

WHAT'S NEW IN INTENSIVE CARE



Is your smartphone the future of physiologic monitoring?

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Introduction

Smartphones are ubiquitous devices, and over 100,000 digital applications (apps) have already been developed for health and medicine [1]. Most apps have been designed for patients to prevent cardiovascular diseases by promoting weight loss, physical activity and smoking cessation and to improve treatment adherence. Several studies have reported short-term benefits [1]. Interestingly, smartphones can also be used to monitor and record physiologic information, either as stand-alone devices or when connected to specific sensors. In this short narrative review, we focus on medical-grade tools and applications that may have value in acute care situations.

Tools for clinicians

Auscultation can be digitized by smartphones. A phone case including a stethoscope membrane is used to direct the sound to the microphone of the smartphone, and a dedicated app displays visual information as old phonocardiograms would do (Fig. 1b). Such tools may provide useful help for non-cardiologists and in noisy environments (e.g., in a mechanically ventilated patient in a busy ICU). The development of smart algorithms could lead to the “Shazam-like” identification of abnormal heart and lung sounds.

Ultrasound evaluations are also possible with a smartphone. Several echo probes—some are wireless—have been developed to transmit images to smartphones (Fig. 1g). As of today, they do not include pulsed or continuous Doppler functionalities. But in the ambulance, in the emergency department or on the wards, they may

help clinicians and rapid response teams to better understand the root cause of cardiorespiratory instability (pericardial effusion, right or left ventricular dysfunction) and to detect other disorders (pleural effusion, B lines, abdominal fluid).

A recent study [2] investigated the ability of an app to assess the left ventricular ejection fraction (LVEF) with the smartphone camera positioned on the carotid artery. A signal was captured from skin displacement images during the cardiac cycle and analyzed to extract hidden oscillations (a.k.a. intrinsic frequencies) from which the LVEF was computed. A significant correlation ($r=0.74$) with reference MRI measurements was reported. However, the agreement between the two methods was moderate (limits of agreements $\pm 19\%$), and half of patients with an LVEF $< 40\%$ were not detected by the app [3].

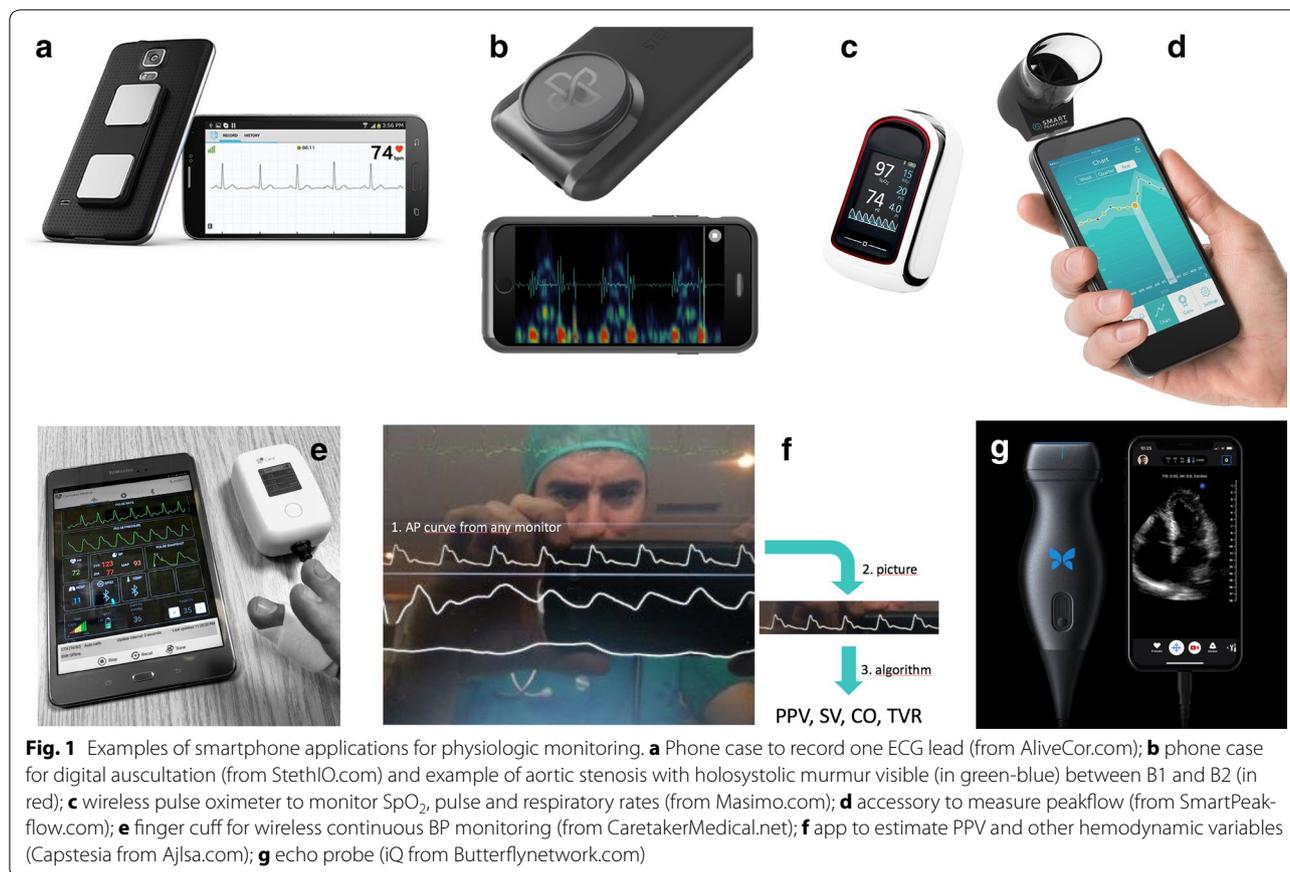
In patients wearing a low-pressure finger cuff connected to a piezoelectric wrist sensor, the pulse decomposition method enables the continuous recording of a blood pressure (BP) curve. This system is wireless, and the arterial pressure waveform can be displayed on a smartphone or an electronic tablet (Fig. 1e). Good agreement (bias 1 mmHg, precision 5 mmHg) with invasive radial measurements has been reported in surgical patients [4]. If future studies confirm these preliminary findings, such tool may have value in the operating room and also on the wards, where continuous monitoring of vital signs throughout the hospital stay may improve patient safety and decrease the number of ICU transfers [5].

