogs.

The criteria for dogs to enter the study were being older than 1 year of age, having good overall health and having no prior diagnosed morbidity. The dog would also need to tolerate the placement of lateral recumbency for 5 minutes without sedation. The study excluded three patients based on clinical parameters; one male boxer with suspicion of DCM, one female Riesenschnauzer with aortic stenosis, and one female French bulldog due to current pregnancy discovered four days after the ECG reading. Two dogs were diagnosed with left bundle branch block (LBBB) based on the ECG findings but were without clinical signs. These, however, were excluded from the study. 6 dogs were too stressed in the clinical setting to allow placement of the electrodes without sedation.

The ten electrodes were placed in accordance with the proposed guidelines[15]. The limb leads, RL, LL, FL and NL were placed on the right front limb, left front limb, left hind limb and right hind limb, respectively. The chest leads were placed in the intercostal spaces on the right and left side in the following order: Chest lead V1 was placed in the first intercostal space on the right side of the thorax. For the placement of the remaining chest leads intercostal space counted from the last rib in a caudal to cranial direction revealing the 6th intercostal space. At the 6th intercostal space, the V4 was placed in between the costochondral junction of the 6th and 7th rib. The chest lead V2 was then attached in the same intercostal space just laterally to the sternum. The placement of the chest lead V3 was then performed in the middle of V2 and V4. The chest leads V5 and V6 were placed dorsally to V4 with the same distance as V2-V3-V4 as displayed in **Figure 2**. The electrodes were then soaked in isopropylene-alcohol to increase the conductance of the electric impulse.

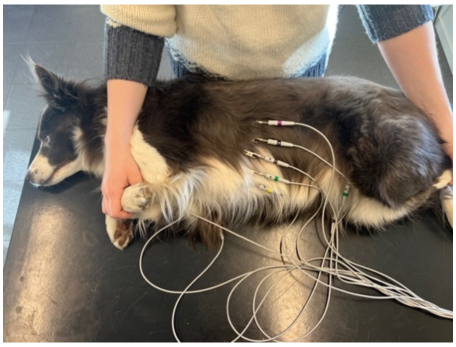

Figure 2 *Fixation of the dog during the placement and measurement with the 12 Lead ECG.*

The ECG measurement requires several factors for a successful reading, hence combining technical accuracy regarding electrode placement and patient comfort, was emphasised in this study. The observations made during the measurements - from electrode placement to waveform characteristics, and even the emotional well-being of both the patient and owner, all contribute to the reliability of ECG results.

To ensure precise and dependable ECG data, the following key factors were closely watched: P wave deflection in the precordial chest lead V1, lead connectivity, PQ and QT intervals, P wave and QRS complex amplitudes, and T wave direction.

The initial assessment was made prior to the initiation of the recording of the ECG (**Figure 3**). Firstly, the polarity of the P wave in the first precordial lead V1 was assessed. This was to ensure proper placement as proper electrode positioning in this specific lead is crucial as it captures the initial atrial depolarization, providing a clear and informative P wave.

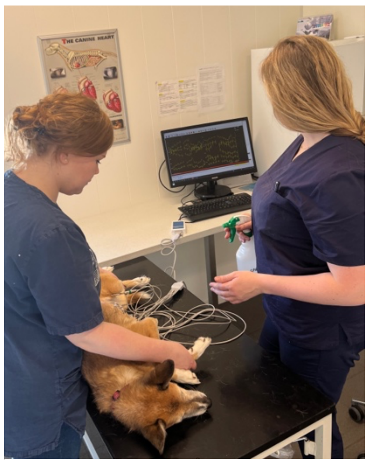

Figure 3 *Initial assessment of conductivity in the ECG leads.*

When a positive depolarization of P wave in V1 was observed in the study, it indicated a too posterior placement of the lead. If a positive depolarization was seen a reassessment of the lead was made. The most common cause for misplacement of this lead was in densely furred animals who had tense pectoral muscles or excessive skin or fat in the region of the first intercostal space.

Another important factor which was observed closely was the connectivity of the lead. As the stability of lead connectivity is significant for evaluation, any inconsistencies in lead connections were noted and addressed promptly. In instances of unstable readings, additional alcohol was used to soak the skin around the lead to enhance conductivity (**Figure 4**), or paper towels were strategically placed between the leads to remove the risk of potential artefacts.

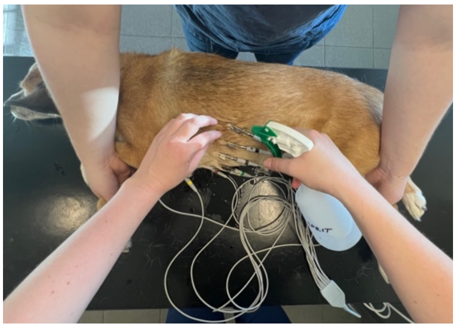
Figure 4 *Isopropyl alcohol used to enhance conductivity for the electrodes.*

The cardiac rhythm was noted indirectly, and the trend displayed a decrease in the heart rate about 1 minute after the placement of the leads. This parameter was used as an indicator to ensure that the animal settled down and parallelly to display to the owners that this is a non-invasive procedure. Simultaneously, if any rhythmic disturbances would be present the animal could be excluded from the study and further diagnosed clinically if necessary. This, however, did not occur during the ECG exam of these dogs except one dog with a single ventricular premature beat during the record. Approximately 5-minute ECG recording of the 12 leads were recorded and stored from each dog.

Beyond the technical aspects of the ECG measurement, the emotional states of both the dog and its owner were considered. Anxiety or stress could potentially influence physiological responses and affect the ECG results. Therefore, creating a safe and quiet environment was essential to mitigate any potential emotional interference during the procedure.

Measurements

The compilation of data for this study was gathered based on the measurement of amplitude and polarity of each lead for the P-wave, the QRS-complex and the T-wave. Each value was linked to the correspondent individual and the age, sex, breed and weight was considered in its significance. The measurements of milliseconds (ms) and amplitude (mV) was measured using the integrated measuring tools in the Cardiax system. The PQ-interval, from the start of the P-wave to the beginning of the Q-wave, and the QT-interval, from the beginning of the Q-wave to the end of the T-wave, were measured in Einthoven II.

During the analysis of the ECG values obtained during the measurements, the polarity and amplitude of the P wave was recorded at the peak of the wave itself. Similarly, the amplitude of the QRS-complex was measured based on highest amplitude. A larger range of R-wave compared to Q and S wave deemed the QRS complex as positive and a smaller R-wave as negative. An equal distribution was regarded as an isoelectric wave.

The direction of the T-wave was also carefully measured. Positive and negative repolarizations were noted, and we also evaluated the concordance with the QRS-complex.

All the values above were measured three times during the recordings, approximately at 1.5, 3 and 4 minutes of the 5-minute-long recordings. The values were noted in Microsoft Excel (version 16.78) where an extensive table was made. The data was then analysed through Pivot tables to create the parameters used in the descriptive statistics.

4. Results

After exclusions, the studied population included 59 dogs, 18 sexually intact males, 3 spayed males, 35 sexually intact females, and 3 neutered females. The following breeds were included: 2 Afghan hounds, 3 Border collies, 1 Borzoi, 1 Cairn terrier, 3 Chihuahuas, 1 Cocker spaniel, 1 Doberman, 1 Dogo canario, 5 Miniature Schnauzers, 14 French bulldogs, 2 Groenendaels, 2 Malinois, 2 Miniature bullterriers, 1 Norwegian elkhound, 7 Shetland sheepdogs, 1 Yorkshire terrier, and 12 mix breeds. The group had a mean ± SD age of 4.8 ± 3.1 years, ranging from 1 to 14 years, and a body weight of 14.5 ± 9.7 kg ranging from 2.1 to 48 kg.

