Detecting heart diseases in underserved areas of Honduras with mobile electrocardiography

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Abstract* – cardiovascular diseases pose significant health challenges in low- and middle-income countries (LMICs), making early detection of heart disease vital to improve outcomes, but access to conventional diagnostic tools. Mobile electrocardiography (MECG) offers a promising solution for remote and resource-limited settings. To evaluate the use of MECG technology to detect cardiac disease in underserved areas of Honduras. It focuses on mobile health technologies' efficacy, challenges, and potential to expand access to cardiovascular diagnosis. MECG devices were deployed in the El Paraíso, Honduras, using Prince 180D devices and a cloud-based mobile application to record and transmit ECG data. A total of 1044 ECGs were collected between November 2023 and January 2024, and the data were analyzed remotely by cardiologists. Among the 1044 ECGs recorded, 262 had abnormalities, such as ischemic heart disease, atrial fibrillation, atrial flutter, and third-degree atrioventricular block. MECG technology demonstrated sensitivity to various cardiac pathologies, and abnormalities were predominantly identified in women and patients aged 41 years or older. MECG technology demonstrated high accuracy and reliability in detecting multiple cardiac pathologies, especially in geographically isolated regions. This system enabled early diagnosis and facilitated timely referrals, offering a scalable solution to health disparities in LMICs.

Keywords-- mHealth, Electrocardiography, Honduras, rural zone, primary health care

I. INTRODUCTION

Heart diseases (HDs) are common congenital disabilities that significantly impact morbidity and mortality, especially in low- and middle-income countries (LMICs). These regions struggle with healthcare delivery due to limited resources and a shortage of specialized professionals, leading to late or missed diagnoses and poor health outcomes. Early detection of HDs is vital, but traditional diagnostic tools like echocardiography and ECG are often unavailable in underserved areas. Mobile health technologies, particularly mobile electrocardiography, offer a transformative solution for detecting HDs in resource-limited settings [1][2].

Mobile electrocardiography (MECG) devices are portable systems with advanced algorithms that capture, analyze, and transmit real-time cardiac data. Features like Bluetooth connectivity and smartphone integration make them versatile for remote diagnostics. For instance, AliveCor's Kardia Mobile [3] connects to smartphones for instant cardiac readings and is used in low-resource settings, allowing healthcare workers to perform ECG tests outside traditional clinics [4].

This technology has significantly impacted several developing countries. In India, MECG devices are integrated into community health programs, enabling health workers to screen for HDs in rural areas, with data sent to urban cardiologists for analysis [5]. In Uganda, they are used in schools to identify heart defects in children, focusing on conditions that may go unnoticed until they cause severe complications [6]. These initiatives promote early detection and track HD prevalence in areas with limited epidemiological data.

MECG devices use advanced signal processing and machine learning algorithms to ensure high accuracy under varying conditions. They employ techniques like wavelet transformation and feature extraction to detect heart abnormalities. Some systems include AI-driven diagnostic tools automatically identifying arrhythmias and other cardiac issues, providing immediate feedback to users and healthcare providers [7]. This is particularly beneficial in areas with limited access to expert ECG interpretation. Moreover, the portability of these devices allows for continuous monitoring, enabling patients to track their heart health in real time and share data seamlessly with their medical teams [8].

These portable and affordable devices make them suitable for low and middle-income countries (LMICs). Unlike traditional ECG machines, they are lightweight and easy to operate, allowing community health workers to conduct cardiac screenings [9]. Their integration with telemedicine platforms enables remote patient monitoring, ensuring continuity of care in isolated regions. Recent advances in MECG technology show promise for early detection of HDs in low-resource settings. Mobile ECG devices provide reliable cardiac assessments that can be integrated into telemedicine, enabling remote monitoring and diagnosis [10]. These technologies reduce in-person visits and empower local healthcare workers to conduct preliminary screenings, expanding cardiac care to underserved populations [11].

MECG technology has promise, but its widespread adoption in underserved areas faces challenges such as device maintenance, data security, and reliable internet connectivity. Cultural and socio-economic factors also impact acceptance and use. Addressing these issues requires a comprehensive approach that includes capacity building, infrastructure development, and community engagement [12][13].

This paper investigates MECG technology, combined with a cloud mobile application, for detecting congenital heart diseases in underserved areas of Honduras. It highlights the effectiveness, challenges, and potential of MECGs in improving cardiac care in resource-limited settings. The findings support mobile health solutions to address critical healthcare needs and emphasize innovation in reducing disparities

II. METHODS

A. Devices

The MECG device selection criteria include portability (under two kilograms and backpack-compatible), cost (US$150 to US$250 for resource-limited areas), and ease of use (accessible interface for staff with minimal training). It should feature automatic alerts for chronic disease management, use common batteries or external USB/solar power, allow data extraction for electronic medical records, and ideally have at least one operational certification within the price range.

