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## Original Research Article

# Disruptive Technological Innovation Through Ambulatory Blood Pressure Monitoring and Telemedicine for Patients with Cardiovascular Risk

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### ABSTRACT

**Objective:** To study the feasibility of using telematics as an innovative method for diagnosing patients with arterial hypertension, using blood pressure curves recorded at regular intervals over 24 hours, obtained by means of an Ambulatory Blood-Pressure Monitoring (ABPM) device and a telemedicine platform.

**Methods:** Between August 2023 and December 2024, a multicenter descriptive observational feasibility study was conducted based on the 24-hour remote assessment of blood pressure readings—every 30 minutes during the day and every 60 minutes at night—in hypertensive patients who attended public hospitals. The diagnosis of blood pressure curves obtained remotely with ABPM was carried out through a telemedicine platform. Subsequently, a team of cardiologists evaluated the results to determine their feasibility for the diagnosis and management of high blood pressure in remote patients. Blood pressure curves and diagnostic results were sent via a telemedicine platform.

**Results:** The remote study of 64 patients with high cardiovascular risk was conducted in 10 hospitals nationwide. Most patients were between 50 and 54 years old, followed by the 40 to 44 and 65 to 69 age groups. The mean age was 54.0 years, and 53.4% were male.

Among the patients, 50.0% had hypertension, 40.0% had uncontrolled hypertension, and 10.0% had normal blood pressure. An average of 40% adherence to treatment was determined among patients diagnosed with hypertension.

**Conclusions:** Our results suggest that it is feasible to use this disruptive technological innovation for the development of a remote, resilient capacity for the diagnosis of patients with high cardiovascular risk through ABPM and a telemedicine platform in public hospitals without cardiology services in Paraguay. In any case, a larger sample size will be required to validate and generalize the study results.

**Keywords**—*Tele-ABPM, Hypertension, Cardiovascular risk, Telemedicine, Teliagnosis, Digital technology, Paraguay.*

## INTRODUCTION

Arterial hypertension is a very prevalent pathology worldwide (approximately 40%)<sup>1</sup> and represents a relevant public health problem, according to the World Health Organization (WHO). According to the latest 2021 update of the WHO Global Health Observer, the prevalence of hypertension in the Paraguayan population in the age group of 30 to 79 years was 61.6% among men and 50.9% among women.<sup>2</sup>

Hypertension is one of the most important risk factors for chronic cardiovascular, cerebrovascular, and renal diseases. In general, most hypertensive patients are undiagnosed, and only one-fifth of hypertensive patients have adequate blood pressure values. The gold standard for determining blood pressure is the blood pressure monitor, or sphygmomanometer, which uses an inflatable cuff connected to a pressure gauge and the aid of a stethoscope. Measurements may be affected by the positioning and arrangement of the inflatable cuff, as well as the calibration of the device, which needs to be performed periodically.

Ambulatory blood pressure monitoring (ABPM) is recommended for patients with elevated blood pressure, those with unstable blood pressure, or those suffering from the white coat phenomenon or masked hypertension.<sup>3</sup> The ABPM device is an essential element for the diagnosis and monitoring of hypertension in patients with fluctuating blood pressures. For this, the use of validated (calibrated) devices and good practice techniques is required to ensure strict diagnostic control and monitoring over a period of 24 hours. It allows measurement of a patient's blood pressure by observing its variations in relation to different times and activities of the day. However, the use of the ABPM method in clinical practice is limited by factors such as the cost of the device, accessibility, and basic training of both physicians and patients,<sup>3</sup> especially in middle-income countries such as Paraguay. In addition, ABPM provides data on many important parameters to define the profile and variability of hypertension, in order to classify the patient into a group of phenotypes, which cannot be obtained with any other form of blood pressure measurement.<sup>4</sup> For all these reasons, ABPM is considered the gold standard for diagnosing hypertension and evaluating the usefulness of

antihypertensive therapy, according to the guidelines of the National Institute for Health and Clinical Excellence (NICE) in the United Kingdom.<sup>5</sup>

This study aims to improve the diagnostic capacity and follow-up of treatment for arterial hypertension in patients from public hospitals without cardiology services in Paraguay, to mitigate cardiovascular events in hypertensive patients by facilitating accessibility and universal coverage through the technological innovation proposed in this study. The specific challenges of our study involve anticipating cardiovascular events and carrying out appropriate interventions to avoid them, in order to impact universal coverage of patients with cardiovascular risk, reduce risk through adequate treatment, and minimize healthcare costs in a low-resource country. Thus, we consider that the ABPM method with telemedicine tools is particularly relevant in Paraguay for the initiation, follow-up, and control of antihypertensive therapy at the national level due to the high prevalence of arterial hypertension in the population. However, this is the first time that this type of study (joint ABPM and telemedicine) is carried out in Paraguay. This study intends to resolve existing problems in a low-income country and seek universal ABPM service coverage with a high standard level.

