수의학석사 학위논문

Artificial Intelligence-assisted Electrocardiography for Screening of Canine Heart Function

개 심장 기능 검사를 위한 인공지능 보조 심전도 활용

2023년 2월

서울대학교 대학원

수의학과 임상수의학과

정 태 규

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정 태 규

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2022년 12월

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Artificial Intelligence-assisted Electrocardiography for Screening of Canine Heart Function

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Abstract

This study aimed to determine the proportion of patients with electrocardiographic changes and to suggest the clinical utility of AI-assisted single-lead ECG for primary screening of canine heart function. Data was obtained from 116 owned dogs referred to Veterinary Medical Teaching Hospital, Seoul National University from June 2020 to December 2021. Single lead ECG traces were recorded and initially interpreted by the provided machine-learning software (CARDIOBIRD®, ANIWARE Ltd., Hong Kong). Among the 116 traces, 36 (31%) had abnormal ECG findings, according to the AI software. The most common abnormalities were wide or tall QRS (n=20), atrioventricular block (AVB) (n=8), and sinus pause (n=4). All data were suitable for interpretation and compatible to manual interpretation by clinicians. Despite some limitations, the newly developed AI-assisted ECG has shown promise for the screening of heart diseases in veterinary emergency or primary hospital without board certified cardiologist.

Keyword: Artificial intelligence, Dog, Electrocardiography, Heart function, Screening

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Table of Contents

Introduction

Electrocardiography (ECG) is not only a fast, non-invasive and inexpensive test, but it also provides invaluable information about heart conditions, especially in terms of the generation and conduction of cardiac impulses. Although recording the ECG trace itself is relatively easy and standardized, the interpretations vary in quality depending on the clinician's expertise. Therefore, resource-limited clinics or emergency rooms without experienced cardiologists are more prone to misinterpret ECG. To minimize these errors, the usefulness of ECG diagnosis using artificial intelligence has been actively studied in human and veterinary medicine recently (Siontis et al. 2021; Kumar and Kumar 2021; Akbilgic et al. 2021; Attia et al. 2021). In Estrada's study in 2021, the computerized electrocardiography algorithm showed a 99.7% of sensitivity and a 99.5% of specificity for the diagnosis of arrhythmias (Estrada et al. 2021). Artificial intelligence (AI)-assisted ECG can reduce human interpretation errors and achieve faster results. Advances in smart and wearable electric devices are accelerating this trend as raw data can be stored directly into digital software (Haverkamp, Fosse, and Schuster 2019; Kumar and Kumar 2021). This study aimed to suggest the utility of AI-assisted ECG in the field of veterinary medicine, especially for screening cardiac diseases in emergency room.

Materials and Methods

1. Animals

This study was conducted retrospectively on 116 dogs visited the emergency room of Seoul National University Veterinary Medical Teaching Hospital from June 2020 to December 2021. All dogs with systemic and non-specific clinical signs such as anorexia, lethargy, heavy breathing or collapse were included in this study.

2. Ethical statement

This study was conducted as a screening test study for cardiac diagnosis and the test was performed with prior permission from all 116 owners.

3. ECG measuring device

CARDIOBIRD® (ANIWARE Company Ltd., Hong Kong) portable ECG device was used in this study. The device is powered by Analog Devices Ad8232 (One Technology Way, USA) heart rate monitor front end. It has been commonly used in portable wireless sensor devices in both human and veterinary medicine (Bravo-Zanoguera et al. 2020; Krvavica et al. 2016; Gicana et al. 2022).

4. ECG data analysis

Animals in this study were subjected to ECG for screening purposes along with basic physical examination. Instead of the conventional 6-lead ECG, single-lead (Lead II) ECG data were acquired in the right lateral position or sternal position according to the patient's convenience to minimize discomfort (Figure 1). Original data were recorded and interpreted by the installed machine learning software. The ECG findings were synthesized after artificial intelligence analyze the patient's clinical information entered by the veterinarian, and it took about 10 minutes.