Similar criteria were applied to the calibration device, requiring local availability, well-documented operation, a review of operational parameters within the last year, and the ability to evaluate the selected MECG effectively.

1) Mobile ECG: We selected the Prince 180D Easy ECG Monitor [14]. It is a portable, handheld electrocardiogram (ECG) device for personal and professional use. It is particularly well-suited for patients who require frequent cardiac monitoring, as well as for healthcare professionals in need of a convenient tool for quick ECG assessments. The device features a 2.8-inch TFT color display, clearly visualizing ECG waveforms and related cardiac parameters. It operates with a single-button interface, ensuring ease of use, and offers 12-bit sampling accuracy with a sampling rate of 250 Hz. The Prince 180D can record up to 300 measurements in its internal memory, and the data can be transferred to a computer via a USB interface for further analysis using proprietary ECG management software.

The device is powered by a rechargeable lithium-ion battery, providing up to 10 hours of continuous use on a full charge. It supports lead I and II measurements, allowing users to switch between them based on the desired assessment. The measurement range includes heart rate detection from 30 to 240 beats per minute, with an accuracy of ±2 bpm or ±2%, whichever is greater. The Prince 180D also features an arrhythmia detection function that alerts users to potential irregularities in heart rhythm, including bradycardia and tachycardia. The monitor is compact, with dimensions of 128 mm x 85 mm x 21 mm and a weight of approximately 106 grams, making it highly portable and convenient for on-the-go monitoring. Your software version is 3.1.0.0, and the viewer version is v4.2.0.1. It has the CE0123 marking and meets IEC 60601-1 and IEC 60601-1-2 standards. Prince 180D can be seen in Figure 1.

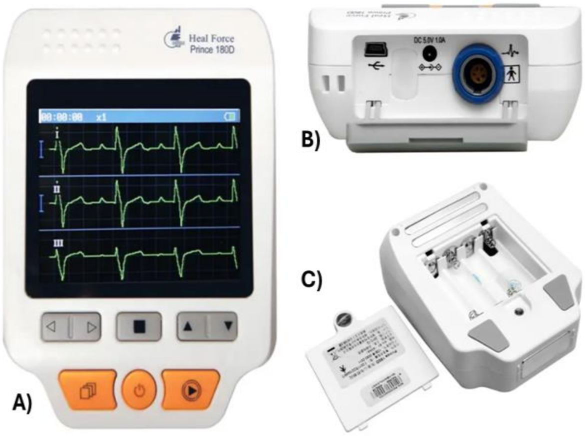


Fig. 1 Prince 180D MECG, A) Main body and screen; B) Connection ports; C) Charger for common batteries.

2) Calibration device: We used the PS-2200 Multi-Parameter Patient Simulator, produced by BC Group International [15]. This device can generate physiological and pathological signals, making it essential for clinical engineering, biomedical equipment maintenance, and quality assurance protocols, see Figure 2.

The PS-2200 capabilities encompass heart rate settings that range from 30 to 350 beats per minute (BPM) with an accuracy of ±1 BPM. It supports the generation of 17 arrhythmia patterns, including atrial fibrillation, ventricular fibrillation, and asystole, and pacemaker simulations with adjustable amplitude and rate. Furthermore, it allows the simulation of both adult and pediatric ECG waveforms.

It can do invasive and non-invasive simulation modes for blood pressure measurement. In invasive mode, it can simulate arterial, venous, and pulmonary artery pressures, with adjustable settings for systolic pressure (ranging from 20 to 250 mmHg), diastolic pressure (from 0 to 200 mmHg), and mean arterial pressure (from 0 to 230 mmHg). The non-invasive mode allows for adjustable systolic pressure (from 60 to 240 mmHg) and diastolic pressure (from 30 to 180 mmHg), with an accuracy of ±1 mmHg. Additionally, the device supports the simulation of various pulse rates (from 30 to 250 BPM) to replicate different physiological conditions.

The PS-2200's temperature simulation ranges from 25°C to 45°C, with an accuracy of ±0.1°C. This capability enables the replication of both hypothermic and hyper-thermic conditions, essential for testing thermometers and patient monitoring systems that track body temperature.

The respiration simulation can be adjusted to deliver between 10 and 120 breaths per minute, with tidal volumes ranging from 100 to 1500 mL. This flexibility allows for precise replicating normal and abnormal respiratory conditions, facilitating com-prehensive testing of respiratory monitors and ventilators. The PS-2200 also includes a cardiac output simulation function, providing outputs ranging from 0.1 to 20.0 L/min with an accuracy of ±0.1 L/min. This feature is especially beneficial for calibrating devices that monitor cardiac output, such as thermodilution catheters.

