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Electrocardiographic Analysis of Five Canine Breeds Using an Arduino UNO Prototype: A Signal Evaluation

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Abstract*– This study presents a quantitative and experimental approach to evaluate cardiac performance in various dog breeds through electrocardiography (ECG). The methodology involves the use of the Python programming language for signal analysis and the implementation of a prototype using Arduino Uno, the AD8232 heart rate sensor, and banana limb electrodes. The research focuses on five canine breeds: Chihuahua, Schnauzer, French Poodle, mixed breed, and Shih-Tzu. The results demon- strate the effectiveness of the prototype in efficiently capturing and processing cardiac signals. Accurate parameterization for cardiac analysis, including sampling frequency and filter settings, was achieved. Integration tests comparing cardiac responses between different dog breeds were conducted, revealing valuable insights. The study emphasizes the applicability and reliability of the developed system, contributing to the advancement of cardiac monitoring at home.

Keywords-- Canine Electrocardiography, Prototype, Signal Evaluation, Heart rate, Signal Processing.

I. INTRODUCTION

The lack of veterinary technology and low investment in research has led to a growing demand in recent years. [1] The lack of canine-specific electrocardiography equipment in veterinary clinics has resulted in sudden deaths or postopera- tive complications. This is attributed to economic constraints or a lack of understanding of the importance of this tool by veterinarians. Canine electrocardiography has been an invaluable tool for veterinarians, allowing them to provide more accurate and effective care for dogs, and promoting cardiovascular health in the canine world. [2] The use of the electrocardiogram (ECG) is distinguished by its detailed examination of the electrical activity in the canines heart, capturing and recording these signals in the form of waves using specialized equipment. [3]. The P wave is related to depolarization of the right and left atria, the QRS complex indicates ventricular depolarization, being a fast and prominent wave, the ST interval, located after the QRS and marking ventricular depolarization, can be used in the diagnosis of ischemia or hypoxia, while the T wave represents ventricular repolarization, indicative of ventricular wall relaxation. [4]

In the study by Vezzosi et al. titled ”Evaluation of a new smartphone-based digital stethoscope featuring phono- cardiography and electrocardiography in dogs and cats,” an innovative digital stethoscope that uses smartphones to capture phonocardiograms and electrocardiograms in dogs and cats was evaluated. This technological approach could overcome limitations in the acquisition of cardiac signals in animals. [5] The inability of dogs to directly communicate their health status underscores the importance of early and accurate diag- nosis. [6] This situation highlights the urgent need to drive research, awareness and investment in veterinary technology to improve the care of heart conditions in dogs and ensure

more effective care. [7]

Previous research was based on signal monitoring and prototyping of canine electrocardiograms by incorporating additional components such as accelerometers, gyroscopes and mobile devices. The purpose of these investigations focused on analyzing heart rate variability, ranging from abnormal measurements to detailed analysis of cardiac performance.

Foster et al. presented the research titled “Preliminary Evaluation of a System with On-Body and Aerial Sensors for Monitoring Working Dogs,” a system for the complete moni- toring of behavior, environment, and physiological responses in working dogs. These efforts reinforce the need to develop specialized technologies for cardiac assessment in dogs. [8]

This study focused on improving the medical care of canines from the comfort of their homes, with the aim of achieving early detection of heart disease. The prototype developed in this context not only introduced significant technological inno- vations, but also proposed new implementations for integration in veterinary clinics. This study aims to achieve remote mon- itoring and assessment of canine electrocardiography (ECG) signals from the comfort at home

II. STATE OF ART

The project focused on the development of a manually designed and constructed canine electrocardiogram (ECG) prototype. This prototype was used to capture and analyze cardiac signals in dogs of different breeds, including Chi- huahua, Schnauzer, Shih-tzu, French Poodle and Mixed Breed. The project was characterized by its quantitative approach and was developed as an experimental study, since it involved the creation of the prototype. The scope of the project focused on the comparison of ECG signals obtained with the canine ECG prototype and statistical analysis between breeds. This allowed to evaluate the efficiency of the prototype in detecting the heart rate of dogs

A. Techniques and Instruments Applied

Each technique and instrument was precisely selected to optimize the efficiency of the canine ECG prototype, ensuring accurate capture of cardiac signals and facilitating rigorous statistical analysis. The strategic choice of these tools supported the validity of the results obtained, providing a solid basis for the comprehensive evaluation of the system performance.

