

Original Article

Cardiac output monitoring: A comparative prospective observational study of the conventional cardiac output monitor Vigileo™ and the new smartphone-based application Capstesia™

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ABSTRACT

Background and Aims: Capstesia is a software designed for smartphones (Android™/iOS™) to estimate the cardiac output and other haemodynamic variables from the waveform obtained from an invasive arterial cannula. The technology has been validated by studies in simulated environmental conditions. We compared the cardiac output (CO) and stroke volume variation (SVV) obtained by conventional cardiac output monitor Vigileo™ with CO and pulse pressure variation (PPV) extracted from Capstesia™, under clinical conditions, intraoperatively. **Methods:** In a Samsung smartphone in which the Capstesia software had been downloaded, the application was opened and a snapshot of the arterial waveform from the monitor screen of anaesthesia workstation was taken. The application instantaneously calculates the CO and PPV after inputting the heart rate and the systolic and diastolic blood pressure variables. These values were then compared with readings from the Vigileo™ monitor. Data was collected from 53 patients and analysed. **Results:** Five hundred and thirty data pairs of CO and an equal number of SVV and PPV pairs were analysed. Cardiac index by Capstesia (CIcap) was found to have a positive correlation with cardiac index by Vigileo (CIvig) using the intraclass correlation for raters, the strength of correlation being 0.757. Upper and lower 95% confidence limits were 1.43 l/min/m² and - 1.14 l/min/m² (Bland Altman's plot). A positive correlation was found between SVV and PPV using the Pearson's correlation ($r = 0.732$). **Conclusion:** Capstesia™ is a reliable and feasible alternative to Vigileo™ for intraoperative CO monitoring in oncosurgical patients.

Key words: Capstesia, cardiac output, smartphone application, stroke volume variation, Vigileo

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INTRODUCTION

Accessibility and cost are two major constraints for sophisticated haemodynamic monitoring in the perioperative period, besides the time consumed in setting up of the monitor and technical expertise required. Smartphones have emerged as an inseparable part of our daily routine. Capstesia™ (GalenicApp, Vitoria, Spain) smartphone application for Android™/iOS™ systems is a potentially transformative device that can make advanced cardiac monitoring simpler, more affordable, and universally accessible. It can calculate the cardiac output (CO), cardiac index (CI),

pulse pressure variation (PPV), rate of left ventricular pressure rise during systole (dP/dt max), and stroke volume resistance (SVR) from pulse contour analysis

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of a snapshot of the arterial pressure waveform.^[1,2] Capstesia™ has immense clinical potential in patient care and monitoring intraoperatively, extending into the intensive care units. The smartphone can now double as an innovative, real time, advanced haemodynamic monitor. Capstesia™ may prove instrumental in making advanced haemodynamic monitoring accessible to remote operating rooms and critical care units in the developing and developed world. A single android smartphone with online facility can simultaneously monitor the CO in any number of patients at a cost of five Euros a month.

The mobile feature extraction technology utilised by Capstesia™ has been validated by studies in simulated environmental conditions,^[3] but ours is the first reported study in the intraoperative period.

Pulse contour analysis devices are broadly classified into (i) Devices requiring an indicator dilution CO measurement for pulse contour calibration (LiDCO System; LiDCO, Cambridge, UK; and PiCCO System; Pulsion, Munich, Germany), (ii) Devices requiring patient demographic and physical characteristics for the estimation of arterial compliance (Vigileo; Flo-trac; Edwards Lifesciences, Irvine, CA, USA).^[3] We now have devices that do not require calibration or preloaded data (Capstesia™; Android/iOS smartphone application and MostCare System; Vytech Health, Padua, Italy).

Our aim was to study the correlation and agreement between CI values (calculated from CO) obtained by two different pulse contour analysis cardiac output monitors, Vigileo™ and Capstesia™. We recorded the cardiac output-vigileo (COvig), stroke volume variation-vigileo (SVVvig), cardiac output-capstesia (COcap), pulse pressure variation-capstesia (PPVcap), dP/dt max (capstesia), heart rate (HR), systolic, diastolic and mean arterial pressure at various time points and derived the CI by dividing the CO with the body surface area (BSA).

Our primary objective defined and established *a priori* at initiation of the study design was to study if agreement and interchangeability exist between the CI measured by Vigileo™ and that measured by Capstesia™ and to ascertain the strength of any existing correlation. Our secondary objectives were to study if a correlation exists, first, between SVVvig and PPVcap, and second, between COcap and dP/dtmax.