Based on the readings performed on the 59 dogs, the average heart rate during the measurement was 112 ± 25 beats per minute ranging from 50 to 160 beats per minute.
All dogs had sinus arrhythmia except the ones with heart rates above 140 bpm, where sinus tachycardia was observed. There was one dog with a simple premature ventricular beat during the 5-minute ECG tracing.

4.1. Results from the total population

Table 1. provides a detailed breakdown of the distribution of positive, negative, and isoelectric findings for the P wave, QRS complex, and T wave across various leads, including both precordial chest leads (V1 to V6) and limb leads (Lead I, Lead II, Lead III, aVR, aVL, and aVF). The data is presented in terms of the number of findings, while the percentile can be found in the text.

4.1.1. Polarity of the P waves in the precordial and limb leads.

In Einthoven-I lead 97 % of the dogs showed positive P-waves, 2 (3.4%) had negative ones, and none had isoelectric. Limb lead-II consistently displayed positive P-waves in all 59 measurements, with no negatives or isoelectric cases. Limb lead-III had 50 (85 %) cases with positive P-waves, 9 (15 %) with negative P-waves, and none with isoelectric P-waves. In aVR, all 59 measurements revealed negative P-waves. In aVL, 59 % of the animals had positive P-waves, 41% had negative ones, and none had isoelectric. In aVF, 98% of the recordings displayed positive P-waves, with only 1 (2 %) negative case.

95 % of the dogs showed negative P-waves in lead V1, and there were only 3 (5 %) cases of isoelectric P-waves in this lead. The chest leads V3-V6 recorded exclusively positive P-waves and 97% of the P-waves were also positive in V2.

Table 1 *Summary of total findings of polarity of the different waves in the whole population studied.*

Limb leads	Lead	+	-	+/-	Total	Precordial Chest leads	Lead	+	-	+/-	Total
P wave	Lead I	*57*	*2*	*0*	59	**P waves**	V1	0	56	3	59
	Lead II	*59*	*0*	*0*	59		V2	*57*	*1*	*1*	59
	Lead III	*50*	*9*	*0*	59		V3	*59*	*0*	*0*	59
	aVR	*0*	*59*	*0*	59		V4	*59*	*0*	*0*	59
	aVL	*35*	*24*	*0*	59		V5	*59*	*0*	*0*	59
	aVF	*58*	*1*	*0*	59		V6	*59*	*0*	*0*	59
QRS Complex	Lead I	*59*	*0*	*0*	59	**QRS complex**	V1	*0*	*58*	*1*	59
	Lead II	*59*	*0*	*0*	59		V2	*59*	*0*	*0*	59
	Lead III	*51*	*7*	*1*	59		V3	*59*	*0*	*0*	59
	aVR	*0*	*59*	*0*	59		V4	*59*	*0*	*0*	59
	aVL	*33*	*26*	*0*	59		V5	*58*	*1*	*0*	59
	aVF	*57*	*2*	*0*	59		V6	*57*	*2*	*0*	59
T waves	Lead I	*22*	*37*	*0*	59	**T waves**	V1	*25*	*32*	*2*	59
	Lead II	*26*	*30*	*3*	59		V2	*48*	*9*	*2*	59
	Lead III	*29*	*28*	*2*	59		V3	*47*	*12*	*0*	59
	aVR	*32*	*26*	*1*	59		V4	*46*	*11*	*2*	59
	aVL	*24*	*35*	*0*	59		V5	*42*	*16*	*1*	59
	aVF	*28*	*31*	*0*	59		V6	*36*	*23*	*0*	59

4.1.2. Polarity of the QRS-complexes in the precordial and limb leads

Regarding the QRS-complexes in the limb leads, Lead I, II consistently showed positive QRS-complexes in 100% of the recordings, with no negative or isoelectric cases. Lead III, however, displayed 86% positive QRS-complexes, 7 (12%) negative QRS-complexes, and 1 isoelectric QRS complex among the 59 individuals. In aVR, all 59 measurements displayed negative QRS complexes. In aVL 56% of the cases showed positive QRS-complexes and 44% were negative. In aVF, 97% of the animals had positive QRS-complexes, and 2 (3%) had negative ones.

In the chest leads, no positive QRS-complexes were noted in V1, the majority (98 %), presented with negative QRS and 1 dog displayed isoelectric QRS complexes in this lead. In leads V2-V4 all measurements were positive. However, variations could be seen in V5 and V6, with 1 (2%) and 2 (3%) isoelectric complexes, respectively. The negative QRS in V5 was followed by a negative QRS in V6 in the same animal. This individual also presented with negative QRS in 2 other leads that was usually positive in most cases; limb lead III and aVF. Interestingly, this dog also had a negative P-wave seen in the limb lead III.

4.1.3. Polarity of the T waves in the precordial and limb leads

In terms of T waves, in Lead I, 38% of the cases had positive T-waves, 63% were negative, and none were isoelectric. Lead II displayed 44% positive T-waves, 51% negative T-waves, and 3 (5%) isoelectric T-waves. Lead III exhibited 49% positive T-waves, 48 % were negative, and 2 (3%) were isoelectric. In aVR, 56% of the recordings showed positive T-waves, 44% had negative ones, and 1 (2%) had isoelectric T-waves. In aVL, 40 of the cases had positive T-waves, 59% were negative, and none were isoelectric. In aVF, 48 % of the animals displayed positive T-waves, with 52% of the cases showing negative T-waves.

In V1, there were 42% of dogs with positive T-wave deflections and 54 % with negative T-wave deflections, with 2 individuals exhibiting isoelectric T-waves. In the lead V2, V3 predominantly positive T-wave deflections (81-80%) were observed with a small percentage of negative T-wave deflections. A slightly lower percentile of positive T-wave deflections was seen in the lead of V4-V6 (78%, 71% and 61%, respectively).

The T waves and QRS-complexes showed highly variable concordance, the highest concordance occurred in V2, where 81.4% of the positive QRS-complexes were followed by a positive T-wave (**Table 2).**

Table 2 *Concordance pairs and their percentage of the group. Values above 50 % are highlighted in bold.*

	Lead I	Lead II	Lead III	aVR	aVL	aVF	V1	V2	V3	V4	V5	V6
Positive QRS complex and T wave	22	26	26		13	27		48	47	46	41	36
Positive QRS complex and T wave %	37,3	44,1	44,1	0,0	22,0	45,8	0,0	**81,4**	**79,7**	**78,0**	**69,5**	**61,0**
Positive QRS and negative T wave	37	30	24		20	30		9		11	16	21
Positive QRS and negative T wave %	**62,7**	**50,8**	40,7	0,0	33,9	**50,8**	0,0	15,3	0,0	18,6	27,1	35,6
Positive QRS and isoelectric T wave		3	1					2	12	2	1	
Positive QRS and isoelectric T wave %	0,0	5,1	1,7	0,0	0,0	0,0	0,0	3,4	20,3	3,4	1,7	0,0
Negative QRS and T wave			4	26	15	1	32					2
Negative QRS and T wave %	0,0	0,0	6,8	44,1	25,4	1,7	**54,2**	0,0	0,0	0,0	0,0	3,4
Negative QRS and positive T wave			3	32	11	1	24				1	
Negative QRS and positive T wave %	0,0	0,0	5,1	**54,2**	18,6	1,7	40,7	0,0	0,0	0,0	1,7	0,0
Negative QRS and isoelectric T wave				1			2					
Negative QRS and isoelectric T wave %	0,0	0,0	0,0	1,7	0,0	0,0	3,4	0,0	0,0	0,0	0,0	0,0
Isoelectric QRS and T wave			1									
Isoelectric QRS and T wave %	0,0	0,0	1,7	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Isoelectrc QRS and positive T wave							1					

4.1.4. Presence of J-wave

17 out of the 59 dogs (29%) presented with J-waves, out of which 5 (29 %) were seen in sexually intact males, 10 (59 %) in sexually intact females, and 1-1 in a neutered male and female dog.

