International Journal of Cardiology xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

International Journal of Cardiology

journal homepage: www.elsevier.com/locate/ijcard

Short communication

# Cardiovascular screening in low-income settings using a novel 4-lead smartphone-based electrocardiograph (D-Heart®)☆

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ARTICLE INFO

*Article history:*
Received 29 October 2016
Accepted 7 February 2017
Available online xxxx

*Keywords:*
mHealth
Low-income settings
Portable electrocardiograph
Telemedicine

ABSTRACT

*Background:* MHealth technologies are revolutionizing cardiovascular medicine. However, a low-cost, user-friendly smartphone-based electrocardiograph is still lacking. D-Heart® is a portable device that enables the acquisition of the ECG on multiple leads which streams via Bluetooth to any smartphone. Because of the potential impact of this technology in low-income settings, we determined the accuracy of D-Heart® tracings in the stratification of ECG morphological abnormalities, compared with 12-lead ECGs.
*Methods:* Consecutive African patients referred to the Ziguinchor Regional Hospital (Senegal) were enrolled (n = 117; 69 males, age 39 ± 11 years). D-Heart® recordings (3 peripheral leads plus V5) were obtained immediately followed by 12 lead ECGs and were assessed blindly by 2 independent observers. Global burden of ECG abnormalities was defined by a semi-quantitative score based on the sum of 9 criteria, identifying four classes of increasing severity.
*Results:* D-Heart® and 12-lead ECG tracings were respectively classified as: normal: 72 (61%) vs 69 (59%); mildly abnormal: 42 (36%) vs 45 (38%); moderately abnormal: 3 (3%) vs 3 (3%). None had markedly abnormal tracings. Cohen's weighted kappa ($k_w$) test demonstrated a concordance of 0,952 ($p < 0,001$, agreement 98,72%). Concordance was high as well for the Romhilt–Estes score ($k_w = 0,893$; $p < 0,001$ agreement 97,35%). PR and QRS intervals comparison with Bland-Altman method showed good accuracy for D-Heart® measurements (95% limit of agreement ±20 ms for PR and ±10 ms for QRS).
*Conclusions:* D-Heart® proved effective and accurate stratification of ECG abnormalities comparable to the 12-lead electrocardiographs, thereby opening new perspectives for low-cost community cardiovascular screening programs in low-income settings.



## 1. Introduction

Mobile health (mHealth) technologies are revolutionizing the practice of cardiovascular medicine. The global diffusion of smartphone devices is producing profound changes in diagnostics, as much relevant data could now be generated locally by the patient rather than centrally by providers [1]. While high-income countries remain at the forefront of developing the latest mobile technologies used in healthcare, the rate of penetration of such technologies in low- and middle-income countries has recently exceeded that of their wealthier neighbors [2]. In general,

☆ Dr. I. Olivotto is supported by the Ministry of Health, Italy: RF-2013-02356787 (Left ventricular hypertrophy in aortic valve disease and hypertrophic cardiomyopathy: genetic basis, biophysical correlates and viral therapy models), NET-2011-02347173 (Mechanisms and treatment of coronary microvascular dysfunction in patients with genetic or secondary left ventricular hypertrophy) and "Monitoraggio e prevenzione delle morti improvvise cardiache giovanili in Regione Toscana" Acronimo ToRSADE - Tuscany Registry of Sudden cArdiac DEath (Bando FAS Salute 2014).

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http://dx.doi.org/10.1016/j.ijcard.2017.02.027
0167-5273/

low- and middle-income countries have major restrictions on their healthcare capacities due to the lack of infrastructures, human resources and logistics. Smartphone technology may overcome several of these limitations by providing an easy and affordable access to accurate diagnostic and monitoring methods [2].

The importance of non-communicable diseases – and especially of cardiovascular related morbidity and mortality [3,4] – is rising steeply in low-income countries, unmasking new unmet needs for risk assessment and early diagnosis [5]. In such setting, widespread availability of accurate ECG screening would represent a major step in the right direction [6,7]. However, a low-cost, user-friendly smartphone-based electrocardiograph, enabling the acquisition of multiple lead electrocardiograms (ECG) with a reliability comparable to the standard ECG, is still lacking. D-Heart® electrocardiograph has been recently developed with this specific aim, both for iOS and Android operative systems, enabling the acquisition of surface electrical signals through 5 electrodes, capturing 3 peripheral and 1 precordial lead (V5), and their transmission to the smartphone via Bluetooth technology (Fig. 1).