It should be noted that the technological innovation proposed in this study is not intended to replace diagnosis in a family medicine or cardiology service, but rather to improve accessibility to ABPM technology and, in this way, facilitate early diagnosis and appropriate treatment, avoiding unnecessary transfers of patients with high cardiovascular risk. This makes it possible to reduce overcrowding in specialized centers and optimize the use of the always-limited resources available in public hospitals. Another aspect to highlight is that, in order to implement the Tele-ABPM service, the telemedicine technician is considered a non-medical professional responsible for placing the ABPM device on the patient and then, after 24 hours, removing it to transfer all the recordings of the blood pressure curves to the telemedicine platform; following a protocol developed by cardiologists from the Cardiovascular Prevention Service of the Ministry of Public Health and Social Welfare (MSPBS).

In this context, the Paraguayan German University (UPA), in collaboration with the Directorate of Telemedicine and the National Cardiovascular Prevention Program (PNPC) of the MSPBS, carried out this study to evaluate the feasibility of using telematics as an innovative, disruptive method for the diagnosis, follow-up, and control of patients with arterial hypertension. We used blood pressure curves recorded by ABPM and a telemedicine platform in public hospitals without cardiology services in Paraguay.

## MATERIALS AND METHODS

A descriptive research design was used to investigate the feasibility of a remote ABPM diagnostic service using a telemedicine platform. The multicenter, cross-sectional descriptive study was carried out between August 2023 and March 2024 in 10 regional public hospitals country-wide without cardiology services in the health regions of the MSPBS. The reporting of this study conforms to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement: guidelines for reporting observational cross-sectional studies. The completed checklist, as a supplementary file, can be found as Annex 1, according to Enhancing the QUALity and Transparency Of health Research.

The diagnosis and remote monitoring of patients with arterial hypertension were performed using the following technological components, following the specific data collection protocol for each component to avoid potential sources of bias:

- The device for ambulatory blood pressure monitoring (ABPM) was used to record all information on blood pressure curves at regular intervals for 24 hours—every 30 minutes during the day and every 60 minutes at night—in hypertensive patients who attended the 10 public regional hospitals of the MSPBS. The ABPM and the management of the recordings of the pressure curves were carried out with an exclusive computer where the digital recordings were downloaded in the device's proprietary format and then processed with proprietary software and stored in the database through a web application. The measuring devices (ABPM)

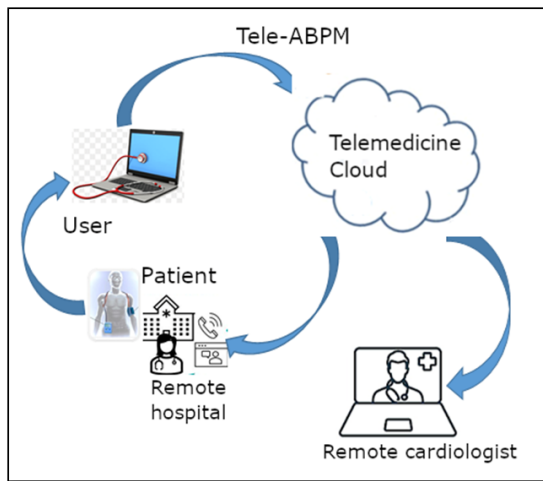
used in the study were validated according to the protocol of the European Society of Hypertension.<sup>6</sup> The ABPM devices used were from a single manufacturer (Eccosur, model MP260, manufacturing year 2022, [www.eccosur.com](http://www.eccosur.com)). The measurements of the blood pressure have a precision of  $\pm 5$  mmHg for systolic (60–230 mmHg) and diastolic (40–130 mmHg) pressure with a 95% confidence interval.