4.1.5. PQ and QT-intervals in Einthoven II

The PQ-interval mean duration was 92.9 ms with a SD ± of 14.5 ms, where the shortest duration was 74 ms and the longest duration was 133 ms.

The QT-interval mean duration was 204.6 ms, with a SD ± of 18.9 ms. The shortest duration observed was 154 ms, whereas the longest duration was 240 ms.

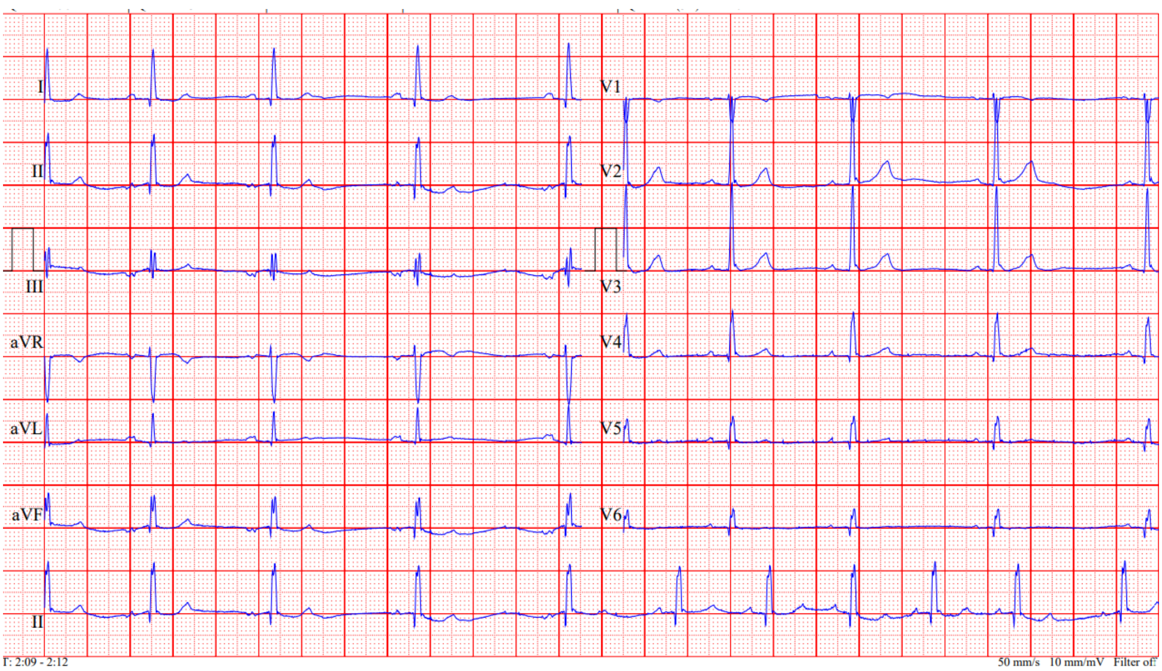

Figure 5 *12-lead ECG recording representing with all positive T-waves in Einthoven I, II, III and avF, V2-V5. Note the positive concordances between the QRS-complexes and T-waves in these leads and negative concordance in aVR and V1.*

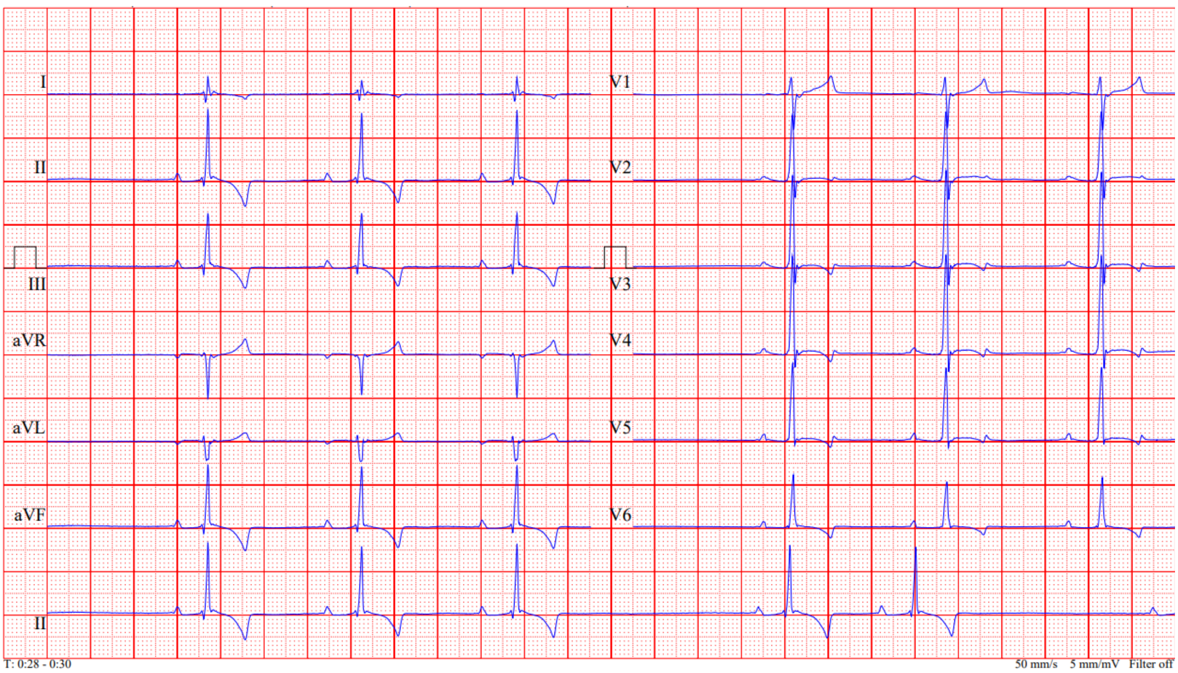

Figure 6 *12-lead ECG recording of a dog with negative T-waves in in Einthoven I, II, III and avF, V3-V6. Note the discordances between the QRS-complexes and T-waves in these and the other leads except V3.*

4.2. Results by breeds

Table 3 displays the findings by breed seen in the limb leads, with particular focus on the P wave. In the Einthoven leads nearly all breeds exhibited positive P-waves, except in lead III where 15% of the animals had negative depolarizations. This entails 2 of 5 (40%) of the examined Miniature schnauzers, 3 of 14 (21%) French bulldogs and 4 of 12 (33%) of the mixed breed dogs. In aVF, only 1 dog presented with a negative depolarization of the P wave, a Miniature Schnauzer.

