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Capstesia™: The smart hemodynamic monitor!

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ABSTRACT

Advanced hemodynamic monitoring can be both time and cost consuming in the perioperative period. Smartphones which have become an important part of our lives, can help circumvent this difficult situation with intelligent applications. Capstesia™ is a novel and promising application of smart phones in this direction. It can calculate the cardiac output, cardiac index, pulse pressure variation, and stroke volume resistance from a snapshot of the arterial pressure waveform. We hereby present a concise overview of it's usage, present limitations and future possibilities. Capstesia™ can be of immense utility in patient care and monitoring both in the operating room and the intensive care units.
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1. Introduction

In our unending quest for a novel and comprehensive hemodynamic monitor, there have been several innovations and inventions. A smartphone is now a universal accompaniment of most perioperative physicians. There have been numerous programs or applications which can be put to clinical use in this age of advanced scientific technology. Captesia™ is a promising step in this direction [1].

Most hemodynamic monitors use the principle of Fourier analysis. It involves summation of a series of sine waves (6–10) that are multiples or harmonics of the fundamental frequency (equals the heart rate). This provides a clinically acceptable replica of the intra arterial pressure waveform. It must be remembered that both the numerical value as well as the shape, timing and respiratory variations of the pulsatile arterial pressure waveform are important for interpretation of hemodynamic status. Capstesia™ is an innovative android smartphone application capable of instantaneous, point of care, calculation of Pulse Pressure Variation (PPV) from a digital image of the arterial line waveform displayed on the screen of a monitor of any make (Drager/Datex Ohmeda/Dell).

2. Discussion and procedural details

Limited availability or monetary considerations in acquiring and maintaining advanced hemodynamic monitors may deprive the patients and anesthesiologists of the valuable information obtained from their monitoring. PPV, Cardiac Output (CO), Cardiac Index (CI), Pulmonary Vascular Resistance (PVR) and the peak of the first derivative (dP/dt max) are the haemodynamic parameters measured by Capstesia™. Capstesia™ does not require initial calibration and is automatically updated. One time cost of 7900 euros for the Vigileo Flotrac cardiac output monitor plus 160 euros per patient for the disposable vigileo flotrac transducer versus just 5 euros a month for any number of uses in any number of patients for Capstesia makes Capstesia economically extremely attractive. Lack of access or prohibitively high cost of advanced hemodynamic monitors can deprive patients likely to benefit from advanced hemodynamic monitoring. Capstesia™ may prove to be a boon for such patients. The team that delivered Capstesia™ comprised Borja Barrachina (an Anesthesiologist), Oskar Alvarez (an IT programmer) and Pedro Berraondo (a Pharmacist).

Steps for perioperative usage of Captesia™ are summarized below

1. Radial artery cannulation after performing modified Allen's Test [2].

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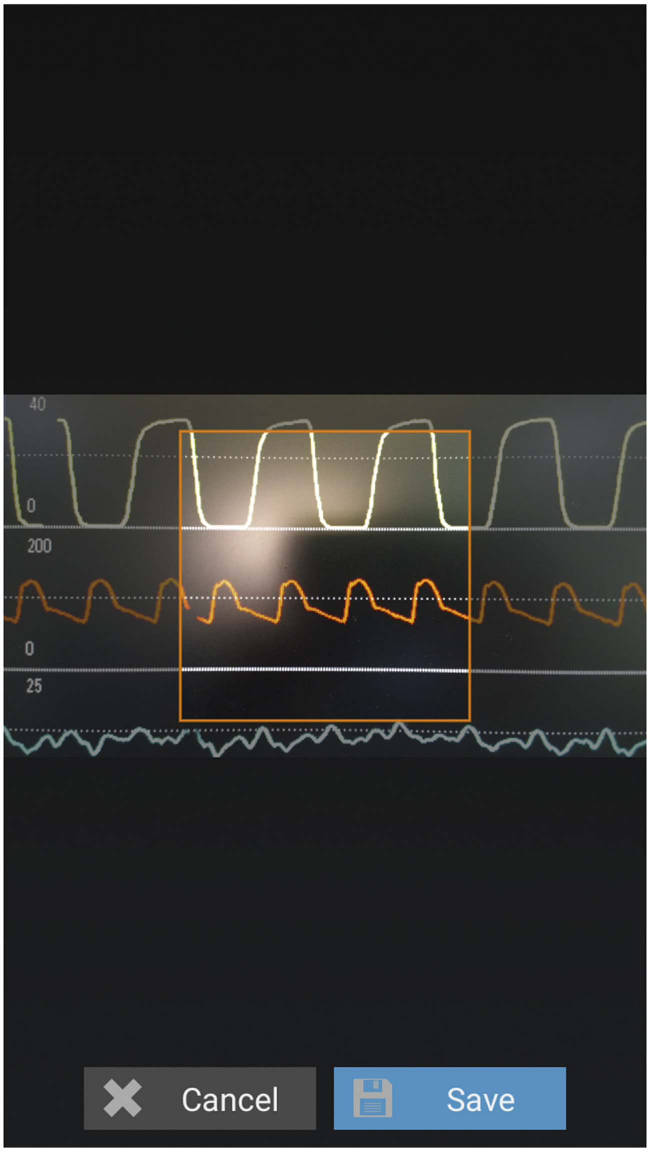