- The telemedicine system, based on information and communication technology (ICT) tools, was used to send digital records of the blood pressure curves obtained by the ABPM device in the 10 regional hospitals of the Tele-ABPM network. The patient's clinical data was attached to the recording of the blood pressure curves through an electronic chart that the telemedicine technician then sends encrypted (SSL type) to the telemedicine platform hosted in the cloud. The digital technology used for the transmission of the images is called store & forward, in which, once the blood pressure curves have been obtained, the patient's electronic record module (web application) is executed for the patient's clinical data and blood pressure curves collection. The communication of the results of diagnosis, monitoring, and control from the remote cardiologists to the doctors responsible for the patient's treatment was carried out through the same telemedicine platform.

The strategy for the diagnosis, monitoring, and control of patients with arterial hypertension was carried out in the following sequence, see Figure 1:

- All patients who met the inclusion criteria underwent ABPM by telemedicine technicians (remote) according to the protocol for recording blood pressure curves established by cardiologists in the 10 hospitals of the Tele-ABPM network, which were also regional referral hospitals for ABPM.
- The cardiologists of the telemedicine diagnosis, monitoring, and control service downloaded the blood pressure curve records from the platform along with the patient's clinical data and carried out the corresponding diagnosis, monitoring, and control in a predefined and standardized format.

- The remote cardiologist's diagnosis, monitoring, and control report was then sent to the attending physician of the hospital where the patient was being treated via the telemedicine platform. Depending on the severity of the pathology, the patient was referred to a specialized cardiology hospital or to its outpatient clinic to receive antihypertensive treatment.



**FIGURE 1.** Implementation steps for the data transmission process of Tele-ABPM.

### Inclusion Criteria

Patients with suspected or confirmed elevated blood pressure, especially those with unstable blood pressure or suffering from the white coat phenomenon or masked hypertension, were included. Hospitals without cardiology services were selected to recruit patients.

### Exclusion Criteria

Patients with signs and symptoms that were not compatible with high blood pressure.

### Population

Patients with arterial hypertension of varying severity, with a medical request for diagnosis by ABPM, were included. Patient recruitment was carried out through outpatient consultations and emergency services in the 10 regional hospitals of the MSPBS Tele-ABPM network, using a prospective sequential sampling strategy to reach the study size.

### Statistical Analysis

According to the study population, design, factor of interest, and results, descriptive statistics (figures) were used to present the data of the studied population. For quantitative and qualitative variables, statistical methods such as frequency distribution, trends, dispersion, averages, and comparisons, among others, were used to analyze the outcomes. To avoid or control confounding and missing data, a consistency check was performed according to a data collection protocol. Interactions of data subgroups and sensitivity analyses were conducted using an analysis protocol defined by the cardiologists of the Cardiovascular Prevention Institute of the MSPBS.

### Ethical and Confidentiality Issues

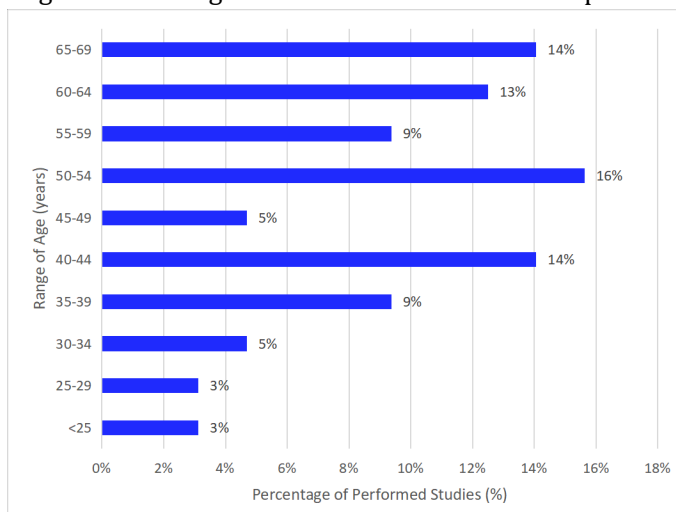
Prior to the study, all patients were informed about its purpose and informed consent was obtained. To ensure the confidentiality of the information, as well as its integrity and consistency, security mechanisms were used in the telemedicine platform, including controlled access to the system (username and password), prioritized queries by type of user, encrypted databases, encrypted communication such as secure sockets layer (SSL), encryption keys, and encryption protocols that provide secure communication. The research protocol was approved by the scientific and ethical committees of the Institute for Research in Health Sciences of the National University of Asunción; the ethics committee approval number is P38/2020.