Table 3 *Polarity of-waves measured in the limb leads for specific breeds. Each lead is represented with the amount of dogs within each breed with a positive, negative or isoelectric polarisation of the P wave in the limb leads. +; positive, -; negative, iso; isoelectric.*

		P wave																	
Limb		Lead I			Lead II			Lead III			avR			avL			avF		
Breed	total	+	-	Iso	+	-	Iso	+	-	Iso	+	-	Iso	+	-	Iso	+	-	Iso
Afghan hound	2	1	1	0	2	0	0	2	0	0	0	2	0	0	2	0	2	0	0
Border collie	3	3	0	0	3	0	0	3	0	0	0	3	0	0	3	0	3	0	0
Borzoi	1	1	0	0	1	0	0	1	0	0	0	1	0	0	1	0	1	0	0
Cairn terrier	1	1	0	0	1	0	0	1	0	0	0	1	0	0	1	0	1	0	0
Chihuahua	3	3	0	0	3	0	0	3	0	0	0	3	0	3	0	0	3	0	0
Cocker spaniel	1	1	0	0	1	0	0	1	0	0	0	1	0	1	0	0	1	0	0
Dogo canario	1	1	0	0	1	0	0	1	0	0	0	1	0	0	1	0	1	0	0
Dobermann	1	1	0	0	1	0	0	1	0	0	0	1	0	1	0	0	1	0	0
Miniature Schnauzer	5	5	0	0	5	0	0	3	2	0	0	5	0	5	0	0	4	1	0
French bulldog	14	13	1	0	14	0	0	11	3	0	0	14	0	12	2	0	14	0	0
Groendale	2	2	0	0	2	0	0	2	0	0	0	2	0	1	1	0	2	0	0
Malinois	2	2	0	0	2	0	0	2	0	0	0	2	0	0	2	0	2	0	0
Miniature bullterrier	2	2	0	0	2	0	0	2	0	0	0	2	0	1	1	0	2	0	0
Norwegian elkhound	1	1	0	0	1	0	0	1	0	0	0	1	0	0	1	0	1	0	0
Other/mix	12	12	0	0	12	0	0	8	4	0	0	12	0	6	6	0	12	0	0
Shetland sheepdog	7	7	0	0	7	0	0	7	0	0	0	7	0	4	3	0	7	0	0
Yorkshire terrier	1	1	0	0	1	0	0	1	0	0	0	1	0	1	0	0	1	0	0
TOTAL		57	2	0	59	0	0	50	9	0	0	59	0	35	24	0	58	1	0

The data displayed in **Table 4 and 5** shows the polarity of the QRS-complexes in the limb and chest leads, respectively. The data indicates consistency in positive depolarization of the QRS-complex in the Limb leads I and II. Slight variation seen in lead III with 86 % positive depolarisation. Only 1 out of 5 Miniature schnauzers had positive QRS-complex in lead III and one of the two dogs that had negative QRS in aVF also belonged to this breed.

Table 4 *Polarity of QRS-complexes seen in the limb leads in different breeds. Each lead is represented with the amount of dogs within each breed with a positive, negative or isoelectric polarisation of the QRS complex in the limb leads. +; positive, -; negative, iso; isoelectric.*

QRS complex																			
Limb		**Lead I**			**Lead II**			**Lead III**			**avR**			**avL**			**avF**		
Breed	**total**	+	-	Iso	+	-	Iso	+	-	Iso	+	-	Iso	+	-	Iso	+	-	Iso
Afghan hound	2	2	0	0	2	0	0	2	0	0	0	2	0	1	1	0	2	0	0
Border collie	3	3	0	0	3	0	0	3	0	0	0	3	0	0	3	0	3	0	0
Borzoi	1	1	0	0	1	0	0	1	0	0	0	1	0	0	1	0	1	0	0
Cairn terrier	1	1	0	0	1	0	0	1	0	0	0	1	0	1	0	0	1	0	0
Chihuahua	3	3	0	0	3	0	0	3	0	0	0	3	0	3	0	0	3	0	0
Cocker spaniel	1	1	0	0	1	0	0	0	1	0	0	1	0	1	0	0	1	0	0
Dogo canario	1	1	0	0	1	0	0	1	0	0	0	1	0	0	1	0	1	0	0
Dobermann	1	1	0	0	1	0	0	1	0	0	0	1	0	1	0	0	1	0	0
Miniature Schnauzer	5	5	0	0	5	0	0	1	3	1	0	5	0	5	0	0	4	1	0
French bulldog	14	14	0	0	14	0	0	12	2	0	0	14	0	9	5	0	13	1	0
Groendale	2	2	0	0	2	0	0	2	0	0	0	2	0	0	2	0	2	0	0
Malinois	2	2	0	0	2	0	0	2	0	0	0	2	0	0	2	0	2	0	0
Miniature bullterrier	2	2	0	0	2	0	0	2	0	0	0	2	0	2	0	0	2	0	0
Norwegian elkhound	1	1	0	0	1	0	0	1	0	0	0	1	0	0	1	0	1	0	0
Other/mix	12	12	0	0	12	0	0	11	1	0	0	12	0	6	6	0	12	0	0
Shetland sheepdog	7	7	0	0	7	0	0	7	0	0	0	7	0	4	3	0	7	0	0
Yorkshire terrier	1	1	0	0	1	0	0	1	0	0	0	1	0	1	0	0	1	0	0
TOTAL		**59**	**0**	**0**	**59**	**0**	**0**	**51**	**7**	**1**	**0**	**59**	**0**	**34**	**25**	**0**	**57**	**2**	**0**

Table 5 *Polarity of QRS-complexes seen in the chest leads in different breeds. Each lead is represented with the amount of dogs within each breed with a positive, negative or isoelectric polarisation of the QRS complex in the chest leads. +; positive, -; negative, iso; isoelectric.*

QRS complex																			
Chest		**V1**			**V2**			**V3**			**V4**			**V5**			**V6**		
Breed	**total**	+	-	Iso	+	-	Iso	+	-	Iso	+	-	Iso	+	-	Iso	+	-	Iso
Afghan hound	2	0	1	1	2	0	0	2	0	0	2	0	0	1	1	0	2	0	0
Border collie	3	0	3	0	3	0	0	3	0	0	3	0	0	3	0	0	3	0	0
Borzoi	1	0	1	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0
Cairn terrier	1	0	1	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0
Chihuahua	3	0	3	0	3	0	0	3	0	0	3	0	0	3	0	0	3	0	0
Cocker spaniel	1	0	1	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0
Dogo canario	1	0	1	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0
Dobermann	1	0	0	1	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0
Miniature Schnauzer	5	0	4	1	5	0	0	5	0	0	5	0	0	4	1	0	3	2	0
French bulldog	14	0	14	0	14	0	0	14	0	0	14	0	0	14	0	0	14	0	0
Groendale	2	0	2	0	2	0	0	2	0	0	2	0	0	2	0	0	2	0	0
Malinois	2	0	2	0	2	0	0	2	0	0	2	0	0	2	0	0	2	0	0
Miniature bullterrier	2	0	2	0	2	0	0	2	0	0	2	0	0	2	0	0	2	0	0
Norwegian elkhound	1	0	1	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0
Other/mix	12	0	12	0	12	0	0	12	0	0	12	0	0	12	0	0	12	0	0
Shetland sheepdog	7	0	7	0	7	0	0	7	0	0	7	0	0	7	0	0	7	0	0
Yorkshire terrier	1	0	1	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0
TOTAL		**0**	**56**	**3**	**59**	**0**	**0**	**59**	**0**	**0**	**59**	**0**	**0**	**57**	**2**	**0**	**57**	**2**	**0**

Most of the QRS-complexes in V1 have proven to be negative, however 3 (5%) isoelectric depolarisations (one was a Miniature schnauzer) were seen in this lead. All chest leads V2-V4 showed positive depolarizations in all examined dogs, but 2-2 negative depolarisations were found in V5 and V6 in three dogs. Two of the three animals were Miniature schnauzers.