Fig. 1. Box used for cropping a portion of the signal to be analysed.

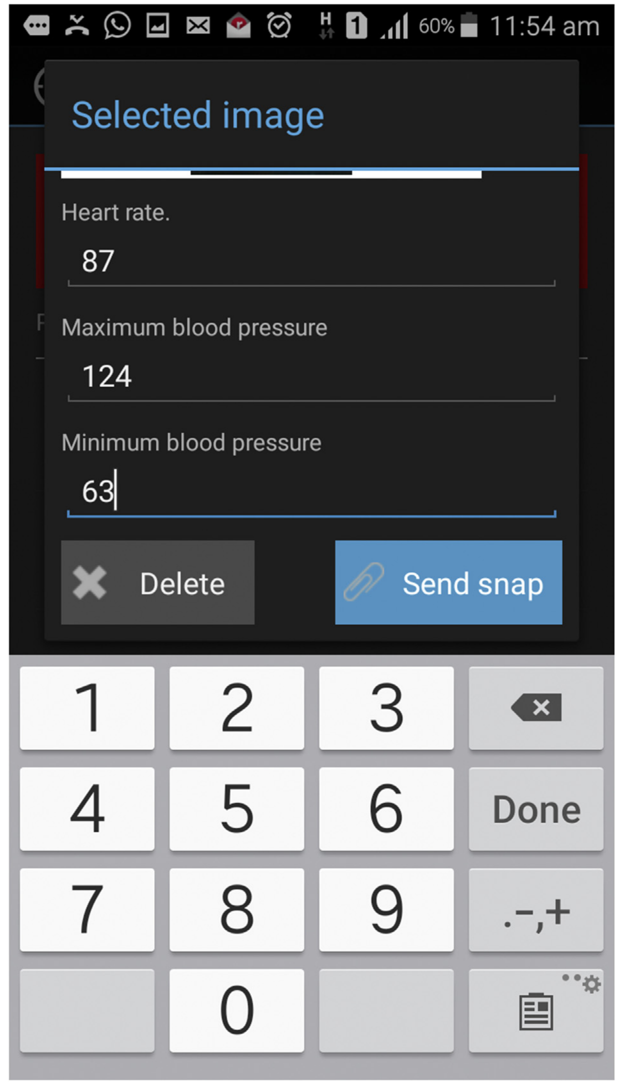

Fig. 2. Smartphone image displaying the entered instantaneous heart rate and blood pressure values.

2. All air bubbles/clots are to be meticulously removed from the fluid filled catheter system. (A small air bubble can lower the natural resonant frequency and cause the monitoring system to resonate, resulting in a false high systolic blood pressure. A large air bubble can cause excessive signal damping leading to spuriously low systolic blood pressure.)
3. The natural frequency and damping coefficient of the monitoring system are assessed from the arterial pressure artifact resulting from a fast flush test. (The time (distance) between adjacent pressure peaks determines the natural frequency and the amplitude ratio of adjacent peaks gives the damping coefficient)
4. The transducer connected to the fluid filled catheter system must be horizontally aligned with the upper fluid level in the vessel from which pressure is to be measured (zeroing).
5. Click a picture of the monitor screen displaying the patient's arterial pulse pressure waveform.
6. Crop the portion of signal to be analyzed by touching the edges of the box (Fig. 1).
7. Enter the instantaneous blood pressure and heart rate values in the smartphone (Fig. 2).
8. Capstesia™ quickly (within 2–5 seconds) digitalizes the signal and provides the PPV, CO and dP/dtmax values (Fig. 3). Cardiac index and stroke volume index can then be deduced by the smartphone in offline mode. If CVP values are entered into the smartphone then systemic vascular resistance (SVR) and systemic vascular resistance index (SVRI) can also be calculated offline. Option for trending the values is also available.