In mechanically ventilated patients, the arterial pulse pressure variation (PPV) may be automatically quantified from the picture of the arterial pressure curve taken with a smartphone (Fig. 1f) [6, 7]. Whether the same method could be used with the appropriate pulse contour algorithm to compute stroke volume and cardiac output remains to be determined. It would certainly help to

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expand the use of cardiac output monitoring in the operating room and beyond.

Tools for (educated) patients

The use of the flashlight to illuminate the fingertip circulation enables the smartphone camera to record a peripheral pulse signal from which the pulse rate and pulse rate variability can be extracted. Several apps are able to detect cardiac arrhythmia and to authenticate atrial fibrillation [8]. One-lead ECG recordings are possible when using a dedicated phone case with two electrodes (Fig. 1a). Studies have shown they are reliable for diagnosing atrial fibrillation [9], measuring QT intervals [10] or detecting ST segment elevation [11]. The “oscilometric finger-pressing method” has recently been proposed to estimate BP from a smartphone. The fingertip presses on both the front camera and screen to increase the external pressure of the underlying artery, while the app measures the resulting blood volume oscillations via the camera and applied pressure via the strain gauge array under the screen [12]. An optical method to track changes in BP from the peripheral pulse signal obtained from a smartphone camera is also under development [13]. These BP monitoring methods are not yet approved

for medical use. In contrast, it is already possible to use wireless pulse oximeters (Fig. 1c), transmitting SpO₂, pulse and respiratory rate measurements to a smartphone used to display and track the information. Connected devices are also available to determine peak flow (Fig. 1d).

These tools and applications may give outpatients the opportunity to record physiologic signals when appropriate (e.g., authentication of atrial fibrillation in case of palpitations, one-lead ECG recording in case of acute chest pain). The ability to perform measurements from home and remotely share the information with clinicians may be useful to adapt therapy in patients who are deteriorating. Recorded trends of physiologic variables may also help clinicians to understand the course of the events the days or weeks preceding the hospital admission for a medical emergency.

Perspectives

We all have a smartphone in our pocket but do not use it often for clinical applications. This may change in the future given the increasing number of physiologic variables we can monitor with it or with connected sensors. Most tools and applications discussed in this article are

CE marked or cleared by the FDA for medical use. However, validation and usefulness studies remain scarce and are of course desirable before clinical adoption. Data protection and privacy are also an important requirement before encouraging patients and clinicians to use them.

Tools for patients may not be accessible to all, since appropriate understanding and education are mandatory. However, in selected patients, they may help to capture and authenticate physiologic events. Tools for clinicians have the potential to make their lives easier and clinical examination more objective and precise, echo probes having potential to replace the stethoscope in their pocket [14]. They may also be particularly useful in emerging countries where medical technologies are not always affordable and readily available [15].

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Compliance with ethical standards

Conflicts of interest

FM is the founder and managing director of MiCo, a Swiss consulting firm. MiCo does not sell any medical products, and FM does not own shares or receive royalties from any medtech company. BB is the co-founder of Galenic App. PS is the chief medical officer of Biospectral SA.

Received: 21 September 2018 Accepted: 15 October 2018

Published online: 19 October 2018

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