The T-wave and its varying nature in dogs have been displayed in **Table 6 and 7**. Positive and negative repolarisations varied in all the leads. In lead-I, II, aVF and V2-V6 four out of five Miniature schnauzers had negative T-waves (and positive ones in aVR), while most dogs had more evenly distribution among the positive and negative deflections in these leads (**Figure 7**). Among the chest leads a positive appearance of the repolarisation wave dominated in V2-V4, except miniature bullterriers, miniature schnauzers and chihuahuas, where this tendency was less obvious or even reversed.

Table 6 *Polarity of T-waves seen in limb leads in different breeds. Each lead is represented with the amount of dogs within each breed with a positive, negative or isoelectric polarisation of the T wave in the limb leads. +; positive, -; negative, iso; isoelectric.*

T wave																			
Limb		Lead I			Lead II			Lead III			avR			avL			avF		
Breed	total	+	-	Iso	+	-	Iso	+	-	Iso	+	-	Iso	+	-	Iso	+	-	Iso
Afghan hound	2	1	1	0	2	0	0	1	1	0	0	2	0	1	1	0	1	1	0
Border collie	3	1	2	0	1	2	0	1	2	0	2	1	0	1	2	0	1	2	0
Borzoi	1	1	0	0	0	1	0	0	1	0	0	1	0	1	0	0	0	1	0
Cairn terrier	1	0	1	0	1	0	0	1	0	0	1	0	0	0	1	0	1	0	0
Chihuahua	3	1	2	0	1	2	0	2	1	0	1	2	0	1	2	0	2	1	0
Cocker spaniel	1	1	0	0	1	0	0	1	0	0	0	1	0	1	0	0	1	0	0
Dogo canario	1	0	1	0	1	0	0	1	0	0	1	0	0	0	1	0	1	0	0
Dobermann	1	0	1	0	1	0	0	0	1	0	1	0	0	1	0	0	0	1	0
Miniature Schnauzer	5	1	4	0	1	4	0	3	2	0	4	1	0	2	3	0	1	4	0
French bulldog	14	7	7	0	9	5	0	10	4	0	6	8	0	5	9	0	11	3	0
Groendale	2	1	1	0	1	1	0	1	1	0	1	1	0	2	0	0	1	1	0
Malinois	2	0	2	0	1	1	0	1	1	0	1	1	0	0	2	0	1	1	0
Miniature bullterrier	2	0	2	0	0	2	0	1	1	0	2	0	0	0	2	0	0	2	0
Norwegian elkhound	1	0	1	0	0	1	0	0	1	0	1	0	0	1	0	0	0	1	0
Other/mix	12	7	5	0	6	6	0	6	6	0	8	4	0	5	7	0	6	6	0
Shetland sheepdog	7	1	6	0	1	6	0	3	4	0	6	1	0	2	5	0	1	6	0
Yorkshire terrier	1	0	1	0	0	1	0	0	1	0	0	1	0	1	0	0	0	1	0
TOTAL		22	37	0	27	32	0	32	27	0	35	24	0	24	35	0	28	31	0

Table 7 *Polarity of T-waves seen in the chest leads in different breeds. Each lead is represented with the amount of dogs within each breed with a positive, negative or isoelectric polarisation of the T wave in the chest leads. +; positive, -; negative, iso; isoelectric.*

T wave																			
Chest		V1			V2			V3			V4			V5			V6		
Breed	total	+	-	Iso	+	-	Iso	+	-	Iso	+	-	Iso	+	-	Iso	+	-	Iso
Afghan hound	2	2	0	0	2	0	0	2	0	0	2	0	0	2	0	0	2	0	0
Border collie	3	1	2	0	3	0	0	2	1	0	2	1	0	2	1	0	2	1	0
Borzoi	1	0	1	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0
Cairn terrier	1	0	1	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0
Chihuahua	3	1	2	0	2	1	0	2	1	0	2	1	0	1	2	0	1	2	0
Cocker spaniel	1	0	1	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0
Dogo canario	1	0	1	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0
Dobermann	1	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	0	1	0
Miniature Schnauzer	5	3	2	0	3	2	0	2	3	0	3	2	0	1	4	0	1	4	0
French bulldog	14	2	12	0	14	0	0	13	1	0	13	1	0	13	1	0	10	4	0
Groendale	2	1	1	0	2	0	0	2	0	0	2	0	0	2	0	0	1	1	0
Malinois	2	0	2	0	2	0	0	2	0	0	2	0	0	2	0	0	2	0	0
Miniature bullterrier	2	2	0	0	0	2	0	0	2	0	0	2	0	0	2	0	0	2	0
Norwegian elkhound	1	0	1	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0
Other/mix	12	9	3	0	10	2	0	10	2	0	10	2	0	8	4	0	7	5	0
Shetland sheepdog	7	3	4	0	6	1	0	6	1	0	6	1	0	6	1	0	5	2	0
Yorkshire terrier	1	1	0	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0
TOTAL		26	33	0	50	9	0	47	12	0	48	11	0	43	16	0	36	23	0