### Satisfaction Survey

To measure the usefulness and satisfaction with the technological innovation implemented in this study, a semi-structured online satisfaction survey was administered to users. A scale from 1 to 5 was used, with 1 being very poor and 5 being excellent. The 5 cardiologists reporting ABPM (100%), the 10 telemedicine technicians (100%)—including radiology technicians, nurses, and nursing assistants who worked as telemedicine technicians—and all patients diagnosed by this innovative remote service were surveyed.

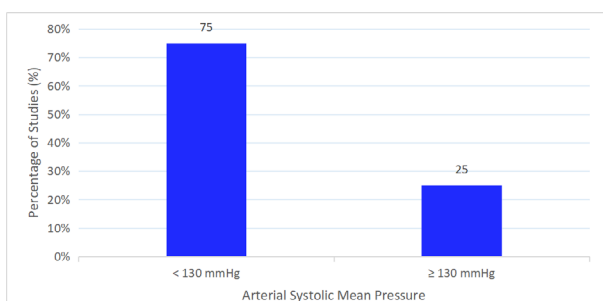
## RESULTS

Sixty-four patients with high cardiovascular risk were diagnosed in 10 hospitals nationwide. Most patients were between 50 and 54 years old, followed by the age groups 40 to 44 and 65 to 69 years, as shown in Figure 2. The average age was 54 years; 53.4% were male. The most frequent findings were hypertension (50%), uncontrolled hypertension (40%), and normal blood pressure (10%). An average of 40% adherence to antihypertensive treatment among patients diagnosed with hypertension was determined by the National Cardiovascular Prevention Program according to their established treatment protocol.



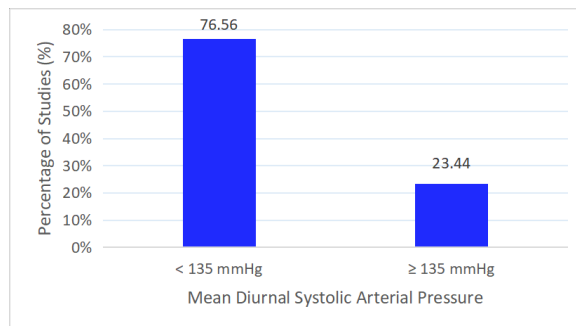
**FIGURE 2.** Age range of patients diagnosed by ABPM ( $n = 64$ ).

The hemodynamic parameters determined and assessed by ABPM over 24 hours in the present study for mean systolic arterial pressure were as follows (Figure 3): 20.3% hypertension and 79.7% normal blood pressure. For mean diastolic blood pressure, 32.8% had hypertension and 67.2% had normal blood pressure.



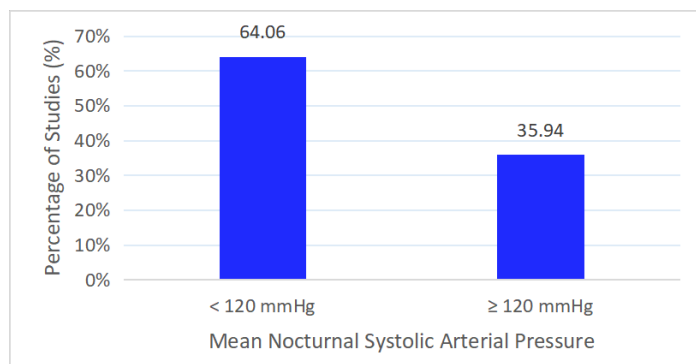
**FIGURE 3.** Mean systolic (24 hours) arterial pressure diagnosed by ABPM ( $n = 64$ ).

For the mean diurnal systolic arterial pressure (Figure 4), 23.4% had hypertension and 76.6% had normal blood pressure. For the mean diurnal diastolic arterial pressure, 28.1% had hypertension and 71.9% had normal blood pressure.