TABLE I
METHODS AND TECHNIQUES

Method	Instrument or Technique
Canine Signal Processing	Python Software
Data collection	Arduino UNO
Signal acquisition	Heart rate sensor
Statistical analysis	Minitab

- Arduino IDE: The Arduino IDE development environment was used to program the Arduino UNO. The commands were configured and loaded into the Arduino UNO, enabling the accurate acquisition of cardiac signals from the selected canine subjects.
- Python Software: With its specialized libraries, this pro- vided a flexible environment to perform filtering, analysis and visualization of the captured ECG signals, also the implementation of signal processing algorithms.
- Heart Rate Sensor: The AD8232 ECG Heart Rate Sensor detected and amplified the electrical signals generated by the dogs' hearts. Its main function was to capture the electrical activity of the heart, which allowed obtaining an accurate representation of the canine electrocardiogram.
- Minitab Software: This statistical tool facilitated the exploration of variability and trends present in the data, with emphasis on specific parameters captured by the prototype.

B. Materials

- Arduino UNO R3 ATmega328
- AD8232 ECG Heart Rate Sensor
- DUNPUNT MH Connection Jumpers
- Banana Limb Electrodes

III. METHODOLOGY

The methodology employed in the study was distinguished by its quantitative and experimental approach, highlighting the rigorously scientific nature of the project in addressing the creation and application of the prototype. The choice of a quantitative methodology was aimed at obtaining objective measurements and numerical data, while the experimental essence underlines the investigative nature of the prototype development, which included the direct manipulation and evaluation of variables under specific conditions.

A. Methodology of Study

The V-methodology organized the software and hardware life cycle in a "V" shaped structure. It started with requirements gathering, progressed through design, coding and implementation, and focused on unit testing, integration and system testing. [9] Validation verified that the system met user requirements, while verification took place at each stage to ensure the quality of the process. This model highlighted the connection between development and testing, ensuring validation and verification throughout the software lifecycle.

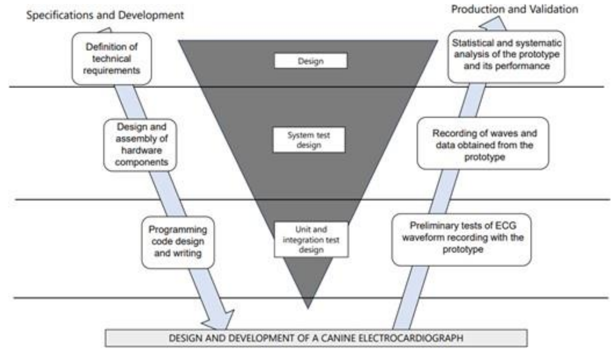

Fig. 1 Methodology V

Heart rate was established as an independent variable, being a crucial indicator of canine cardiovascular health and used to evaluate the efficacy of the ECG prototype. As for the dependent variables (signal quality, signal capture time and canine breed group), they were selected to measure the clarity, temporal efficiency and the influence of physiological variations between breeds on the electrocardiographic signals captured by the system. [10]

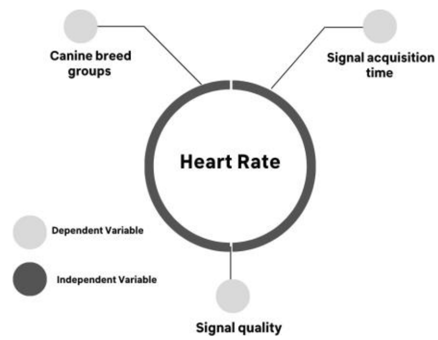

Fig. 2 Dependent and Independent Variables

IV. RESULTS

A. Schematic Design

A schematic design of the constituent elements of the prototype was carried out, with the purpose of demonstrating its operation in a representative manner. This methodological approach was adopted in order to provide a comprehensive and accurate view of the operation of the various components integrated in the prototype.