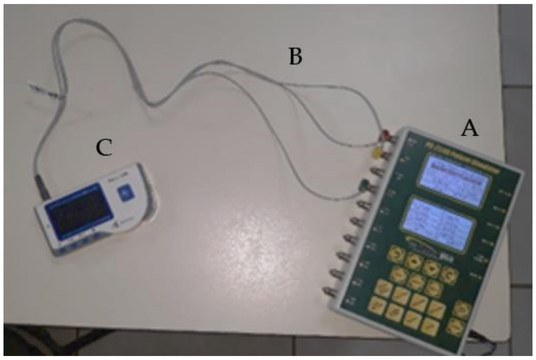


Fig. 2 Prince 180D MECG, A) Main body and screen; B) Connection ports; C) Charger for common batteries.

B. *Software*

In pursuit of automating the processes of data capture, transmission, storage, and querying, a platform has been developed that enables the input of information via an Android application. This platform not only streamlines data storage but also facilitates the recording of electrocardiograms, which a specialist will subsequently analyze through a web application. The professional will assess the results and, at their discretion, identify which cases necessitate further attention.

The development of this platform utilizes various tools, including Firebase as the database management system, Android Studio as the integrated development environment for Android applications, and Java as the primary programming language. Express.js served as the framework for web development, while Node.js functioned as the web server. JavaScript was employed for both backend and web development. Furthermore, HTML, Bootstrap, and JavaScript were utilized for frontend development.

Users must input their credentials and the corresponding password to access the application. The main interface will be presented upon successful authentication, which offers various options for viewing patient data, including general information, search functionalities, and stored electrocardiograms. The process of capturing electrocardiograms commences with a series of instructions, followed by the presentation of an interface for data capture from the device. Additionally, within the section designated for administrators, options about statistical data are made available. Some screenshots can be seen in Figure 3.

The application was developed using Android Studio, specifically employing version 29 of the Software Development Kit (SDK), with a minimum compatibility requirement established at version 26 of the SDK. The programming language utilized for development was Java, which is the native language of the Android platform. The application's architecture is structured around 11 primary classes.

User hardware was defined as any device operating on the Android operating system with internet connectivity. In instances where tablets were accessible, wooden bases were designed and produced to accommodate their placement and enhance the ability of primary care staff to perform electrocardiograms.

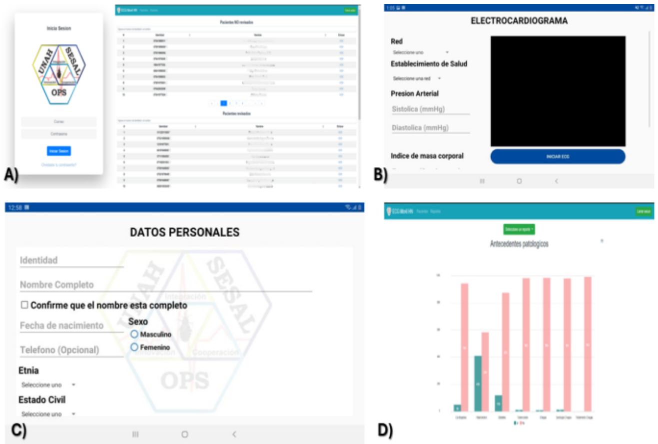


Fig. 3 The application was developed for MECG, which includes: A) Login and main screen; B) Capture screen; C) Patient data form; D) Statistics.

C. *Calibration procedure*

To calibrate a MECG with a PS-2200 patient simulator, we need to confirm that both devices are powered and operational. The simulator should be connected to the MECG with the right leads, ensuring secure attachment and proper positioning by standard configurations. This configuration is critical for the accurate transmission of signals.

Next, the PS-2200 simulator must be configured to produce a standard sinus rhythm waveform characterized by a heart rate of 60 beats per minute (bpm) and an ECG signal amplitude of 1 millivolt (mV), which corresponds to a 10 mm deflection at a gain setting of 10 mm/mV. These parameters establish the baseline for calibration.

To continue this process, accessing the calibration menu of the MECG machine and selecting the correct options according to the manufacturer's operating manual are needed. The initial step is to record the waveform generated by the PS-2200 simulator; the MECG should exhibit a peak-to-peak amplitude of 10 mm if the simulator is correctly set to 1 mV, ensuring an accurate representation of the simulator's output.

Following the initial calibration, verifying the accuracy of the MECG waveform about the output from the PS-2200 is necessary. Should the amplitude deviate beyond ±0.2 mm from 10 mm or the heart rate fall outside ±1 bpm of 60 bpm, further adjustment will be required. Calibration is deemed successful if the ECG device accurately reflects the simulator's settings within these tolerances; otherwise, additional adjustments or maintenance will be necessary.