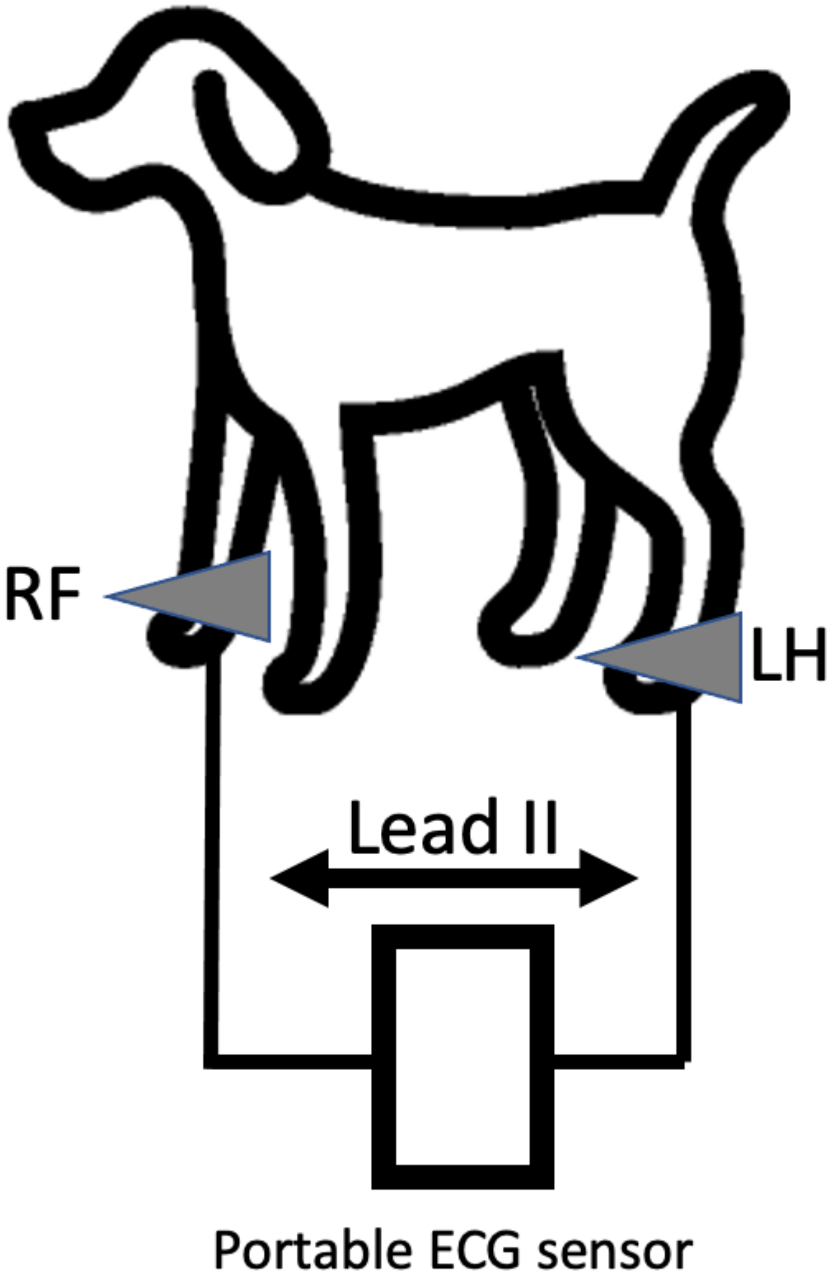

Figure 1. Diagram of ECG measurement using CARDIOBIRD®.
RF: Right forelimb, LH: Left hindlimb

5. Clinical setting

AI-assisted ECG was performed as a part of the whole-body screening test. Additional heart-related tests such as standard 6 lead-ECG (ECG-1950K Cardiofax VET, Nihon Kohden, Tokyo, Japan), echocardiography and Holter monitor were performed according to the initial screening test results and clinical needs.