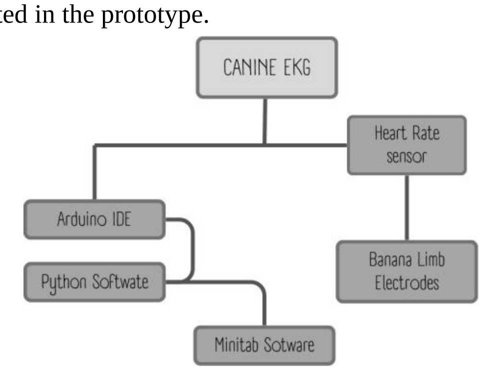

Fig. 3 Schematic Design

B. Integration Test Design

During the test design phase, an analysis of the filters applied to the cardiac signals captured by the prototype through the arduino connection was performed. The use of specialized Python libraries, such as NumPy and SciPy, al- lowed the efficient implementation of digital filters to improve signal quality and reduce unwanted noise. [11] The precise interconnection of electronic components was complemented by the application of filters designed to attenuate artifacts and non-relevant frequencies in canine cardiac signals. Validation of interoperability with external systems was enriched by the ability to graphically represent these signals in a comprehensible and detailed manner.

C. Characterization of the Participating Sample

Variability in electrocardiogram (ECG) signals across diverse dog breeds, including Chihuahua, Schnauzer, French Poodle, Shih-Tzu, and mixed breeds, is contingent upon various factors, notably the age and weight of the canine subjects. [12]For Chihuahuas, their diminutive size exerts influence over heart rate and other ECG parameters, while Schnauzers, characterized by standard and miniature sizes, exhibit variations influenced by both age and weight. [13]

French Poodles, encompassing various sizes, manifest ECG alterations correlated with age and weight. Similarly, Shih- Tzus, being a petite breed, undergo age- and weight-related ECG fluctuations, with due consideration for the impact of obesity.

D. Data of the Evaluated Sample

Variations in electrocardiogram (ECG) signals among dog breeds such as Chihuahua, Schnauzer, French Poodle, Shih-Tzu and mixed breeds depended on factors such as age, weight and size.

TABLE II
DATA OF THE EVALUATED SAMPLE

Breed	Weight	Age	Tot. Mes.	Quality
Chihuahua	3 kg	2 years	3	Excellent
Mixed Breed	24 kg	11 years	2	Moderate
Shih-tzu	12 kg	2 years	1	Moderate
Schnauzer	19 kg	3 years	1	Moderate
French Poodle	21 kg	4 years	1	Moderate

E. Electrode Placement

In the search for a precise arrangement of the electrodes to prevent interference and reduce superfluous noise in the electrocardiogram (ECG) acquisition in canines, we chose to position the animals in right lateral decubitus. In this position, their limbs were positioned perpendicular to the body and slightly apart, providing stability and facilitating access to the areas necessary for electrode placement. [14]

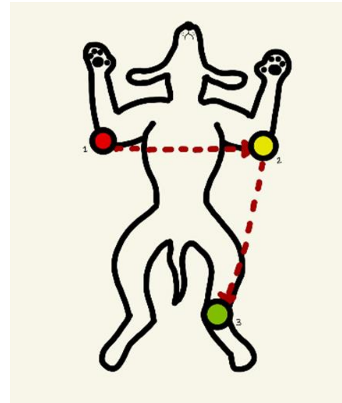

Fig. 4 Electrode Placement

F. Filter Aplication

Several parameters were defined to suit the particular characteristics of physiological signal acquisition and analysis. For example, lowcut frequency and highcut frequency were used to set the frequency limits in the Butterworth bandpass filter, thus determining the range of frequencies relevant to the analysis. [15] The notch frequency parameter was crucial for specifying the mains frequency that was removed by the Notch filter, addressing common electrical interferences, such as the 60 Hz frequency. The choice of sample rate was decisive, as it affected the accuracy of signal processing and heart rate analysis.

G. Comparative Evaluation

A detailed visual method was implemented to evaluate the electrical activity of the heart. During this screening process, both rightward and leftward axis deviations were identified, indicating possible irregularities in cardiac electrical conduction. These findings provided valuable information about the cardiovascular health of the canines under study. Attention was specifically focused on lead I, which focuses on the frontal

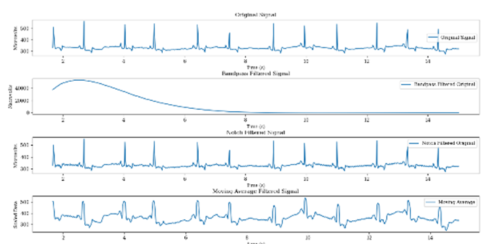

Fig. 5 Filter Aplication in Chihuahua´s Signals

plane and provides a detailed representation of electrical activity in that specific dimension. Interpretation of the information from this lead allowed the detection of particular patterns indicating possible alterations in the propagation of electrical signals throughout the cardiac tissue.