To further ensure the accuracy of the MECG machine, calibration at various heart rates (30 bpm, 120 bpm, 180 bpm) and amplitudes (0.5 mV, 2 mV) is advisable. Each configuration should yield a corresponding waveform, such as a 5 mm deflection for 0.5 mV, with the heart rate remaining within ±1 bpm of the designated value. This comprehensive testing guarantees consistent accuracy across diverse clinical scenarios.

For future reference, it is imperative to document the calibration results, including the tested heart rates, amplitudes, and corresponding MECG readings, while indicating whether the machine passed or failed at each stage. If all measurements fall within the specified tolerances, the machine is deemed ready for clinical application; if not, further calibration or repair is warranted. Adhering to these procedures ensures precise calibration and reliability in clinical practice.

D. MECG procedure

The procedure for employing a MECG device, particularly within a clinical environment involving multiple patients, necessitates strict adherence to established protocols to ensure accuracy, hygiene, and patient safety. Initially, it is imperative that the device is fully charged, and the corresponding application is installed and functioning correctly on a smartphone. Before placing electrodes, the patient's skin must be cleansed with an alcohol swab to eliminate any oils or debris that may compromise signal quality. Subsequently, the electrodes should be affixed to the designated anatomical sites typically the wrists, chest, or hands by the manufacturer's guidelines and relevant clinical protocols, such as those delineated by the American Heart Association (AHA) or other pertinent regulatory bodies.

Before the electrocardiogram, patients rested for at least ten minutes. If they re-ported the use of stimulants (e.g., drugs, coffee), the study was not conducted. Questions about medications and medical history were also asked to document relevant data. The patient was instructed to remain in an appropriate position while the ECG recording was initiated via the application, which typically captures the heart's electrical activity for approximately 30 seconds. Upon completion of the recording, the ECG trace was displayed on the smartphone for immediate review. In instances involving multiple patients, it is essential that after each use, the electrodes and any re-usable components are cleaned and disinfected by the infection control protocol or the manufacturer's instructions. Additionally, disposable electrodes should be disposed of appropriately.

The ECG data obtained were stored in the device, securely transmitted to a cloud application, and sent to the cardiologist for additional analysis or confirmation of diagnosis if necessary. Following these procedures, which include comprehensive cleaning and disinfection between patients, guarantees the dependable and safe utilization of MECG devices in alignment with established medical standards and protocols.

Finally, the mobile application assessed the accuracy of the electrocardiogram technique in real time. Healthcare professionals received instructions for adjustments as needed. Patients were advised to seek a comprehensive evaluation if significant cardiac alterations were detected. For non-life-threatening alterations, the cardiologist decided remotely whether further evaluation was necessary or if follow-up would continue with primary care teams. This study followed the ethical principles of the 1964 Declaration of Helsinki and its later amendments for research involving human subjects, with all participants providing informed consent prior to inclusion.

E. *Cost analysis*

A cost analysis was performed to provide an overview of the prices related to manufacturing and acquiring electrocardiographic equipment and ECG study prices in public and private healthcare settings. This involved systematically exploring publicly available data using targeted internet searches with keywords like “electrocardiogram cost Honduras” and “low-cost medical cardiology diagnostics.”

Price listings were collected from private clinics, hospitals, and diagnostic centers in Honduras to assess current market rates for ECG services. Simultaneously, platforms like Amazon, eBay, and Alibaba were surveyed for pricing data on mobile ECG devices, from consumer-grade to hospital-certified models. Additionally, technical specifications and cost estimates of components used in open-source ECG development kits were analyzed to evaluate the feasibility of in-house fabrication.

Manufacturer datasheets and procurement records validated pricing and functionality. This approach enabled data triangulation for an informed economic assessment of mobile ECG deployment's viability and scalability. Results were categorized by use case (public health facility, private clinic, remote/mobile application) and framed within accessibility, affordability, and health system integration.

III. RESULTS

A. *MECG controlled tests*

The MECG device simulated several pathological conditions to determine its sensitivity. One of them is a standard calibrated electrocardiogram (10 mm/mV and 25 mm/s) was performed, which showed a non-sinus rhythm, with an average heart rate of 60 beats per minute, and an axis of the QRS complex, the P wave, and the T wave of +60 degrees. The electrocardiographic findings are consistent with a second-degree atrioventricular block of the Mobitz type I (Wenckebach block), characterized by:

1. Progressive prolongation of the PR interval until a pause in atrioventricular conduction occurs (blocked P wave), thus observing the Wenckebach phenomenon.

2. The PR interval is longer immediately before the pause

3. The PR interval is shorter immediately after the pause

4. Progressive shortening of the R-R interval until the pause occurs. The ECG of this condition can be seen in Figure 4, identified with the letter "A".