6. Diagnostic criteria

Initial diagnosis by AI software was based on measured electrocardiographic parameters such as amplitudes, durations or intervals of each wave, according to the commonly known reference ranges (Willis, Oliveira, and Mavropoulou 2018; Tilley 1985; Mukherjee et al. 2020). Tall R wave was diagnosed when the R wave amplitude was greater than 2.5 mV. First-degree atrioventricular block (AVB) was diagnosed when the PR interval exceed 130 ms and the P wave and following QRS complex was completely related. Second-degree AVB was diagnosed when there was an intermittent loss of P-QRS coupling. It was further classified into low-grade and high-grade, according to the ratio of coupled and non-coupled P waves. Mobitz typing also could be made in second-degree AVB by whether the P-R interval was steady or not in beat-to-beat analysis. Third-degree, or complete AVB was diagnosed when there was no relationship between the P wave and QRS complex. Sinus pause was diagnosed when the pause of sinus rhythm exceeded 3 times the previous P-P interval or 3 seconds.

Physiological arrhythmias were arrhythmias that could appear temporarily depending on the patient‘s respiration or excitement state and did not indicate certain pathological conditions. In this study, sinus arrhythmia, sinus tachycardia, and wandering pacemaker without any other abnormality were considered physiologic changes and regarded as normal.

Results

1. Animals

The signalments of the dogs included in this study were shown in Table 1. Maltese had the most proportion of 19.8% (n=23), followed by Toy Poodles (12.9%, n=15) and Shih-tzu (11.2%, n=13). By age, 62% (n=72) of dogs were geriatric (>=8 years old), 36% (n=41) of dogs were adults (1-7 years old), and 2% (n=3) were pediatric patients.

Table 1. Signalments of patients in this study

Breed	Proportion (n=116)	Sex		Total
		Male	Female	
Maltese	19.8%	12	11	23
Toy Poodle	12.9%	11	4	15
Shih Tzu	11.2%	7	6	13
Pomeranian	8.6%	4	6	10
Yorkshire Terrier	6.0%	6	1	7
Bichon Frise	3.4%	1	3	4
Chihuahua	3.4%	1	3	4
Dachshund	2.6%	2	1	3
Labrador Retriever	2.6%	2	1	3
Others	29.3%	17	17	34
Total	100%	63	53	116

2. AI-assisted ECG report

ECG data were interpreted based on reference ranges previously reported (Tilley 1985; Mukherjee, et al. 2020). Wave morphology analysis was performed by installed machine-learning software. Examples of ECG reports with abnormal findings were shown in Figure 2. Electrocardiographic parameters and its patterns were visualized in the report.