Even though it is too early to recommend the use of this application in all patients needing invasive arterial line monitoring, it is still a promising tool for easy hemodynamic monitoring. A study comparing accuracy of PPV obtained by Capstesia™ against standard manual determination of PPV showed a 10% reproducibility, a low measurement error of 9% and a low bias of 0.6%. 204 pairs of data at different sweep speeds (6–12mm/sec), pulse pressure (30,45 and 60 mmHg), respiratory rates 10–15 breaths/min and pulse pressure variation values (2–24%) were studied to reach this conclusion [1].

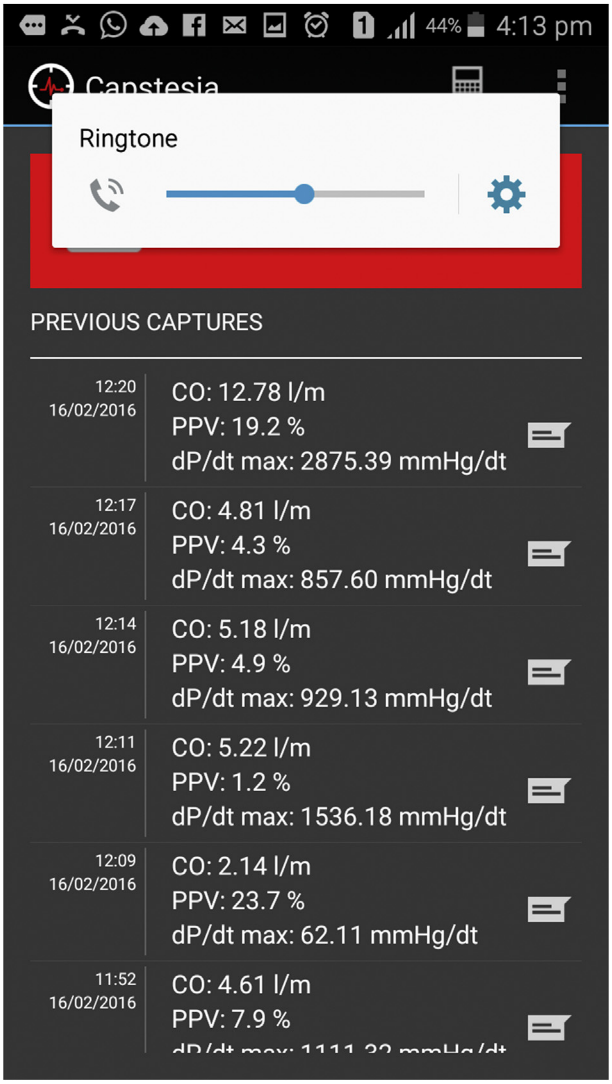

Fig. 3. Cardiac Output (CO), Pulse pressure variation(PPV) and dP/dtmax values provided by Capstesia after digitalizing the signal.

3. Limitations and precautions

A disadvantage of Capstesia ™ which we found relevant on clinical use, is that it is difficult to endorse the quality of snapshot of the arterial waveform. We found that the images taken from an angle are distorted and gave a false higher value of cardiac output as compared to regular images. In this regard, a safeguard to filter out and prevent analysis of images taken at an angle to the monitor screen may be incorporated to reduce errors. In fact, the authors personally avoided this human error by ensuring that the upper and left borders of the monitor screen and the upper and left borders of the smartphone screen respectively, were parallel to each other (Fig. 4) while taking the snapshot. Another important point to improve was that the waveform should have a clear dicrotic notch in it and must not be damped to prevent wrong calculation of values.

Direct measures of positive-pressure ventilation-induced variations in left ventricular stroke volume are excellent measures of preload responsiveness for a fixed tidal volume (8–12 mL/kg). TEE directly measures SVV while esophageal pulsed Doppler and arterial pulse contour analysis (Vigileo and Capstesia) are indirect measures. Another limitation is that arterial contour analyses have only been validated under steady-state conditions against indirect measures of cardiac output, such as the thermodilution or dye dilution techniques and have not been validated to monitor rapid changes in stroke volume, (as may occur over a single breath), which could induce non-steady-state) [3]. Algorithms used to calculate stroke volume by the manufacturers are proprietary, thus making any direct analysis of their ability to track actual stroke volume impossible. The scale of the arterial pulse pressure and it's decay profile provide a unique stroke volume for any given arterial resistance. Analysis of this pressure profile is different based on different algorithms employed by different manufacturers. Different weightage is given to mean arterial pressure, spectral power analysis and resistive versus compliant elements by different published algorithms. The algorithm used in Capstesia is not detailed and could be better or worse when compared to other commercial devices.