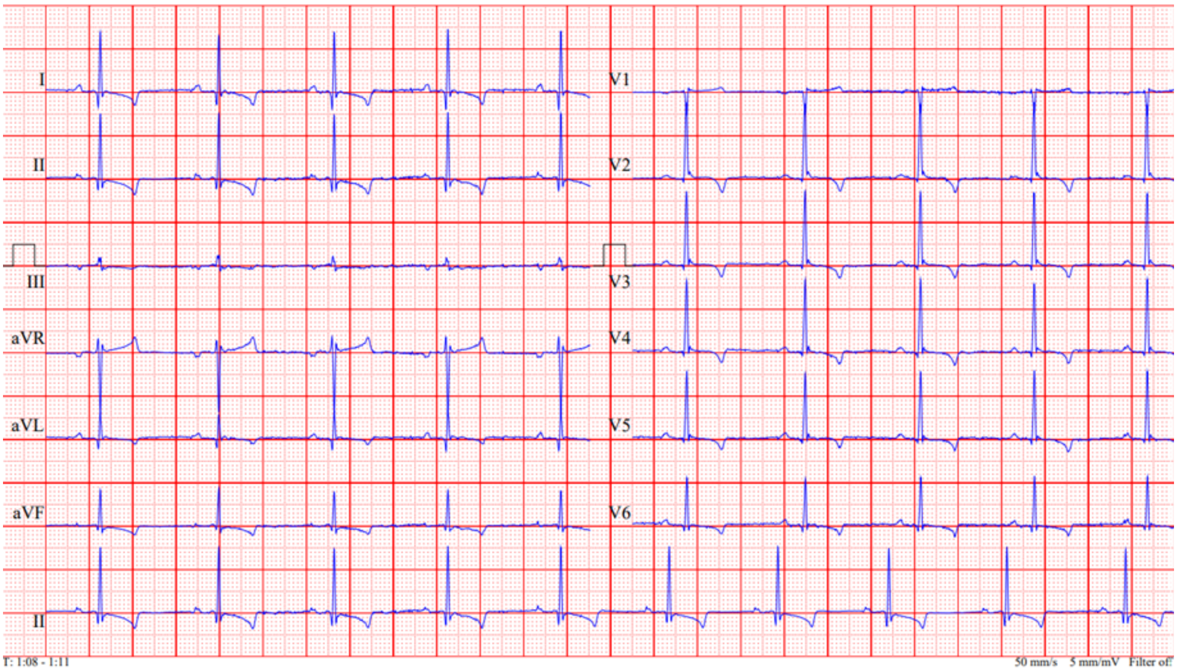

***Figure** 7 A miniature schnauzer dog with negative T wave in lead I, II, III, aVF and V2-V6.*

There were 2 dogs of the 70 originally examined individuals with abnormal ECG findings. Two dogs had left anterior block patterns. Even though they were excluded from the final analysis their ECGs recorded with 12 lead system were analysed and presented in Figures 8 and 9.

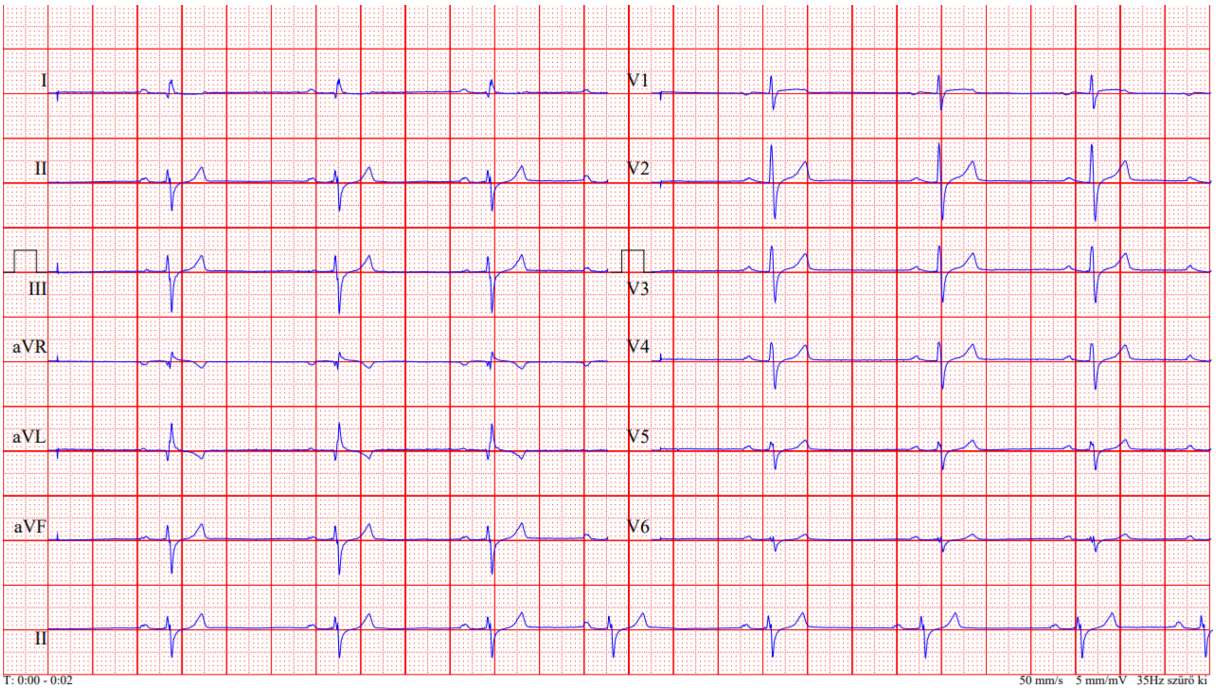

***Figure** 8 Left anterior fascicular block pattern in a clinically healthy dog (female, Beagle, 10 kg).*
Notice the typical pattern of qR in aVL and lead I and rS in II, III, aVF and V5. The apical left sided chest leads (V4-V6) all showing this QRS appearance (rS pattern). Leads V1-V3 are isoelectric leads, (V3 is slightly negative in sum polarity), while V4-V6 are negative QRS-complexes.

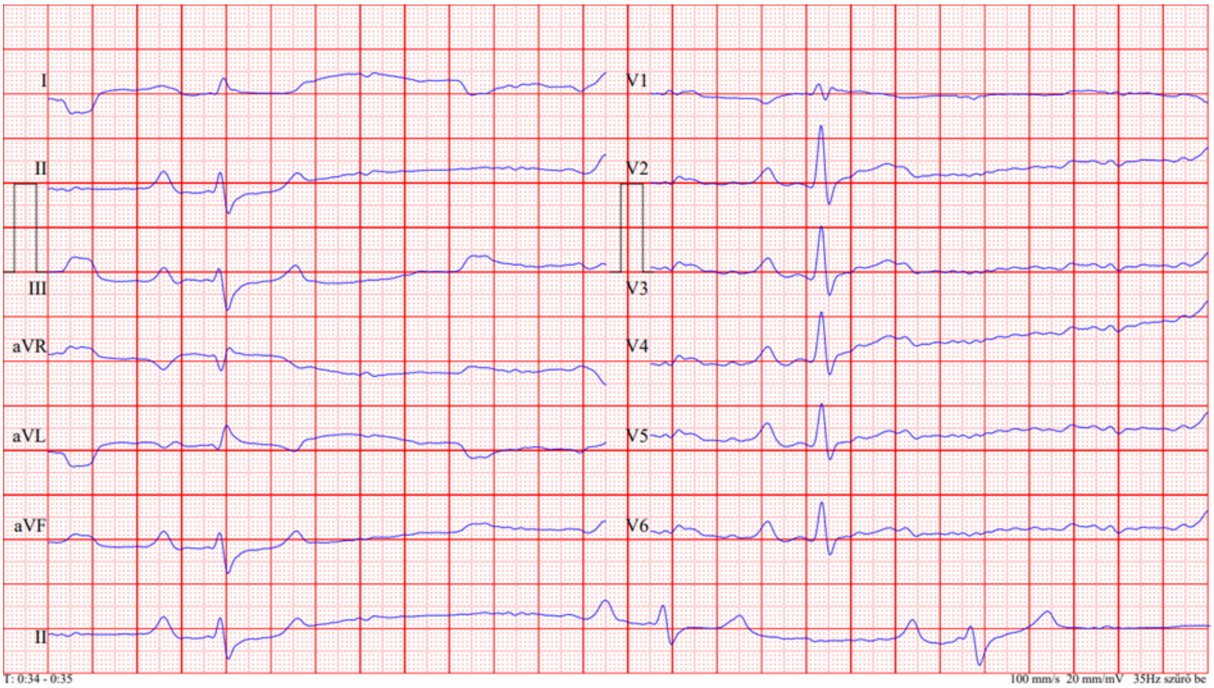

Figure 9 *Left anterior fascicular block pattern in the limb leads of a 10-year-old female border collie mix. Interestingly, the chest leads show normal orientation (isoelectric, slightly negative QRS in V1, positive QRS in V2-V6).*

5. Discussion

Despite the 12-lead ECG´s further diagnostic capabilities, the use is often eluded due to additional work, time and electrodes needed for the reading. It also requires additional cooperation both from the animal and its handler to perform stabile enough readings to provide a diagnostic value. Prior to the discoveries of more consistent readings with placing the V1 in the first intercostal space, the precordial leads have also been deemed to give inconsistent values due to the axial deviation based on chest confirmations.