Because of the potential impact of such technology in low-income countries, we performed a validation study of D-Heart® in a community hospital in Senegal, comparing the accuracy of D-Heart® tracings for the stratification of ECG morphological abnormalities compared with a standard 12-lead technique.

## 2. Methods

### 2.1. Study population

Consecutive patients referred at the Ziguinchor Regional Hospital (Senegal) for routine medical evaluation at Radiology, Medicine and Surgical Departments were enrolled from January to February 2016. The study was undertaken in the setting of the cooperation program set by the Center for International Cooperation and Development (CICOPS) of the University of Pavia, Italy.

### 2.2. ECGs acquisition

D-Heart® and 12-lead recordings were subsequently obtained (within 2–5 min) in each subject. Severity of ECG abnormalities was defined by a semi-quantitative score based on the sum of 9 criteria (based on reference 8): abnormal cardiac rhythm, QRS duration ≥ 100 ms, Romhilt–Estes (R-E) score ≥ 5, fascicular block and/or bundle-branch block, ST-T abnormalities, ST-T segment elevation ≥ 0.2 mV, prolonged QTc interval, pathological Q waves and absence of normal Q wave. Four ECG groups were identified: normal (0 criteria); mildly abnormal (1–3 criteria); moderately abnormal (4–6 criteria); markedly abnormal (7–9 criteria).

ECGs from D-heart® were assessed by two independent observers (J.I. and N.M.) that categorized in a separate database the ECG abnormalities, whereas two other independent observers (A.F. and M.T.) analyzed the tracings from standard electrocardiograph.

### 2.3. D-Heart® smartphone electrocardiograph technology

The D-Heart® device was conceptualized by N.M. and N.B. as a device for electrocardiographic screening in low income settings. It's is constituted by a battery-powered device for ECG measurement on multiple leads (3 peripherals and one precordial (V5)) connected through the use of Bluetooth low energy to a smartphone. The device was created for the electrocardiographic measurement allowing the user to perform a measurement of up to 8 leads. The front end is constituted by 3 Sigma Delta modulators able to sample the ECG signal and then filter the signal in a digital way. The module Bluetooth Low Energy is able to send data to the smartphone or Tablet deputy to the ECG signal display, whereas Lithium battery ensures the functionality during measurement. The actual components of the device offer a manufacturing price of <35 $ per unit.

The sample was described by means of the usual descriptive statistics: for continuous variables by mean, standard deviation or median and interquartile range, when appropriate and for categorical variables by proportions. The concordance between D-Heart® and standard 12 lead electrocardiographs was assessed by:

- the weighted $k_w$-Cohen index, with its relative significance, taking as the endpoint variable the ECG group;
- the Bland-Altman method, with a 95% confidence level, for the PR and QRS interval measurements. Since differences between the two measurements did not follow a normal distribution, a non-parametric approach (median value and 2.5^ and 97.5^ percentiles) was used to determine the limits of agreement.

p values were two-sided and considered significant at the 0.05 level. All analyses were performed using SPSS/for Windows, version 20.

## 3. Results

The study enrolled 117 patients of African origin (69 males, mean age 39 ± 11 years) with a mean blood pressure of 119 ± 21/78 ± 9 mm Hg. Eight (7%) patients had a diagnosis of hypertension, whereas