After, a new ECG was performed with a standard calibration of 10 mm/mV and 25 mm/s, which showed a Sinus Rhythm, a heart rate of 79 beats per minute, a QRS complex axis of -60 degrees, and a P wave axis of +60 degrees. The electrocardiographic findings show a pattern consistent with left ventricular hypertrophy, as it meets the Lewis criteria (Lewis Criteria for Left Ventricular Hypertrophy: Score less than 17 mm), with a value of 14 mm [(S in III + R in I) – (R in III + S in I)]. Additionally, an R wave in lead I + S wave in lead III of 26 mm is observed (Left Ventricular Hypertrophy Criteria by Summation of R Wave in DI + S Wave in DIII: Score more significant than 25 mm) and a leftward deviation of the QRS complex axis. The ECG of this condition can be seen in Figure 4, identified with the letter "B".

Subsequently, another electrocardiogram was performed with standard calibration (10 mm/mV and 25 mm/s), which showed a non-sinus rhythm with a heart rate of 30 beats per minute and a QRS complex axis of +60 degrees. Electrocardiographic tracing reveals extreme bradycardia and complete atrioventricular dissociation (total absence of electrocardiographic relationship between the P waves and the QRS complexes, with a higher frequency of P waves than that of the QRS complexes). Constant P-P intervals and a ventricular escape rhythm with narrow QRS complexes are also observed. These findings are typical of third-degree atrioventricular block (complete heart block). The ECG of this condition can be seen in Figure 4, identified with the letter "C".

Finally, an ECG was performed with a standard calibration of 10 mm/mV and 25 mm/s, which showed a Sinus Rhythm, a heart rate of 79 beats per minute, and a QRS complex axis at 0 degrees. The electrocardiographic tracing shows an ST-segment elevation greater than 1 mm in lead DIII. Additionally, in lead DI, there is a slight ST segment depression, exclusive R wave, an intrinsic deflection time of 60ms, and asymmetric T wave inversion. These findings are consistent with ischemic heart dis-ease (likely acute coronary syndrome with ST-segment elevation in the inferior wall). The ECG of this condition can be seen in Figure 4, identified with the letter "D".

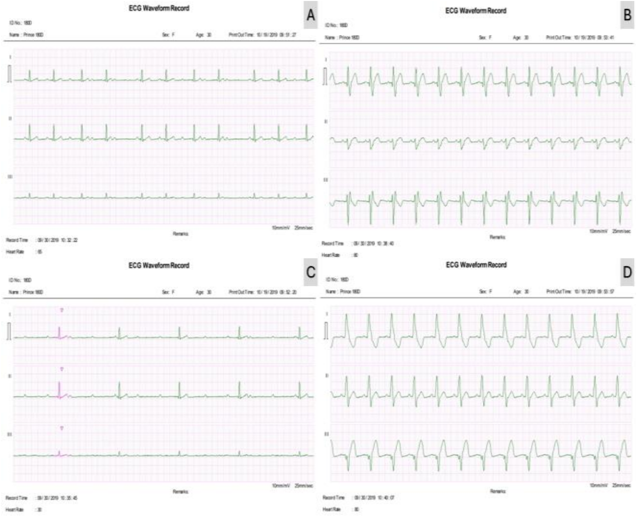


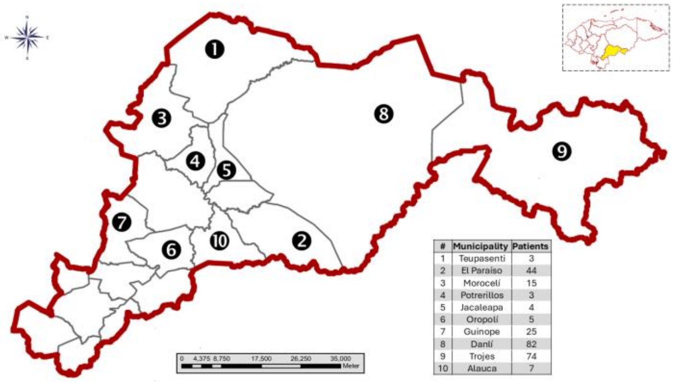
Fig. 4 Pathologies simulated on MECG 180D device for sensitivity purposes performed with the PS-2200 multi-parameter patient simulator

B. MECG performed in field

To deploy the MECG devices, along with the software and connectivity to storage services that leverage the SaaS (Software as a Service) infrastructure of mobile technologies, it was decided, at the suggestion of the Ministry of Health of Honduras, to conduct field tests in the department of El Paraíso. This area, significantly underserved by national health systems, has 19 municipalities and an approximate population of half a million people, mostly in rural areas and subsistence economic conditions. Most residents only seek health services in emergencies due to the geographical inaccessibility of care centers.