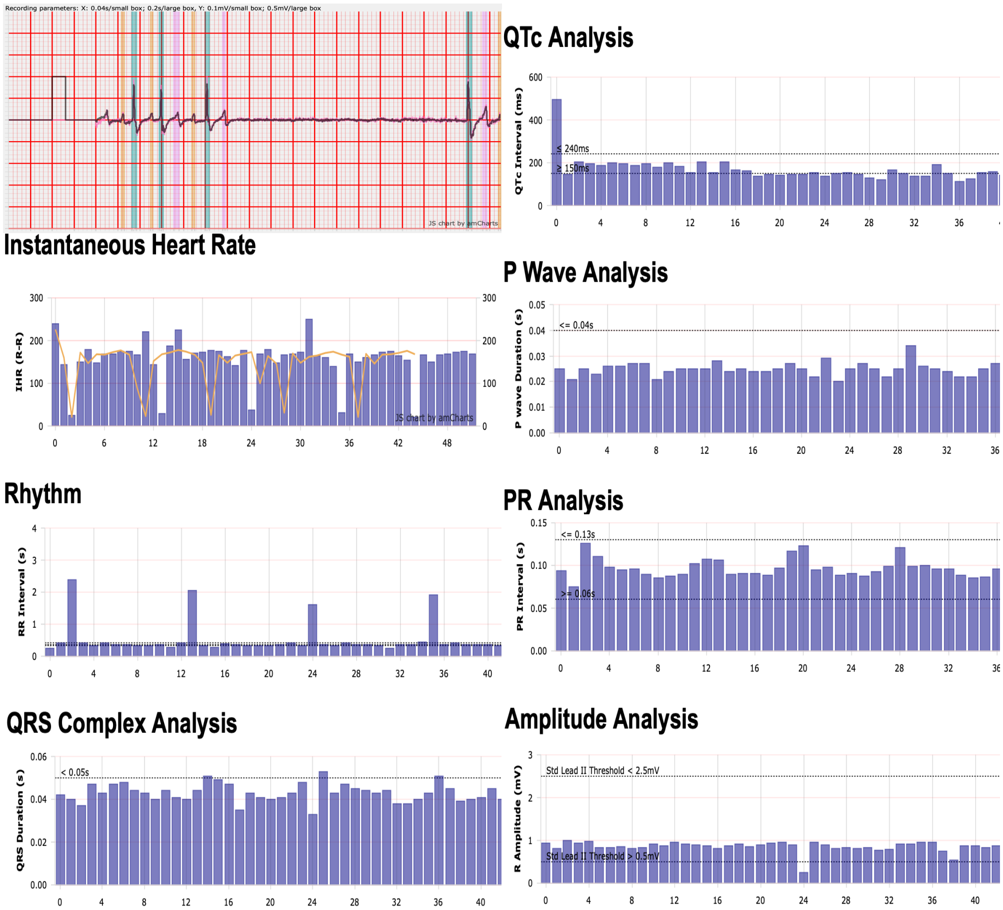

Figure 2. An example of ECG report

3. Comparison between standard ECG and AI-assisted ECG

In some patients with abnormalities, standard ECG and AI-assisted ECG were performed at the same time, and the results were compared and analyzed (Figure 3). The findings of 3rd degree AVB with ventricular escape rhythm were consistent with both devices, and the installation of a pacemaker was recommended. In another patient, also consistent impressions of sinus pause were made.

Figure 2. Comparison between lead II of standard ECG and AI-assisted ECG in patients with abnormal ECGs.

A) Diagnosed as 3rd degree atrioventricular block. Left: Standard ECG(10 mm/mV, 50 mm/s), right: AI-assisted ECG (10 mm/mV, 25 mm/s)

B) Diagnosed as sinus arrest. Left: Standard ECG (10 mm/mV, 50 mm/s), right: AI-assisted ECG (10 mm/mV, 25 mm/s)

4. Analysis of abnormal ECG findings

Abnormalities were observed in 31% of patients (n=36). The most common abnormality was wide or tall QRS complex (n=20), followed by atrioventricular block (AVB) (n=8), sinus pause (n=4), and supraventricular premature complex (n=3). Other ECG findings included wide or tall P wave (n=3), and ventricular premature complex (n=2) and ventricular tachycardia (n=2) (Table 2). Among AVBs, 4 cases showed 1^{st} degree, one showed 2^{nd} degree, and three showed complete AVB. One case with second-degree AV block was further diagnosed as low-grade Mobitz type 2 AVB. All 3 cases with third-degree AV block showed junctional escape rhythm other than ventricular escape.

Table 2. Proportion of ECG abnormalities found

Type of abnormality	Number of patients	Proportion of examined dogs (n=116)	Proportion of patients with arrhythmia (n=36)
Wide or tall QRS complex	20	17.2%	55.5%
Sinus Pause	4	3.4%	11.1%
1st degree AVB	4	3.4%	11.1%
Complete AVB	3	2.6%	8.3%
Premature Atrial Complex	3	2.6%	8.3%
Wide or tall P wave	3	2.6%	8.3%
Premature Ventricular Complex	2	1.7%	5.6%
Ventricular Tachycardia	2	1.7%	5.6%
2nd degree AVB	1	0.9%	2.8%

* AVB: Atrioventricular Block

Discussion

Screening ECG test is clinically important because disturbance of cardiac impulse formation or conduction occur in high proportion. The proportion of patients with abnormal ECG findings in this study was 31% (36/116), which was similar to or higher than that of the previous study. In one study, arrhythmias were found in 39.55% of tested dogs (Noszczyk-Nowak et al. 2017). Other studies reported that up to 27.8% of the patients had ECG changes (Aptekmann et al. 2010; Gabriel 1992; DF, DK, and RP 1961). The relatively high prevalence of abnormal findings in this study seemed to be because the test was conducted on patients with obvious systemic symptoms. Most of the previous studies have been done on apparently healthy dogs.