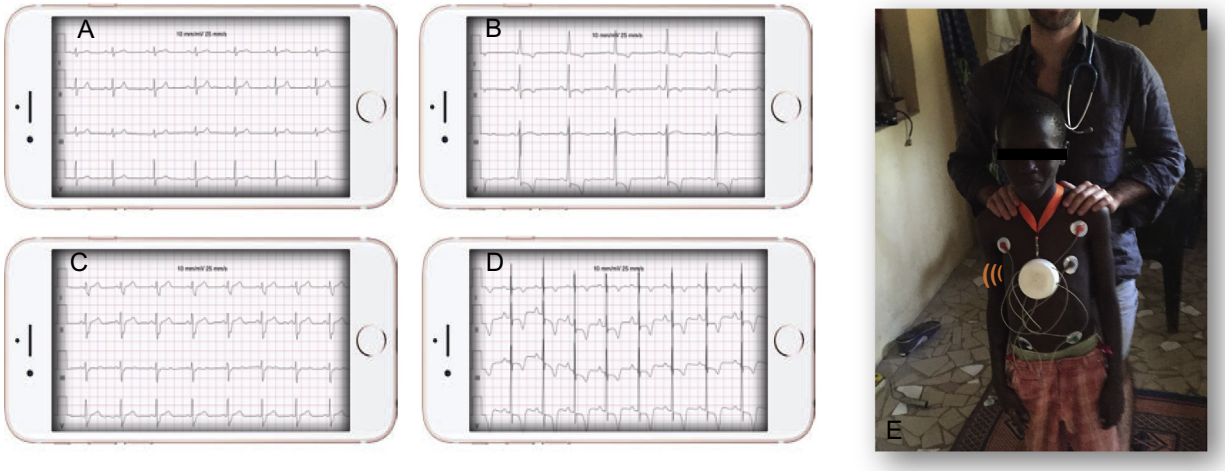


**Fig. 1.** D-Heart system configuration. Panels A, B, C and D represent different ECGs from D-Heart as displayed on the smartphone. Panel E shows a pediatric patient wearing D-Heart Device.

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5 (4%) presented a history of coronary artery disease. D-Heart® and Twelve-lead ECG tracings were respectively classified as: normal: 72 (61%) vs 69 (59%); mildly abnormal ECG: 42 (36%) vs 45 (38%); moderately abnormal ECG: 3 (3%) vs 3 (3%).

Agreement was obtained in 116/117 (99%) cases with D-Heart tracings and in 115/117 cases with 12-lead ECGs. When there was disagreement, ECGs, both from D-Heart and standard 12 lead electrocardiograph, were adjudicated by an independent observer (I.O.). Weighted Cohen's kappa ($k_w$) test showed a concordance of 0,952 ($p < 0{,}001$) with an agreement of 98,72% between the two techniques. Thus, while the 12-lead ECG was – as expected - more sensitive for mild abnormalities, there was a 100% concordance for the moderately abnormal tracings.

Of note, concordance was also high for the Romhilt–Estes score ($k_w = 0{,}893$; $p < 0{,}001$). Comparison of PR and QRS intervals (Bland-Altman method, non-parametric approach) showed excellent concordance for D-Heart® measurements (95% limit of agreement −20 to +20 ms for PR and −10 to +10 ms for QRS).

## 4. Discussion

Cardiovascular diseases (CVD) are an emerging threat to populations of low-income countries. It is estimated that, in 2013, CVD accounted for >40% of all causes of death in sub-Saharan Africa [9]. Concomitantly, these areas are affected by dramatic shortage of health professionals who are mainly concentrated in urban areas, while 60% of the patients still live in rural settings [6]. In a country such as Cameroon, there is one cardiologist every 50,000 inhabitants, compared with the EU standard of 1 every 500 [10]. Telemedicine is an appealing alternative to direct access to medical structures, by providing easy and affordable access to specialist care and reducing the need for rural patients to travel for health-related issues [11].

Additionally, telemedicine may play a pivotal role in reducing healthcare costs in low-income settings, for both the patients and the hospital facilities, including a >70% cost reduction in the setting of obstetrics and cardiology services [12]. Lastly, telemedicine opens the possibility for international cross-border services, aimed at managing and reporting the enormous amount of data acquired, as well as at linking global (remote) experts with local health workers [11].

Several smartphone based electrocardiographs are commercially available, such as AliveCor or Cardiosecur, but both are mostly intended for rhythm analysis rather than morphological interpretation, thus unsuitable for electrocardiographic population screening in low income settings. In the present study, the potential role of the D-Heart® device was evaluated in the only hospital present in Casamance, the Southern region of Senegal. The cardiology center at Ziguinchor Regional Hospital serves a region expanding on a total surface of 28,350 $km^2$. Basic health services to the population are delivered via 8 Community Health Centers and 12 Service Pharmacies. Although D-Heart allows immediate and on site interpretation of the electrocardiogram and therefore is not solely intended for telemedicine purposes, its potential for telemedicine is obvious and relevant. The present device validation study might lay the foundation for future telemedical screening protocols aimed to improve the appropriateness and efficacy of referral to specialized medical care. Potential benefits range from early diagnosis of acute heart conditions to screening of high-risk populations, to remote monitoring of known chronic conditions.