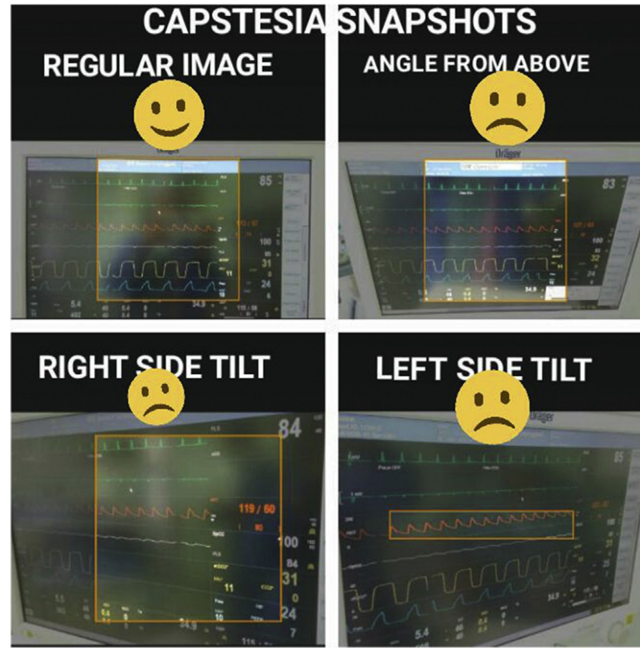

Fig. 4. Capstesia snapshots showing the effect of tilting and angulation (parallax error) of the smartphone while taking the snapshots.

We took snapshots of various waveforms like ECG (electrocardiogram), SpO2 (oxygen saturation), EtCO2(end tidal carbon dioxide), airway pressure (Paw), CVP and bispectral index (BIS) to find out if this application reads/misreads these parameters as well. A common value for heart rate (72/min), systolic BP (120 mmHg) and diastolic BP (80 mmHg) for each of the snapshots were inserted and the snapshots were analyzed by Capstesia™ (Fig. 5). A message reading that the data furnished was incorrect flashed on the screen for EtCO2, BIS and CVP waveforms. Capstesia™ mistook the ECG, SpO2 and Paw waveforms for the arterial pressure waveform and gave grossly high cardiac output readings for ECG and fairly high readings for SpO2 and Paw snapshots.

The various hemodynamic monitoring options in current use are summarized and compared with Capstesia™ below (Table 1).

4. Conclusions

To conclude Capstesia™ is a novel tool to extend the use of advanced hemodynamic monitoring to even remote operating rooms and critical care units in the developing and developed