'Wide or tall QRS complexes' was observed in 17.2% (20/116) of all patients and 55.5% (20/36) of abnormal findings. Although not all these patients underwent to further diagnostic tests, this ratio seemed to be overrated in following reasons. It was probably influenced by posture of the patients. According to previous studies, the Q and R wave of lead II tend to be overestimated in the standing or sternal position, and 12 out of 17 cases with this finding in this study were measured in the standing position (Willis, Oliveira, and Mavropoulou 2018).

Premature complexes or premature beats are generated by electric signals made earlier than expected R-R interval, from the subsidiary pacemaker or damaged myocardial cells. They are classified as supraventricular or ventricular according to their location. In general, isolated and monomorphic premature complexes within allowable number are considered subclinical or para-physiologic (Lown and WOLF 1971). However, premature complexes were regarded as an abnormal finding regardless of their number or continuity because the link has been suggested between premature complexes and arrhythmia-induced systolic dysfunction in humans and animal model (Akoum et al. 2011; Sharma et al. 2017).

Among brady-arrhythmias, atrioventricular block (AVB) had the highest rate, accounting 6.8% (8/116) of all, and 22.2% (8/36) of abnormal findings, which is corresponding to previous reports (Noszczyk-Nowak, et al. 2017). In this study, there was one case with second-degree AV and further diagnosed to low-grade Mobitz type 2 AVB. Common causes of AVB are electrolyte abnormalities, cardiac fibrosis, calcification, endocarditis, or less commonly, MVD, neoplasia, and iatrogenic (Willis, Oliveira, and Mavropoulou 2018). However, due to the nature of the retrospective study, the primary cause is not fully elucidated due to various clinical situations.

Four traces showed sinus pause, accounting for 3.4% of the total and 11.1% of the abnormal findings. All the cases showed this finding were older than 12 years old and weighed less than 7.7 kg. Sinus pause can be caused by various conditions, such as sick sinus syndrome or electrolyte abnormalities, and brachycephalic breeds are known to have a predisposition to sinus pause due to excessive vagal tone due to heavy breathing (Willis, Oliveira, and Mavropoulou 2018).

A notable feature found among the signalments was the weight of the patients. Fifty six percent (n=65) weighed less than 5 kg and 82.7% (n=96) weighed less than 10 kg, which reflects the fact that small and toy breeds occupied most of the companion dogs in Korea. This made differences in proportion of some breed-predisposed abnormal ECG findings reported in previous studies. Previous studies reported that atrial fibrillation (AF) was one of the most common arrhythmias in dogs, accounting for 10 to 15% of arrhythmias (Noszczyk-Nowak, et al. 2017; Aptekmann, et al. 2010; Guglielmini et al. 2020). However, this study did not show any AF. The difference appeared to be mainly due to the breed of the animals included in the study. The development of AF involves two main mechanisms. According to the multi-wavelet model, a sufficient atrial size called a ‘critical mass’ is required for AF to occur (Willis, Oliveira, and Mavropoulou 2018). Therefore, breeds known to be prone to AF should be large breeds such as German Shepherds. On the other hand, in this study, more than 80% were small dogs under 10 kg, and only 7.8% (9 cases) were over 20 kg. These cultivar distributions appear to have led to differences in AF prevalence in this study compared to previous reports.