Despite the many ways in which telemedicine may transform healthcare for the better, mHealth faces a number of major challenges. Specifically, the validation of novel technologies represents a critical step in our understanding of whether they can substitute or implement current used methodologies [13–15]. With this aim, we assessed the accuracy of the D-Heart® electrocardiograph, demonstrating that tracings obtained from smartphones may compare favorably with the current gold standard 12-lead in identifying ECG abnormalities. D-Heart was originally conceived based on the evidence that a system with 5 electrodes (3 peripheral leads plus V5), had a 95% sensitivity compared with a 12-lead tracings in conventional recordings [16]. However, since the 12-lead ECG was found to be more sensitive in identifying minor ECG abnormalities, we decided to improve the clinical accuracy of D-Heart. Particularly, since the 3 mildly abnormal tracings mislabeled by D-Heart® were misclassified because of the lack of specificity for Left Ventricular Hypertrophy (LVH) Criteria we decided to derive the augmented leads (aVL, aVF and aVR) and insert an additional precordial electrode (V2) to explore more reliably the anterior territories of the heart and enable the correct identification of LVH.

Of note, the present study was based on a low-risk patient cohort, with limited prevalence of abnormal tracings, as would be expected in a young community-based African population.

## 5. Conclusions

D-Heart® ECGs proved accurate, allowing a stratification of ECG abnormalities comparable to the standard 12-lead ECG in a low-income setting. Novel smartphone-based techniques open promising perspectives for low-cost cardiovascular screening programs. Further studies are clearly needed to assess if these theoretical advantages are supported by patient-centered outcomes and positive cost-benefit analysis.

## Conflict of interest

Niccolò Maurizi and Nicolò Briante are the co-founders of the social innovative start-up D-Heart.

## Acknowledgments

Essential contribution to the development of the hardware and software of D-Heart device was given by Niccolò Maurizi, Nicolò Briante.

Screening procedures in Senegal have been carried out by Niccolò Maurizi, Alessandro Faragli, Jacopo F. Imberti, Fulvio Avvantaggiato and Gian Battista Parigi.

Patients were enrolled from Amadou Sall and Abibou Cisse outpatient clinics (Dept. of Radiology, Medicine and Surgery of Regional Hospital of Ziguichor, Casamance, Senegal).

Data analysis was carried out by Niccolò Maurizi, Alessandro Faragli, Jacopo Imberti, Iacopo Olivotto, Mattia Targetti and Katia Baldini.

Statistical support was provided by Biostatistic Department of the University of Pavia, particularly by Francesca Gigli Berzolari and Paola Borrelli.

Manuscript conceptualization and writing has been provided by Niccolò Maurizi, Iacopo Olivotto, Franco Cecchi, Niccolò Marchionni and Stefano Perlini.

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# Feasibility of cardiovascular screening in low-income settings using smartphone-based technologies

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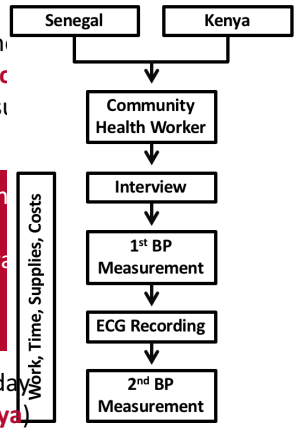
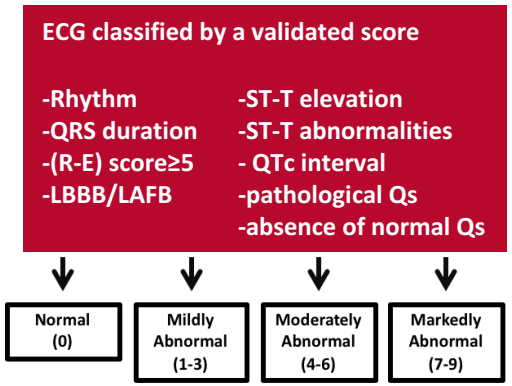
**Introduction.** Mobile health (**m-Health**) technologies revolutionizing cardiovascular (CV) medicine. However, m than 80% of heart disease related deaths occur in **lo income settings**, that are unable to take advantage of su innovations for healthcare awareness and prevention.

**Purpose.** To assess the feasibility of a pilot CV screen campaign with smartphone based m-health devices:
-D-Heart®, a validated low-cost 8-lead electrocardiogra (199€)
-iHealth® blood pressure (BP) recorder (~70€)

**Methods.** A total of 231 patients were enrolled in a two-da screening at 4 rural dispensaries, 2 in Kitui District (**Kenya**) and 2 in Ziguinchor District (**Senegal**).