A total of 28 interconnected ECG machines were used via mobile devices through the cellular data network, which operated on UMTS (Universal Mobile Telecommunications System), HSPA (High-Speed Packet Access), and, in some locations, HSDPA (High-Speed Downlink Packet Access). The assessments for this study were conducted from November 21, 2023, to January 17, 2024, with 1044 ECGs, of which 262 showed abnormalities, which were considered for the study. Among these, there were 197 studies in women and 95 in men. Regarding the age of the patients, in the category of 41 years or older, 64 men and 132 women were recorded; in the group of 19 to 40 years, there were 27 men and 55 women; and finally, in the group of 18 years or younger, 4 men and 10 women were reported (Figure 5).

A non-probabilistic convenience sampling method was used to select participating patients during visits to rural populations. Although this method does not guaran-tee statistical representativeness of the general population, it is suitable for exploratory studies in rural contexts, where access to medical services is limited and technologies need to be evaluated in hard-to-reach scenarios.



#	Municipality	Patients
1	Teupasenti	3
2	El Paraíso	44
3	Morocelí	15
4	Potrerillos	3
5	Jacaleapa	4
6	Oropolí	5
7	Guinope	25
8	Danlí	82
9	Trojes	74
10	Alauca	7

Fig. 5 Map of the department of El Paraiso, listing the municipalities visited and the number of patients treated in each one

C. *MECG abnormalities identified*

The most common abnormal ECG pathologies were arrhythmias and ventricular hypertrophy, demonstrating the usefulness of ECG devices for early diagnosis and timely referral. Figure 6 shows six abnormal ECG traces and medical analyses.

In the image “A”, a sinus rhythm is observed (the P wave precedes the QRS complexes), with a heart rate of 100 beats per minute, a regular R-R interval, no AV blocks, and evidence of ST segment depression. It is concluded that the ECG suggests an established ischemic process. However, more leads are required to identify the anatomical area of the heart affected, so the patient must be urgently referred. In the image “B”, a sinus rhythm is observed (the P wave precedes the QRS), with an average heart rate of 83 beats per minute and a regular R-R interval. Additionally, there is a symmetrical inversion of the T wave, indicating a high-risk pattern for acute ischemic heart disease. In this case, it is concluded that the ECG shows a high-risk pattern for ischemic heart disease (Wellens syndrome type B).

In the image “C”, the ECG shows a non-sinus rhythm, with an unmeasurable heart rate due to the irregularity of the rhythm (at least 10 beats are required for evaluation), irregular R-R interval, absence of P waves, and presence of F waves. Additionally, the tracing shows low voltage in the QRS, which strongly suggests atrial fibrillation. In image “D”, the ECG presents a sinus rhythm (the P wave precedes the QRS complexes), with a heart rate of 107 beats per minute, a regular R-R interval, and no AV blocks; there is also evidence of electrical alternans (the amplitude of the QRS is not constant). It is concluded that this electrocardiogram consists of sinus tachycardia and electrical alternans.

In image “E,” the ECG shows a non-sinus rhythm, with an average heart rate of 150 beats per minute and a regular R-R interval. Characteristics of atrial flutter arrhythmia are observed; however, complete electrocardiographic tracing is required for a more accurate assessment. It is concluded that the electrocardiogram is compatible with atrial flutter arrhythmia. In the image “F,” the ECG shows a non-sinus rhythm with an average heart rate of 65 beats per minute and an irregular R-R interval, a typical finding of ventricular premature beats with low voltage QRS amplitude. It is concluded that the electrocardiogram is compatible with isolated premature ventricular contractions without ischemia, necrosis, or areas of inactivation.

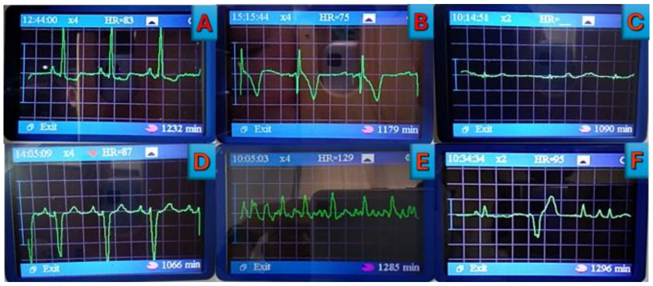


Fig. 6 ECG taken, showing multiple conditions.

IV. COST ANALYSIS

In Honduras, private health services charge about USD 20 to USD 25 for electrocardiograms (ECGs) [16] [17]. In contrast, the state-subsidized hospitals can charge only USD 2 for the same test [18], highlighting the disparities introduced by public financing mechanisms. These costs can present a substantial economic barrier for patients requiring continuous cardiac monitoring or recurrent outpatient services. Consequently, there is growing interest in adopting affordable diagnostic technologies, promoting broader cardiovascular assessment access.