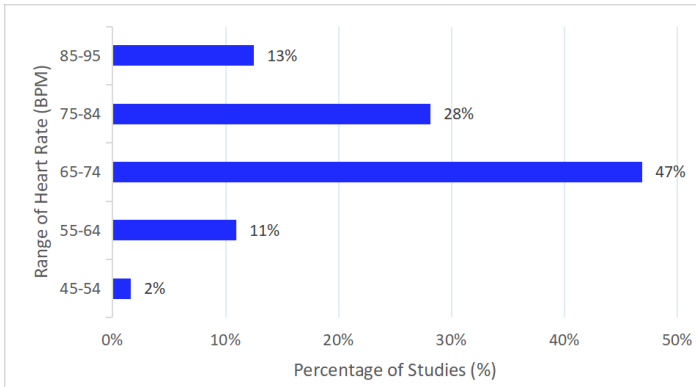
**FIGURE 4.** Mean diurnal systolic arterial pressure diagnosed by ABPM ( $n = 64$ ).

For the mean nocturnal systolic arterial pressure (Figure 5), 35.9% had hypertension and 64.1% had normal blood pressure. For the mean nocturnal diastolic blood pressure, 60.9% had hypertension and 39.1% had normal blood pressure.



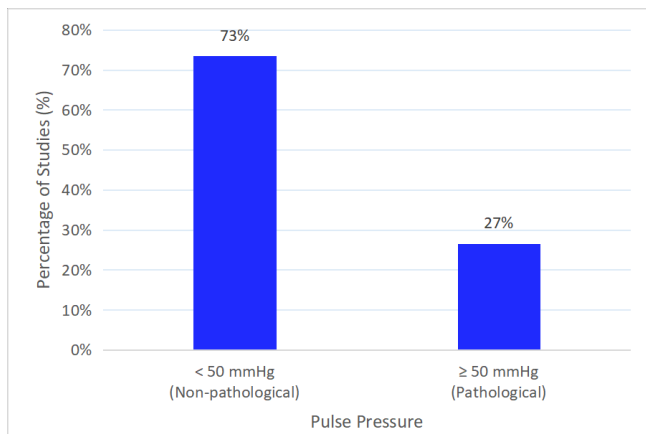
**FIGURE 5.** Mean nocturnal systolic arterial pressure diagnosed by ABPM ( $n = 64$ ).

The heart rate range (Figure 6) was 47.0% between 65–74 bpm and 28.0% between 75–84 bpm. The percentage of systolic burden was 35.9% pathological and 64.1% non-pathological. The percentage of diastolic burden was 39.1% pathological and 60.9% non-pathological.



**FIGURE 6.** Heart rate range diagnosed by ABPM ( $n = 64$ ).

Pulse pressure (Figure 7) was 27.0% pathological and 73.0% non-pathological. Among the main reasons for performing ambulatory blood pressure monitoring were arterial hypertension (40.6%), chest pain (17.2%), white coat hypertension (4.7%), dyspnea (3.1%), masked hypertension (1.6%), and uncontrolled hypertension (1.6%).



**FIGURE 7.** Pulse pressure of patients diagnosed by ABPM ( $n = 64$ ).

### Satisfaction with the Remote Diagnostic Service

The degree of satisfaction expressed by patients using the Tele-ABPM service regarding the care received from remote specialists was rated as “excellent” by 94.6%. Additionally, all reporting physicians and telemedicine technicians stated that they “agreed” (62.5%) or “strongly agreed” (37.5%)—the highest rating—with the ease of use and quality of care offered by the Tele-ABPM system. Among the most frequent complaints reported by patients were sweating of the arm with the bracelet (40.0%) and

difficulty falling asleep due to the inflation of the bracelet (40.0%). For the reporting technicians and physicians, the most common difficulties were internet service instability (13.0%), disconnection of the ABPM bracelet tubing during measurements (7.0%), and limitations in using computer tools (3.0%). Missing data were identified in 7.0% of all patients, mainly due to disconnection of the ABPM bracelet during the measurement process, particularly overnight.

### DISCUSSION

Taking into account the high prevalence of arterial hypertension in the country<sup>2</sup> and the need for a system that is accessible and universally available within the public services of the MSPBS for the diagnosis, monitoring, and control of high-risk hypertensive patients, the ABPM method was used in the present study because it is the most widely recommended<sup>5,7</sup> for detecting, recording, and analyzing variations in blood pressure, pulse pressure, heart rate, and the dipper phenomenon.<sup>5,8,9</sup> The dipper phenomenon refers to the variations observed when evaluating the percentage ratio between the average blood pressure during sleep and the average blood pressure during wakefulness. A patient is considered a dipper, or having a nocturnal drop in blood pressure, when there is a decrease greater than or equal to 10% in systolic and/or diastolic blood pressure during sleep compared to wakefulness.