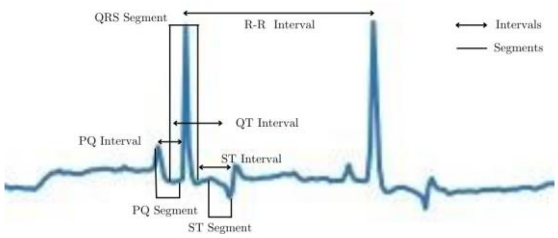

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Fig. 6 Captured Intervals and Segments

H. Response Analysis

Retrospective analysis of the responses generated focuses on the evaluation of canine electrocardiogram (ECG) interpreta- tion. Overall, most ECG readings were identified as accurate, providing substantial information about the electrical activity of the heart in the canines examined. However, significant vari- ation was observed in the cases of canines with larger amounts of fur. In canines with abundant fur, a higher impedance was found in the banana limb electrodes used for data capture. Impedance, understood as the resistance of a biological tissue to electric current [16], affected the quality of the captured signal and, therefore, the accuracy of the readings.

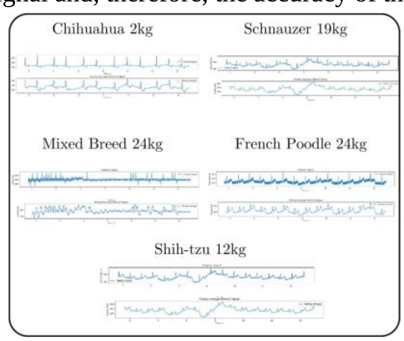

Fig. 7 Captured Intervals and Segments

I. Comparative Display

Heart rate in dogs, a crucial cardiovascular indicator, is influenced by size, age, breed, and overall health. Notably, heart rates vary significantly between breeds, with smaller breeds like Chihuahuas exhibiting higher numbers due to their faster metabolism. In the case of a mixed breed, the highest recorded heart rate was 170 beats per minute, with age (11 years) being a significant contributing factor. Advanced age in dogs leads to notable physiological changes in the cardiovascular system, often associated with chronic conditions or underlying heart disease, contributing to increased heart rates.

TABLE III
COMPARISON OF HEART RATE READINGS (BPM)

Canine Breed	Heart Rate (BPM)
Chihuahua	155.773723
Schnauzer	122.688312
Mixed Breed	170.212766
Shih-tzu	125.857143
French Poodle	120.623762

J. Statistical Analysis Between 5 Dog Breeds

Evaluation of the differences between groups on a specific variable are shown in table 4. A distinction is made between between between-group variation (”Factor”) and within-group variability (”Error”). The ”Factor” Source with 4 degrees of freedom compares 5 groups, while the ”Error” Source with 55 degrees of freedom addresses within-group disparities.

The ”Adjusted Sum of Squares” indicates the total adjusted variability, being 42,687 for the ”Factor” Source (between groups) and 563,816 for the ”Error” Source (within groups). The ”Adjusted Mean Squares” reveals the average between-group (10.672) and within-group (10.251) variability.

The ”F-value” of 1.04 for the ”Factor” Source indicates that between-group differences are more notable than within-group differences. The ”p-value” of 0.395 suggests that there is insufficient evidence to reject the null hypothesis that there are no significant differences between groups.

TABLE IV
VARIANCE ANALYSIS

Source	DF	SS	MS	F Value	p Value
Factor	4	42687	10672	1.04	0.395
Error	55	563816	10251		
Total	59	606502			

The means and standard deviations of cardiac parameters in different canine breeds are shown in Table 5. For Chihuahuas, the mean was 93.1 with standard deviation of 77.0 (95% CI: 34.6-151.7). Schnauzers had a mean of 90.5 and standard deviation of 71.9 (95% CI: 31.9-149.0). The mixed breed showed a high mean of 161.0 with standard deviation of 160.9 (95% CI 102.4-219.5). In Shih-tzu, the mean was 92.9 with standard deviation 72.5 (95% CI 34.4-151.5). For French Poodle, the mean was 107.1 and standard deviation 94.8 (95% CI 48.6-165.7). These data reveal significant differences in cardiac parameters between dog breeds.