AliveCor’s KardiaMobile, a mobile ECG device that captures single-lead cardiac signals, is available at approximately USD 99. The enhanced six-lead model, offering more detailed electrophysiological data, is priced at USD 149 [19] [20]. Additional alternatives, such as the Wellue ECG Monitor and the Checkme Pro, provide expanded functionalities, including wireless data transfer via Bluetooth, local storage, and automated interpretation using artificial intelligence algorithms. These devices range in price from USD 65 to USD 299, depending on features and clinical integration [21].

From a manufacturing standpoint, the cost to fabricate a mobile ECG device at scale is significantly lower than its retail price. Basic units integrating analog-to-digital conversion, a low-noise instrumentation amplifier, and a microcontroller with Bluetooth or USB communication can be produced for under USD 40 in quantities exceeding 1,000 units. Components such as the AD8232 analog front-end (commonly used in compact ECG designs), lithium-polymer battery modules, and low-power displays are readily available from suppliers in Asia at low cost. The embedded firmware responsible for signal acquisition and filtering is typically developed in C/C++ for real-time operation, while companion mobile applications, often developed in Java/Kotlin (Android) or Swift (iOS) to enable visualization, cloud synchronization, and basic diagnostics.

Moreover, the software architecture supporting mobile ECG devices plays a critical role in their usability and clinical value. Modern platforms incorporate signal pre-processing (e.g., baseline wander removal, QRS detection), secure data transmission using Bluetooth Low Energy (BLE) or Wi-Fi, and cloud-based analytics using machine learning algorithms trained to detect arrhythmic events. Some devices comply with international data standards such as HL7 or FHIR, allowing integration into electronic health record (EHR) systems and telemedicine workflows. The ability to transmit ECG data to clinicians in real-time or asynchronously expands their utility in remote health monitoring, especially in underserved or geographically isolated regions.

By comparison, traditional hospital-based ECG systems have a considerably higher acquisition cost. Basic devices with 3 to 6 channels typically range from USD 350 to USD 700, while 12-lead models equipped with thermal printers and digital archiving capabilities cost between USD 800 and USD 1,200 [22] [23]. Beyond the base purchase price, operational expenses such as calibration, maintenance, consumables (e.g., thermal paper), and proprietary software licenses must also be considered.

High-end electrocardiographs, like the GE MAC 5500HD, commonly used in tertiary-care hospitals, may exceed USD 6,000. These models offer advanced features such as automated arrhythmia detection, HL7 compatibility, and cloud-based data management systems [24]. Other high-precision ECG platforms, such as the Philips PageWriter TC70 and the Schiller Cardiovit AT-102, are similarly priced in the USD 4,000 to USD 8,000 range, depending on configuration and connectivity [25].

Although mobile ECG devices are limited in diagnostic scope and may lack full clinical validation, they present a cost-effective solution for community-based screening and longitudinal follow-up, particularly in underserved populations. Their integration into public health campaigns, rural outreach programs, telemedicine platforms, and primary care settings can significantly expand access to cardiac evaluation while minimizing infrastructural demands.

V. DISCUSSION

The results demonstrate the efficacy of the MECG device in identifying various cardiac pathologies in both controlled and field environments, underscoring its diagnostic potential in underserved regions. Through a series of simulated and field-tested electrocardiograms (ECGs), the MECG exhibited sensitivity to various cardiac abnormalities, including atrioventricular blocks and ischemic heart diseases. These findings are consistent with the research conducted by Faruk et al. (2021) [26] and Sana et al. (2020) [27], which investigated the accuracy of mobile ECG devices in diagnosing arrhythmias and myocardial infarction. Their conclusions indicate that portable ECG devices can reliably detect multiple pathologies in clinical and remote settings. The controlled tests performed under standard electrocardiographic conditions highlight the precision of the MECG in diagnosing well-established pathological conditions. In contrast, the field tests underscore the significance of this technology in regions with limited healthcare infrastructure.

The controlled MECG tests demonstrated the device's ability to detect significant cardiac abnormalities, including second-degree atrioventricular block (Mobitz type I), left ventricular hypertrophy, third-degree atrioventricular block, and ischemic heart disease characterized by ST-segment elevation. Each condition was distinctly identified by the MECG, aligning with established diagnostic criteria. Research conducted by Encinas and Morin (2022) [28], Walker et al. (2009) [10], and Le et al. (2016) [29] corroborated the capabilities of mobile ECG devices in controlled settings, demonstrating high sensitivity in detecting various forms of atrioventricular block and hypertrophic patterns, particularly when adhering to traditional diagnostic criteria. The accurate identification of progressive PR interval prolongation in Mobitz type I block, and precise measurement of QRS axis deviations in left ventricular hypertrophy, suggest that the MECG can perform comparably to conventional ECG systems in clinical diagnostics.