In this study, 58 patients with high cardiovascular risk were identified using the ABPM device, which is recommended by several national and international institutions<sup>4-6,10,11</sup> for confirming diagnosis, monitoring hypertension, and evaluating the effectiveness of pharmacological treatment. The diagnostic model developed and applied in this feasibility study combined the ABPM device with telemedicine tools, representing an innovative and disruptive approach for the country’s public health. This approach offers technology considered the gold standard for diagnosing arterial hypertension, making it feasibly accessible to the population and universally covered across health regions through the MSPBS telemedicine platform.<sup>12</sup> One of the major advantages of this technological innovation is its potential to anticipate serious cardiovascular

events and enable timely interventions to prevent them. Based on the results obtained, health authorities adopted a proactive stance to control arterial hypertension in the studied population by providing free antihypertensive medication within the service areas of the Tele-ABPM units implemented in the 10 regional hospitals. This strategy was utilized by the Cardiovascular Prevention Institute of the Ministry of Health to improve treatment adherence among hypertensive patients.

The hemodynamic parameters determined and assessed in this study through ABPM are consistent with findings from similar research and hold diagnostic significance according to scientific literature. Specifically, the pulse pressure differential (the difference between systolic and diastolic pressure) is considered an indirect predictor of adverse cardiovascular and cerebrovascular outcomes,<sup>5,13-16</sup> which are attributed to arterial stiffness. In this context, other studies have found that untreated hypertensive patients exhibiting the dipper phenomenon have higher arterial stiffness compared to non-dipper patients, with stiffness values inversely related to nocturnal decreases in blood pressure.<sup>5,17,18</sup> Additionally, research has identified pulse pressure variability, dipper status, and systolic and diastolic blood pressure as independent predictors of arterial stiffness.<sup>5,19</sup>

Patients rated the accessibility of this diagnostic method within their communities very positively. Regarding the usability of the ABPM system, the main complaints were sweating under the bracelet and the annoying noise caused by the periodic inflation of the device's cuff.<sup>20-22</sup> For telemedicine technicians and physicians, the primary advantages included the ease of use of the Tele-ABPM web application. The most frequently reported challenges were internet service instability, disconnection of the ABPM cuff during measurements, and limitations in using computer tools. The satisfaction survey results from this study aim to provide valuable feedback from both patients and technical users to enhance the Tele-ABPM system's usability and align with findings from similar studies.<sup>20-22</sup>

As with any patient diagnostic system, Tele-ABPM has both advantages and disadvantages. Among the advantages, three stand out: 1) Ambulatory blood pressure monitoring (ABPM) is recommended for patients with elevated or unstable blood pressure, including those experiencing the white coat phenomenon or masked hypertension; 2) The ABPM device is essential for diagnosing and monitoring hypertension in patients with fluctuating blood pressures; 3) It enables measurement of blood pressure variations throughout different times and daily activities. Regarding disadvantages, four points are notable: 1) Clinical use of ABPM is limited by factors such as device cost, accessibility, and the need for basic training for both physicians and patients; 2) Serious risks from ambulatory blood pressure monitoring are rare; 3) Minor side effects reported include pain or discomfort (9%), skin irritation (8%), noise from the device (8%), and inconvenience at work (3%); 4) A minority of patients report sleep disturbances, although the vast majority eventually adapt to the monitor.

The results of this pilot study are very promising, as they enable cross-referencing of hemodynamic parameters to assess the indirect predictive capacity of factors such as dipper status, pulse pressure variability, and others for adverse cardiovascular and cerebrovascular outcomes. Consequently, it can be concluded that this innovative combination of the ABPM device with telemedicine has the potential to mitigate the limited availability of adequately equipped cardiology centers and specialized staff to meet demand. However, data saturation (sample size) was not reached in this study, and a larger sample size will be necessary to validate and generalize these findings. The results are consistent with similar research.<sup>22,23</sup> This is especially important for public hospitals without cardiology services, as it offers a viable alternative to optimize the use of scarce human and technological resources, while promoting equity and universal access to advanced diagnostic technologies in low-income countries such as Paraguay. These findings suggest that it is possible to overcome the socioeconomic barriers that currently limit the widespread use of such technologies in resource-constrained settings.<sup>23-27</sup> Additionally, this innovative approach provides important benefits to patients, including early diagnosis and timely treatment,

which helps avoid unnecessary transfers of patients at high cardiovascular and cerebrovascular risk.<sup>25</sup> It is expected that an increase in the number of diagnosed and subsequently treated patients will translate into clinical benefits and overall population health improvements.<sup>26</sup> However, the real impact of this intervention on patient health outcomes will be assessed in a planned future study focused on clinical endpoints. Moreover, this approach reduces out-of-pocket expenses for patients by minimizing transfers, easing overcrowding in specialized centers, and optimizing the limited resources available within public hospitals.