TABLE V
DESCRIPTIVE STATISTICS BY BREED

Factor	N	Mean	Std. Dev.	95% CI
Chihuahua	12	93.1	77.0	(34.6; 151.7)
Schnauzer	12	90.5	71.9	(31.9; 149.0)
Mixed Breed	12	161.0	160.9	(102.4; 219.5)
Shih-tzu	12	92.9	72.5	(34.4; 151.5)
French Poodle	12	107.1	94.8	(48.6; 165.7)

Figure 4 details the cardiological intervals, analyzing car- diac electrical activity and recording each interval, from QT to QRS, along with identification of the canine breed. The results revealed distinctive patterns, such as shorter intervals in Chihuahuas compared to mixed breed dogs. This variability suggests notable physiological differences between breeds, possibly related to genetic influences and specific anatomical features. The graph highlights the ability of ECG intervals to indicate the health status of dogs, especially in cases of cardiac conditions, where atypical intervals, either shorter or longer than normal, are observed.

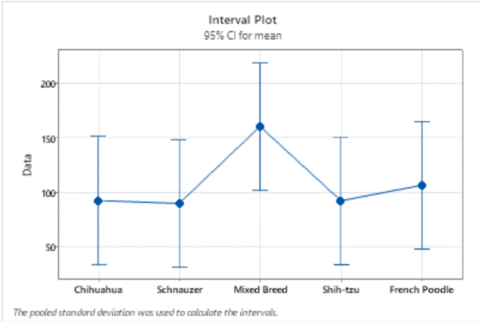

Fig. 8. Interval Plot

The data distribution of five dog breeds in terms of signal amplitude (measured in microvolts) is shown in Fig.6, Chihuahuas exhibited a concentrated distribution with a median of 100 microvolts and an interquartile range (IQR) of 25 microvolts, indicating a signal amplitude between 75 and 125 microvolts. In contrast, the schnauzer showed a wider spread, with a median of 125 microvolts and an IQR of 50 microvolts, with amplitude ranging from 75 to 175 microvolts.

The mixed breed had a similar distribution to the schnauzer. The shih-tzu had a more pronounced variation, with a median of 150 microvolts and an IQR of 75 microvolts, ranging from 75 to 225 microvolts. Finally, the french poodle stood out for its wide variability, with a median of 200 microvolts and an IQR of 100 microvolts, showing a signal amplitude from 100 to 300 microvolts.

The "Factor" with 3 degrees of freedom analyzed the variability among 4 breeds, with an Adjusted SC of 2062, indicating the difference in means. The Adjusted MC of 687.5 showed the average variability in scores, and the F-value of 0.11 suggested minimal differences between breed means.

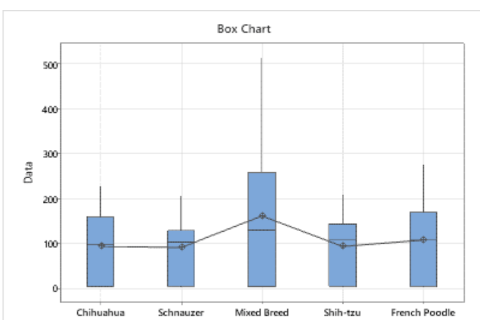

Fig. 9 Captured Intervals and Segments

The p-value (0.955) was above the 0.05 threshold, without sufficient evidence to reject the null hypothesis of equality in means. In summary, there were no statistically significant differences between dog breeds in the variable evaluated.

TABLE VI
VARIANCE ANALYSIS WITHOUT MIXED BREED

Source	DF	SS	MS	F Value	p Value
Factor	3	2062	687.5	0.11	0.955
Error	44	278869	6339.3		
Total	47	280931			

The Total Sum of Squares (S) with a value of 79.6200 reflected the total variability in the data, encompassing all sources of variation considered by the model during the retrospective analysis. The R-squared, with a modest value of 0.73\%, indicated the proportion of the total variability that could be explained by the model. This value suggested that the model had limited ability to explain variation in the dependent variable. However, the adjusted R-squared, with a value of 0.00\%, adjusted this indicator by the number of variables in the model, revealing that the explanatory capacity practically disappeared after this adjustment.