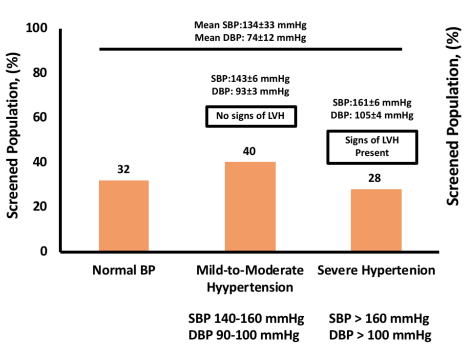




**Figure 1.** Blood Pressure mesaurment results

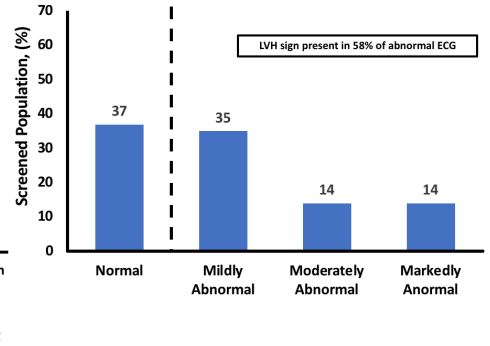



**Figure 2.** ECG Screening results

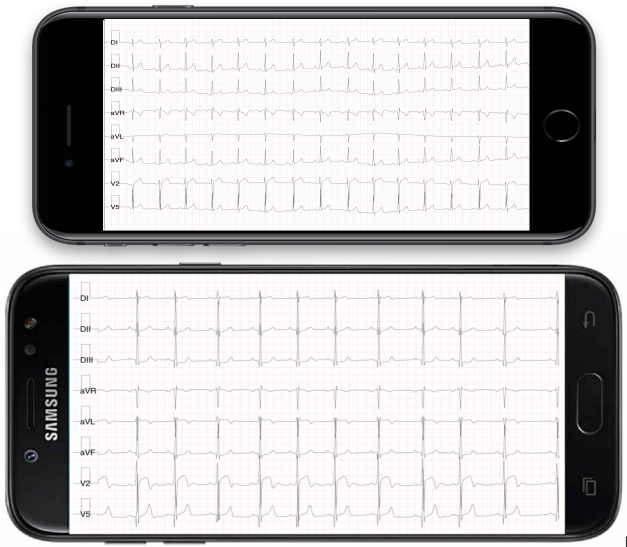



**Figure 3.** Samples of D-Heart ECGs recorded

**Results.** Clinical characteristics of the 231 patients are summarized in **Table 1, Figure 1 and Figure 2.**

**Table 1. Baseline characteristics of the screened population**

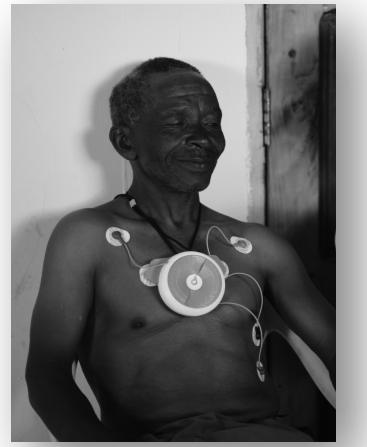
| | Overall | Men | Women | p |
|---|---|---|---|---|
| **Demographics** | | | | |
| Population – N, (%) | 231 | 121 (52) | 110 (48) | |
| Age | 36±21 | 41±17 | 32±12 | <0.01 |
| BMI | 24±2.9 | 22.3±1.5 | 27.2±1.1 | <0.01 |
| **CV risk Factors** | | | | |
| Smoking Hx – N, (%) | 78 (34) | 60 (50) | 18 (16) | <0.01 |
| Alcohol (>2.5 U/day) – N, (%) | 92 (40%) | 67 (55) | 37 (33) | <0.01 |
| HTN Hx – N, (%) | 11(5) | 5 (4) | 6 (5) | ns |
| Diabetes Mellitus | 15 | 7 (6) | 8 (7) | ns |
| **Previous AMI** | 3 (1) | 2 (2) | 1 (1) | ns |

**71% never had BP measured before**

**91% never had ECG recording before**

**Cost-Effectiveness Analysis.** Taking into account:
-device price
-consumables
-salaries
-USB solar powered technology
-visit time (6±2 minutes).

**€1.10/patient**
- **€0.80 for community health worker**
- **€0.30 for consumables**



**Conclusions.** D-Heart® ECG screening combined with smartphone BP measurement proved **efficient** and **cost-effective**. This should encourage to develop low-cost/high-technology community-based CV screening programmes in low-income settings.

**Disclosures**. Dr. Fumagalli was awarded a research grant from D-Heart Srl in December 2017