The author of this study was made aware of the invaluable diagnostic potential of the ECG, revealing previously undetected issues in dogs that displayed no outward symptoms. Interestingly, these abnormal findings had eluded detection during routine physical examinations, possibly due to the inherent subjectivity of such assessments or a simple lack of prior exposure to the assessment of overall cardiovascular health.

However, the true power of the ECG became evident through its consistent and standardized readings. It appeared to seamlessly complement the conventional physical examinations and other diagnostic investigations, hence, proving to enrich the overall quality of care which can be provided to veterinary patients.

Throughout the work of this study, several situations, not only pertaining to the ECG reading was experienced. Although the process of lead placement itself proved to be a straightforward task, dealing with the dogs who were already apprehensive in the clinical setting was a different scenario. The dogs that usually manifested signs of fear and anxiety, perhaps exaggerated by the expectation of the owner for the dog to act this way, could at times make the ECG readings challenging. Another obstacle that was needed to be assessed was the considerable variation in how the handlers managed to restrain the animals during the procedure.

In retrospect, a set of trained handlers during the procedure would have shortened the timeframe needed to perform the reading as well as the duration of stress the animal had to succumb to. In some cases, experienced in other clinical settings, the animal may also exhibit less signs of fear when the owner is not present. This was on the other hand, in most cases, overcome by proper explanation prior to the measurement or in some instanced, taking the initiative to position the animal in lateral recumbency and only afterwards transfer the responsibility of restraint over to the owner.

A pattern of placement in leads also proved to increase the success rate of the readings. By placing the limb leads first, with generous amounts of praise and petting, the placement of the chest leads proved to be simplified. This was however not always the case in dogs of small size or with minimal flexibility of the skin, as the distance between each electrode either became too sparse or minimized the area possible to grasp with the clamps for the ECG. However, the disturbances caused by narrow placements of leads could in most cases be avoided by placing pieces of paper-towels in between the clamps of the leads.

The author also became aware of, due to the fact of a high number of student-owned dogs, the overall anxiousness pertaining to ECG analysis among students. This was also later realized in the clinical setting, where otherwise experienced veterinarians, shied away from the use of the ECG due to its perceived complexity. Hence, a personal inclination to develop a poster to simplify the use of ECG for practitioners and students emerged. This is a phenomenon widely available in the field of human medicine but seems to be lacking or hard to encounter in the veterinary field. This may be due to the overall differences among species and sizes of the specific breeds, but perhaps also because the conformational chest constructions previously have produced variable results.

In our study on 59 dogs, the observed heart rates, PQ and QTS intervals were in accordance with previous publications [6, 14, 15].

Understanding the direction of wave propagation in the ECG can enhance our comprehension of cardiac electrical events and provide further understanding in the field of cardiac electrophysiology. From the collected data the findings were derived to display a comprehensive description of the polarity of the PQRST waves in healthy dogs. Although the breed itself did not appear to alter the polarity in these waves in most of the cases, some interesting observations were made during the study.

Among the chest leads V1 consistently exhibited a negative P-wave, which was almost always followed by a negative QRS complex. In contrast, leads V2-V6 displayed positive P-waves accompanied by positive QRS complexes. The data provided by this study in agreement with the existing literature [14]. It seems that in normal dogs both the atrial and ventricular depolarization consistently travel towards the left thoracic wall.

In the limb leads: atrial depolarisation mostly pointed to caudal and left direction, manifested as almost exclusively positive waves in Einthoven I, II, III, avF. In aVR, all 59 measurements revealed negative P waves which is consistent with current data for healthy individuals [5, 6]. In lead III some variability was observed, and negative P-waves seemed more common in French Bulldogs and Miniature schnauzers. Even though data on normal ECG results exist in French bulldogs [16], this publication is only providing the electric axis of atrial depolarisation. The published atrial electric axis (0-76) is indirectly supporting our observation. However, no specific electrocardiographic data could be found about miniature schnauzers.

Similar (caudal and left) direction of the main force during ventricular depolarisation was observed when analysing the QRS complexes' polarities in the limb leads. Interestingly, but not contrasting the existing literature a small percentage of dogs showed negative QRS complexes in lead III. It was particularly evident in miniature schnauzers in our study. These animals had varying degree of left axis shift but different from the typical left anterior hemiblock pattern. As we are not aware of breed specific data on this breed further studies are needed to reveal the background of this finding.

The direction of repolarization, as anticipated, exhibited great variability. Contrary to Romito et al 2022 who found mostly positive and concordant T-waves in lead-II (77% and 82%, respectively), our study found only 46% positive T-waves that were only concordant in 43% of with these positive QRS complexes. This is agreement with an earlier smaller scale study in our institution [1]. Different breed composition of the studies may explain the difference as it has been already shown that breed specific changes exist in the appearance of the ECG of healthy dogs.

Previous findings have shown consistency in the negative display of the formation of the repolarization wave in V10, simultaneously mostly positive in V2 and V4 [1, 17]. The observation in our study revealed that the predominant direction of the propagation of repolarisation waves in V2, V3 and V4 were positive, aligns with the findings from earlier studies. All this suggest that the repolarization wave primarily travels away from the apical parts of the left hemithorax into basal direction. Interestingly, again miniature schnauzers, together with chihuahuas and miniature bullterriers were different form this general observation. Little is known about miniature schnauzers and bullterriers but the chihuahua breed has been the target of debate about the repolarisation direction in this breed, especially in V10 [17]. Unfortunately, we did not perform V10 lead ECG exam in our patients, so no further conclusions can be drawn from the observed peculiarities.

The prevalence of J-waves in our study (29%) was lower than the observed appearance rate (43%) of this wave in a larger study [7]. However, that former study already emphasised the breed differences in the prevalence rate of the J-wave that may vary from 0- 91%. Most probably the different breed composition of the two studies explains the difference in the results. We found a slight female predisposition for observing this repolarisation wave, but the already mentioned larger scale study did not show any sex predominance [7].

Even though left anterior block pattern have been long recognised in standard limb leads in both dogs and cats, this conduction anomaly has not been described in the new chest leads to our knowledge besides mentioning the rS QRS pattern in V5. The two dogs had slightly different appearances of the hemiblock in the chest leads, which may suggest slightly different conduction abnormality or biological variation. Further research is needed to study the significance of chest leads in the diagnosis of conduction abnormalities in the dog.

In conclusions, we described the 12-lead standard ECG depolarisation and repolarisation wave appearances in a relatively large clinically healthy cohort of dogs. Some interesting observations about the left shift of the mean QRS axis (in particularly in miniature schnauzers) needs to studied further in the future. It is vital to recognize, however, that while the ECG plays an irreplaceable role in cardiac diagnostics, synergistic use of clinical evaluation and echocardiography in conjunction with ECG findings is needed to form the cornerstone of comprehensive patient care, ensuring a well-rounded and accurate assessment of cardiac health.