The predictive R-squared, with a value of 0.00\%, suggested that the model had a very limited ability to predict future values of the dependent variable, regardless of the inclusion of the mixed race variable. These results indicated that the exclusion of the mixed-race variable did not have a significant impact on the model's ability to explain and predict variability in the data.

TABLE VII
VARIANCE ANALYSIS WITHOUT MIXED BREED

S	R-squared	Adjusted R-squared	R-squared (pred)	
-	79.62	0.73%	0.00%	0.00%

The absence of the mixed breed has led to noticeable alterations in both the central tendency and variability of the variable under investigation within these specific breeds. Initially, when the mixed breed was considered, it exhibited a substantially higher mean compared to other breeds, along with a notable standard deviation indicating significant variability. However, upon excluding the mixed breed, the means and standard deviations of the remaining breeds underwent substantial changes.

TABLE VIII
DESCRIPTIVE STATISTICS FOR EACH FACTOR

Factor	N	Mean	Std. Dev.	95% CI
Chihuahua	12	93.1	77.0	(46.8; 139.5)
Schnauzer	12	90.5	71.9	(44.1; 136.8)
Shih-tzu	12	92.9	72.5	(46.6; 139.3)
French Poodle	12	107.1	94.8	(60.8;153.4)

The 95% confidence intervals around each data point were essential to understand the uncertainty associated with estimating the true mean of the electrical signals. This information was crucial for assessing the reliability and variability of the measurements, allowing for more accurate interpretation of the results.A key observation from the graph suggested that smaller dogs, represented by the Chihuahua, exhibited more pronounced cardiac electrical signals compared to larger breeds.

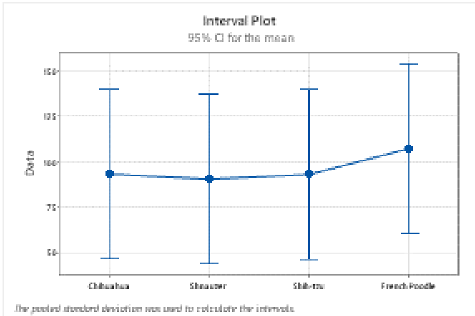

Fig. 10 Captured Intervals and Segments

Distinctive voltage patterns in various dog breeds. revealed complex cardiac electrical responses. Chihuahuas showed heterogeneous and widely distributed voltage changes, indicating genetic or physiological factors contributing to diverse car- diac responses. Schnauzers exhibited more uniform voltage changes, implying a consistent cardiac response. Shih-tzus and French poodles displayed intermediate distributions, suggesting a mix of variability and uniformity.

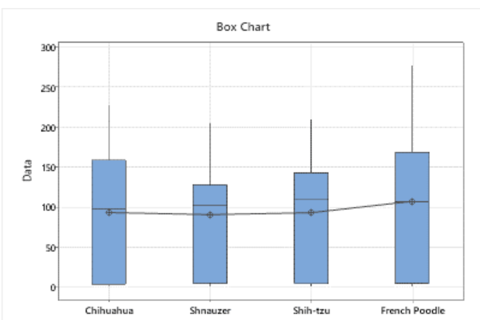

Fig. 11 Box without Mixed Breed

V. Conclusions

This study introduces a quantitative and experimental approach to assess cardiac performance in various canine breeds through electrocardiography (ECG). Utilizing Python for signal analysis, we implemented a prototype featuring Arduino Uno, the AD8232 heart rate sensor, and banana limb electrodes. The investigation focuses on Chihuahua, Schnauzer, French Poodle, mixed breed, and Shih-Tzu. Results demonstrate the prototype is efficient for capturing and processing cardiac signals, achieving accurate parameterization for analysis. Integration tests comparing cardiac responses between breeds yield valuable insights, emphasizing the applicability and reliability of the developed system. Despite identified limitations, effective remote canine signal monitoring was achieved. This work informs the development of robust canine cardiac monitoring systems, serving as a valuable tool for at-home monitoring.

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