The deployment of Mobile Electrocardiogram (MECG) devices in rural Honduras has illustrated their scalability and potential in areas with limited healthcare access. 1,044 electrocardiograms (ECGs) were conducted throughout the study, with 262 indicating abnormalities. This finding suggests a significant prevalence of cardiac issues, particularly among women and older adults. These results align with the research conducted by Vilme et al. (2019) [30], Dilraj et al. (2015) [31], and Masucci et al. (2006) [32], which reported elevated rates of cardiovascular disease detection in rural environments utilizing mobile telemedicine technologies. The studies indicated that women and the elderly were disproportionately affected by undiagnosed cardiac conditions, thereby underscoring the gender and age-related disparities in healthcare access. The successful implementation of MECG systems via mobile data networks further highlights the potential for expanding mobile diagnostic tools in low-resource settings, as evidenced by the findings of this field study.

The electrocardiograms (ECGs) conducted during the field tests exhibited diverse abnormalities, with no predominant condition emerging. This diversity underscores the adaptability of the mobile ECG (MECG) system in practical applications. These findings align with a study by Singh et al. (2014) [5], which assessed the detection of arrhythmias and ischemic heart disease through mobile ECGs in rural India. The study demonstrated that mobile ECGs could identify a broad spectrum of abnormalities, ranging from atrial fibrillation to ischemic changes, without a discernible pattern of prevalence, mirroring the outcomes of the current investigation. Importantly, ischemic processes and arrhythmias, including atrial fibrillation, Wellens syndrome, and atrial flutter, were identified, further substantiating the

MECG system's diagnostic efficacy across various cardiac conditions.

While the MECG system demonstrated strong performance in controlled and field settings, certain limitations warrant consideration. The employment of non-probabilistic convenience sampling in rural areas restricts the generalizability of the results to the broader population. This limitation is consistent with the findings of Landinez et al. (2015) [33], who evaluated mobile ECG technology within rural health campaigns. They underscored similar sampling concerns, indicating that although exploratory studies utilizing convenience samples yield valuable insights, the challenge of generalizing findings to the entire population persists. Nevertheless, such methodology remains justifiable for exploratory purposes in hard-to-reach areas, as it facilitates the immediate assessment of the MECG's effectiveness in identifying cardiac abnormalities in contexts where traditional medical infrastructure is insufficient.

Although MECG has demonstrated encouraging results, additional research is necessary to assess its long-term effects on patient outcomes and its capacity for integration within existing healthcare systems. Furthermore, including a more comprehensive electrocardiogram (ECG) leads to the utilization of larger datasets, which would enhance diagnostic accuracy in complex clinical scenarios, such as ischemia or atrial flutter.

Finally, mobile ECG technology significantly enhances decentralized healthcare delivery. Its portability allows for point-of-care diagnostics in underserved areas, while its low cost makes it attractive for resource-limited primary care networks. With minimal training, primary care personnel can perform basic cardiac assessments, enabling early detection of abnormalities like arrhythmias. This is particularly beneficial in rural settings with limited access to cardiology specialists. Early detection facilitates timely referrals, improving outcomes and reducing the burden of advanced cardiac disease. Therefore, integrating mobile ECG technology into primary care could strengthen cardiovascular health systems in low- and middle-income countries.

VI. CONCLUSIONS

The MECG exhibited significant accuracy in detecting pathological conditions, including second-degree atrioventricular block (Wenckebach block), left ventricular hypertrophy, third-degree atrioventricular block, and ischemic heart disease. The device reliably recognized characteristic electrocardiogram (ECG) patterns, affirming its sensitivity to diverse arrhythmic conditions and structural abnormalities of the heart. Implementing 28 Mobile Electrocardiogram (MECG) devices in the remote El Paraíso region of Honduras enabled cardiovascular evaluations for more than one thousand patients in a locale characterized by restricted access to medical services. Utilizing mobile network technologies, including UMTS, HSPA, and HSDPA, facilitated connectivity for the real-time transmission and analysis of electrocardiograms (ECGs), thereby demonstrating the viability of employing MECG in geographically isolated and resource limited settings.

Among the 1,044 electrocardiograms (ECGs) conducted in the field, 262 demonstrated abnormalities, which included ischemic heart disease, atrial fibrillation, atrial flutter, premature ventricular contractions, and electrical alternans. The capability of the MECG device to identify these varied and potentially life-threatening conditions underscores its significance for early detection and prompt intervention in patients who may otherwise have limited access to immediate healthcare services.

In regions characterized by limited access to healthcare, particularly in rural areas such as El Paraíso, MECG technology presents a viable solution for mitigating the high prevalence of undiagnosed or untreated cardiovascular conditions. By detecting patients exhibiting high-risk patterns, including ischemia or atrial fibrillation, this device facilitates early referral and intervention, which has the potential to substantially decrease morbidity and mortality associated with heart disease in these populations.

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