Among the main limitations of this study are the limited number of ABPM devices available in district hospitals and health centers, as well as the scarcity of research focused on improving the scientific evidence regarding the classification of hypertensive patients into phenotypic groups within the country, which is essential for enhancing cardiovascular and cerebrovascular prevention programs and enabling early intervention to prevent adverse events. The observed 40% adherence rate to antihypertensive treatment among patients is concerning and indicates a need for additional support mechanisms to improve adherence, especially in remote settings. Our findings suggest that the primary factor contributing to low adherence is the geographical distance between patients and treatment centers, which, according to the Ministry of Health's Cardiovascular Prevention Institute strategy, could be addressed by expanding Tele-ABPM services closer to rural and underserved communities.

## CONCLUSIONS

In this preliminary study, we aimed to improve the diagnosis, monitoring, and control of patients with high cardiovascular risk across 10 public hospitals in Paraguay without cardiology services by evaluating the feasibility of an innovative telematics approach using Ambulatory Blood Pressure Monitoring (ABPM) devices integrated with a telemedicine platform. Our results revealed a high prevalence of hypertension (50%), uncontrolled hypertension (40%), and normal blood pressure (10%)

among the studied population, with an average adherence to antihypertensive treatment of only 40%. Despite these challenges, the findings are encouraging as they suggest potential improvements in both patient outcomes and public health system efficiency through better resource optimization. Importantly, patient satisfaction with the Tele-ABPM service and care from remote specialists was rated as excellent, underscoring the promise of this technological innovation to enhance accessibility and management of hypertension in resource-limited settings.

This tool also holds significant potential for monitoring the progress of hypertensive patients undergoing antihypertensive treatment in remote communities with limited access to specialized healthcare professionals, particularly in middle- and low-income countries. Additionally, it could be valuable in higher-income countries, where healthcare resources might be reallocated to other pressing health programs. Nevertheless, to validate and generalize these promising findings, studies with larger sample sizes will be necessary.

## ANNEX

EQUATOR, <https://www.equator-network.org/reporting-guidelines/strobe/>. Retrieved July 5, 2024.

## AUTHOR CONTRIBUTIONS

Conceptualization, P.G. and E.H.; Methodology, P.G. and E.H.; Software, S.S.; Validation, P.G., J.O., S.S., and E.H.; Formal Analysis, P.G., J.O., and E.H.; Investigation, P.G. and E.H.; Resources, S.S. and M.B.; Data Curation, S.S.; Writing–Original Draft Preparation, P.G.; Writing–Review & Editing, E.H.; Visualization, S.S.; Supervision, M.B.; Project Administration, P.G.; Funding Acquisition, J.J.

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### CONFLICTS OF INTEREST

The authors declare no conflict of interest.

### FUNDING

The author(s) received no financial support for the research, authorship, and/or publication of this article.

### ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The research protocol was approved by the scientific and ethical committees of the Institute for Research in Health Sciences at the National University of Asunción, in accordance with the ethical principles of the Declaration of Helsinki. The ethics committee approval number is P38/2020.

### INFORMED CONSENT/PATIENT CONSENT

Before the study, all patients were informed about its purpose, and informed consent was obtained. To ensure the confidentiality, integrity, and consistency of the information, security mechanisms were implemented in the telemedicine platform.

### TRIAL REGISTRATION NUMBER/DATE

The research protocol was approved by the scientific and ethical committees of the Institute for Research in Health Sciences at the National University of Asunción (Approval No.: P38/2020).

### DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author, Dr. Pedro Galván.

### CONSENT FOR PUBLICATION

Before the study, all patients were informed about its purpose, and informed consent was obtained. To ensure the confidentiality, integrity, and consistency of the information, security mechanisms were implemented in the telemedicine platform.

### FURTHER DISCLOSURE

Not applicable.

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