6. Summary

The electrocardiogram (ECG) continues to be a valuable diagnostic tool for health care providers in both human and veterinary care. Its use in daily practice provides an opportunity to perform a variety of tasks overall providing better care for our patients.

The aim of this study is to describe the polarity of the PQRS-T waves and their concordance using the 12-lead ECG in healthy dogs and to investigate the trends of the chest and limb leads.

The experiment design included healthy dogs older than 6 months old and without known morbidities. The dogs also had to comply to stay in right lateral recumbency, without anaesthesia or behaviour-modifying drugs, for the duration of the ECG monitoring.

The study was performed on 70 healthy dogs. After excluding dogs that were not cooperative enough to perform the ECG in the standard right lateral recumbent position and those that showed some ECG abnormality there remained 59 dogs. The 59 dogs belonged to various breeds of both sexes, with different weights and chest confirmations. The median age and weight were 4,7 years and 12kg, respectively. The following breeds had more than 3 individuals: Border collie, Chihuahua, French bulldog, Miniature schnauzer, and Shetland sheepdog. The remaining were either mixed breeds or represented less than 3 individuals of the respective breed.

Derived from the collected values, a description of the polarity of the PQRS-T waves in healthy dogs was obtained. The breed of the dog didn't appear to alter the parameters in the polarity of the waves. The chest lead V1 with a negative P-wave was almost always followed by a negative QRS complex. There were 3 dogs with isoelectric P-waves and one of them also had an isoelectric QRS complex in V1. In the V2-V6 leads the QRS complexes were positive and followed by positive T-waves. However, they were not correlated with the limb leads. The data did support the current literature on the presumption of positive P-waves and QRS complexes in lead I, II, III, aVF and V2-V6 while mostly negative in aVR and V1. The T-wave also proved to be variable in the different leads but showed a higher frequency of positivity in the chest leads V2-V4.

The results of our study are intended to contribute to the normal variability of the appearance of ECG waves in different standard leads of the dog. The study will also contribute to the description of the normal appearance of the polarity and concordance of T-waves in healthy dogs although an even larger sample size would have been ideal to investigate the effect of different breeds on these variables.

Összefoglaló

A 12 elvezetéses EKG-vizsgálat alkalmazása egészséges kutyákon

Az elektrokardiogram (EKG) továbbra is értékes diagnosztikai eszköz az egészségügyi dolgozók számára mind az emberi, mind az állatorvosi ellátásban. A napi gyakorlatban való alkalmazása felhasználható diagnosztikai vagy monitorozási célokra, összességében jobb ellátást nyújtva betegeinknek.

A tanulmány célja a PQRS-T hullámok polaritásának és konkordanciájának leírása a 12 elvezetéses standard EKG segítségével egészséges kutyákon, továbbá a mellkasi és a végtagi elvezetésének változékonyságának vizsgálata.

A kísérletbe 6 hónaposnál idősebb egészséges kutyák vettek részt, amelyek nem szenvedtek semmilyen betegségben. A kutyáknak meg kellett felelniük annak is, hogy jobb oldali fekvő helyzetben maradjanak érzéstelenítés és viselkedésmódosító gyógyszerek nélkül az EKG monitorozás ideje alatt.

A vizsgálatot 70 egészséges kutyán végeztük. Miután kizártuk azokat a kutyákat, amelyek nem voltak elég együttműködőek ahhoz, hogy az EKG-t a standard jobb oldali fekvő helyzetben végezzék el, továbbá azokat, amelyek valamilyen EKG-rendellenességet mutattak, 59 kutya maradt. Az 59 kutya különböző fajtájú és nemű volt, változatos testmérettel és mellkas alakulással. A medián életkor 4,7 év, testtömeg 12 kg volt. A következő fajtákból fordult elő több mint 3 egyed: Border collie, Chihuahua, francia bulldog, miniatűr schnauzer és Shetlandi juhászkutya. A többi vagy keverék kutya volt, vagy kevesebb, mint 3 egyedet képviselt az adott fajtából.

Az összegyűjtött EKG görbékből leírtuk a PQRS-T hullámok polaritását a különféle EKG-elvezetésekben egészséges kutyákban. Úgy tűnt, hogy a kutya fajtája nem befolyásolta az EKG-hullámok megjelenését, polaritását és különféle paramétereit. A V1 mellkasi elvezetésben a negatív P-hullámot szinte mindig negatív QRS-komplexum követte. 3 kutyának volt izoelektromos P-hulláma, és egyiküknek izoelektromos QRS-komplexum is V1-ben. A V2-V6 elvezetésekben a QRS-komplexumok pozitívak voltak, melyeket pozitív-T hullámok követtek. Ezek azonban nem korreláltak a végtagi elvezetésekkel. Az adatok alátámasztották a jelenlegi szakirodalmi adatokat, amely szerint a P-hullámok és QRS-komplexumok többnyire pozitívak Einthoven I, II, III és aVF, továbbá V2-V6 elvezetésekben, míg többnyire negatívak aVR-ben és V1-ben. A T-hullám változékonynak

bizonyult a különböző elvezetésekben, de nagyobb gyakorisággal volt pozitív a V2-V4 mellkasi elvezetésekben.

Vizsgálatunk eredményei hozzájárulnak az EKG-hullámok megjelenésének normális változékonyságának megismeréséhez kutyák standard EKG-elvezetéseiben. A tanulmány hozzájárul a T-hullámok polaritásának és konkordanciájának leírásához egészséges kutyákban, bár nagyobb mintaméret ideálisabb lett volna a fajtajelleg ezekre a változókra gyakorolt hatásának vizsgálatához.

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Thesis progress report for veterinary students

Name of student: **Vatne Ingeborg Marie**

Neptun code of the student: **GL1IGO**

Name and title of the supervisor: **Dr. Manczur Ferenc, Professor and head of department**

Department: **Department of Internal Medicine**

Thesis title: **The application of the 12-lead ECG in healthy dogs**

Consultation – 1st semester

Timing				Topic / Remarks of the supervisor	Signature of the supervisor
	year	month	day		
1.	2023	03	11	Thesis topic plan	[signature]
2.	2023	04	01	Litterature review planning	[signature]
3.	2023	04	10	Guidance for ECG placement and material and methods	[signature]
4.	2023	06	03	Statistical analysis plan	[signature]
5.	2023	06	25	Literature review plan	[signature]

Grade achieved at the end of the first semester: ....5..........................

Consultation – 2nd semester

Timing				Topic / Remarks of the supervisor	Signature of the supervisor
	year	month	day		
1.	2023	07	20	Discussion of findings	[signature]
2.	2023	09	18	Review litterature	[signature]
3.	2023	09	16	Review of main findings and results	[signature]
4.	2023	10	01	Review	[signature]
5.	2023	10	16	Finalization of thesis paper, translation of summary	[signature]

Grade achieved at the end of the second semester: ....5..............................

The thesis meets the requirements of the Study and Examination Rules of the University and the Guide to Thesis Writing.

I accept the thesis and found suitable to defence,

....

signature of the supervisor

Signature of the student: ....

Signature of the secretary of the department: ....

Date of handing the thesis in: 2022/10/05

I hereby confirm that I am familiar with the content of the thesis entitled

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DECLARATION

I hereby declare that the thesis entitled The application of the 12-lead ECG in healthy dogs is identical in terms of content and formal requirements to the TDK research paper submitted in 2023.

Date: 16.11.2023

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