This study had some limitations. Because the study was conducted with a relatively small number of cases, it was not possible to analyze the breed, sex, and age predisposition of each ECG abnormality. Also, since it was a retrospective study and the results of additional diagnostic tests were incomplete due to the clinical environment at the time, there was a limitation in analyzing the concordance between tests. This agreement was postulated by the high accuracy of AI-assisted ECG reported in a previous papers (Akbilgic, et al. 2021; Attia, et al. 2021; Siontis, et al. 2021). In addition, the nature of single-lead measurements had significant limitations in identifying axial deviation and cardiac conduction abnormalities such as distinguishing types of bundle branch block. In previous studies, single lead measurements showed high concordance for rhythm abnormalities, but relatively low accuracy for conduction disturbances or waveform analysis (Haverkamp, Fosse, and Schuster 2019; Himmelreich et al. 2019). This should be supplemented with a conventional 6-lead, 12-lead, or Holter ECG depending on the clinical environment.

Despite limitations above, AI-assisted ECG had some apparent advantages. Smartphone-based nature made it require less equipment than conventional ECGs, so AI-assisted ECG had the better accessibility, which could increase patient compliance and minimized artifacts caused by excitement or movement (Krvavica, et al. 2016). This was particularly advantageous for the diagnosis of bradycardia, which requires a relatively long measurement time. The study also used a smartphone-based radio and AI-enabled device and obtained data with good patient compliance, and all 116 traces were of interpretable quality.

In human medicine, AI-based electrocardiogram analysis showed potential for more diverse applications. Even in the 12-lead ECG, the AI showed an high accuracy compared to the cardiologists (Attia, et al. 2021; Siontis, et al.

2021). Recently, AI-assisted ECG interpretation is utilized in more specific and various scenarios such as point-of-care of atrial fibrillation related to potassium abnormalities and prediction of heart failure (Lin et al. 2022; Akbilgic, et al. 2021). Although it was used for the purpose of initial screening of heart disease in this study, AI-assisted ECG had potential to be used in more specific conditions such as monitoring in patients with certain underlying diseases.

Conclusion

A new developed smartphone-based and AI-assisted ECG was evaluated to suggest its utility in screening of heart problems in dogs. It could obtain data which has sufficient quality for interpretation and with minimal patient discomfort compared to traditional 6-lead ECG. Interpretation itself by AI software was also compatible with clinicians. Regarding these aspects, AI-assisted ECG could be useful in primary clinics or emergency settings where specialized cardiologists were not available. Furthermore, it seemed to have high potential to be used as more specific diagnostic and monitoring tools.

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국문 초록

개 심장 기능 검사를 위한 인공지능 보조 심전도 활용

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심전도 검사(ECG)는 심장질환을 진단하는데 유용한 검사이지만, 많은 임상환경에서 임상가들은 심전도의 검사해석의 모호함을 느끼고 있다. 이 연구는 인공 지능(AI) 보조 심전도 기기를 이용하여 심전도 이상이 발견된 환자의 비율을 확인하고, 응급 상황에서 간편한 스크리닝 진단도구로써 AI 보조, 단일유도(lead II)

심전도의 임상적 유용성을 제안하는 것을 목표로 하였다. 검사는 2020 년 6 월부터 2021 년 12 월까지 서울대학교 수의과대학 응급의학과에 내원한 116 마리의 환자로부터 측정되었다. 본 연구에 사용된 AI 기반 심전도 기기에(CARDIOBIRD®, ANIWARE Ltd., 홍콩) 따르면 116 개의 심전도 기록 중 36 마리(31%)가 비정상적인 심전도 소견을 보였다. 가장 흔한 이상은 '넓거나 높은 QRS' (n=17), '방실 차단(AVB)' (n=8), '동정지' (n=4)였다. 모든 데이터는 해석에 적합한 품질을 보였으며 임상의의 해석과도 높은 일치율을 보였다. 개의 심장기능을 스크리닝하는데 있어 새로 개발된 스마트폰 기반의 인공지능 보조 심전도의 효용성이 평가되었다. 인공지능 보조 심전도는 특히 심장전문의가 없는 일차병원이나 응급실 환경에서 유용할 것으로 기대된다.

주요어: 개, 심장기능, 심전도, 스크리닝, 인공지능

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