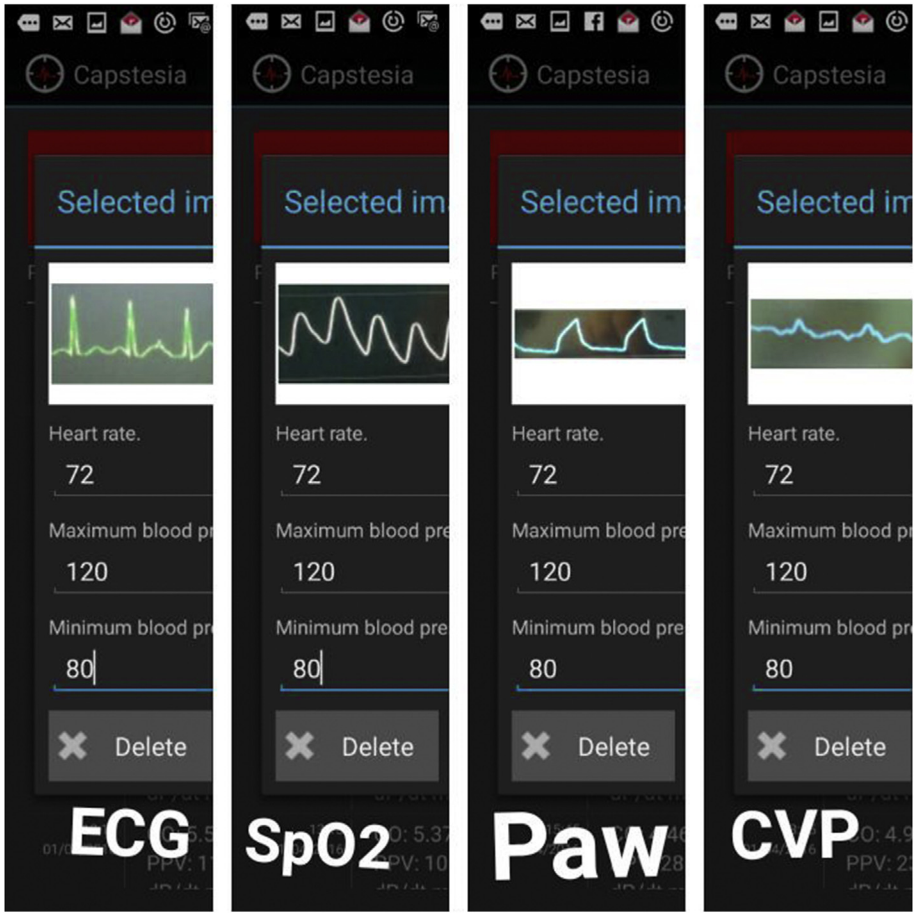

Fig. 5. Effect of insertion of common values for heart rate and blood pressure along with images of ECG, pulse oximeter, airway pressure and central venous pressure respectively instead of arterial pressure waveform.

Table 1
Hemodynamic monitoring options in current use compared with Capstesia™.

Name of parameter	Description of monitor	Invasiveness	Normal range
CVP	Peripherally inserted long line (basilic vein) Neck line (IJV; EJV; Subclavian) compatible with anaesthesia workstation	INVASIVE (requires central venous cannulation)	2–6 mmHg (spontaneous resp) 8–12 mmHg (mechanically ventilated patient)
SVV (Stroke Volume Variation) [3–5]	1. FloTrac/Vigileo (Edwards Lifesciences, Irvine, CA, USA) Cardiac output monitor 2. PiCCO system, which requires transpulmonary thermodilution	1. SEMI-INVASIVE (requires arterial cannulation) 2. INVASIVE (Requires pulmonary artery catheterization)	SVV < 10% unlikely to be preload responsive > 13–15% likely to be preload responsive SVV = (SVmax − SVmin)/[(SVmax + SVmin)/2] × 100
PVI (Pleth Variability Index) [6]	Masimo signal extraction technology (SET) utilizing a Radical-7™ finger pulse co-oximeter (Masimo Corp., Irvine, CA, USA)	NON-INVASIVE	4–18 PVI = PI max − PI min/PI max × 100 Where Perfusion Index (PI) = AC/DC × 100
OESOPHAGEAL DOPPLER [7] (SV; CO; SVR; DO2(Oxygen Delivery)	*CardioQ-ODM* [™ Deltex Medical, West Sussex, UK]	NON-INVASIVE	SV = 60–100 ml/beat DO2 = CaO_2 × CO × 10 = 950–1150 ml/min CO = 4–8l/min SVR = 800–1200 dyn sec/cm^5
IVCD(Inferior venecava Diameter) [8] DI (Distensibility Index)	Transseophageal echo; TEE probe (TEE 022 Esaote; 7.5–3 MHz)	NON-INVASIVE	IVCD = 10–20 mm DI = IVCDmax − IVCDmin/IVCDmin > 18% pt likely to respond to fluid filling
LVEDA [8]	Transseophageal echo; TEE probe (TEE 022 Esaote; 7.5–3 MHz)	NON-INVASIVE	LVEDA < 10cm^2 = Hypovolemia LVEDA > 20cm^2 = Volume Overload
CAPSTESIA [1] (CO; PPV) SVR; SVRI	CAPSTESIA™; Android phone application	INVASIVE (requires arterial cannulation)	CO = 4–8 l/min PPV < 10% unlikely to be preload responsive > 13–15% likely to be preload responsive (PPmax − PPmin)/[(PPmax + PPmin)/2] × 100

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world. Further randomised controlled trials are required to prove it's accuracy and it definitely has a promising future. It can be used to simultaneously monitor the cardiac output in any number of patients, if an android smartphone with online facility is available.

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