METHODS

This single blind prospective observational single arm study is registered with the Clinical Trial Registry of India (Reg No: CTRI/2017/03/008198). It was conducted from April 2017 to September 2017 in the Major Operation Theatre of a tertiary care oncology centre after obtaining approval from the Scientific Committee and Institutional Review Board of the centre. The study was conducted in accordance with the Helsinki Protocol after taking written informed consent from all the patients. A total of 53 adult patients of either sex, aged between 20 and 75 years, weighing between 40 and 90 kg, with ASA physical status II and III undergoing elective major oncosurgery requiring placement of an arterial line and CO monitoring were included in the study. Patients with a Negative Allen's test in bilateral radial arteries and in whom a radial arterial line could not be secured were excluded from the study. Patients having a pacemaker or automated implantable cardioverter-defibrillator *in situ*, persistent arrhythmias, a history of heart and/or lung transplant, and intra-aortic balloon pump or other mechanical cardiac support were also excluded from the study. All patients scheduled for major surgery requiring CO monitoring were considered to be potentially eligible. Out of these, the patients who met our age and weight inclusion criteria were eligible.

Capstesia™ (GalenicApp, Vitoria, Spain) smartphone application for Android™/iOS™ systems, is a software downloaded into a smartphone. It calculates the CO by pulse contour analysis of a snapshot of the arterial pressure waveform clicked by the smartphone. The systolic blood pressure, diastolic blood pressure, and heart rate values have to be inputted into the smartphone, and an internet connection is required to obtain the CO and other advanced haemodynamic parameters within seconds on the smartphone screen. No external calibration is required. The pulse contour analysis model is based on the interrelationship between blood pressure, SV, arterial compliance, and SVR.^[4] SV can be deduced from the arterial pressure waveform if the arterial compliance and SVR are known. Aortic compliance is age-related^[4] and nonlinear, being high at low distending pressures but rapidly reducing at higher pressures, which is an inbuilt mechanism to prevent overstretching.^[5,6] SV multiplied by the HR provides the CO. Commercially available pulse contour systems, although based on the same basic principle, use dissimilar pressure-volume conversion algorithms.^[6-8]

Vigileo™ (Edwards Lifescience, USA) CO monitor is attached to a Flo Trac sensor (disposable component) which is connected to the arterial catheter. We utilised this monitor upgraded to the latest fourth generation algorithm (Software Release Version No.: VO4.00, PIC V2.0). It calculates the CO by pulse contour analysis of the arterial pressure waveform. External calibration, thermodilution, or dye dilution is not needed but demographic data of the patient has to be entered before monitor setup is complete. Values given by Vigileo™ are standard deviation of 2000 arterial waveform points.^[4]

Before induction of anaesthesia a radial arterial line was secured after performing the Allen's test.^[9] The FloTrac™ pulse contour device was attached to the arterial cannula, and its sensor was connected to the display unit to obtain CO and SVV readings. The patient's demographic data (height, weight, age, and gender) were entered into the device as per manufacturer's recommendations. COvig is stated as an averaged value over 20 s via a proprietary algorithm.

After IV midazolam 0.03mg/kg and preoxygenation for 3 min, anaesthesia was induced with IV fentanyl 2 µg/kg and IV propofol 1.5 mg/kg. Additional 10 mg boluses of propofol were administered as and when required until loss of response to verbal commands. After checking for adequate mask ventilation, atracurium 0.5 mg/kg was injected and trachea was intubated. Anaesthesia was maintained with BIS-guided propofol

infusion and peripheral nerve stimulator-guided atracurium infusion along with hourly fentanyl boluses and 40% oxygen in medical air.

Five minutes after induction, recording of variables at 5 min intervals in each patient for 10 such readings was accomplished. The variables included: CO and SVV (Vigileo), CO, PPV and dp/dt max (Capstesia), heart rate (HR), systolic blood pressure (SBP), diastolic blood pressure (DBP), and mean arterial pressure (MAP).

Figure 1 displays three screenshots of the android smartphone screen (Samsung Galaxy E7) depicting the functioning of Capstesia™ application. The left side shows a red-margined selection box which is to be placed only over the arterial waveform excluding all other artefacts. In the centre is the image showing entry of data (HR, SBP, and DBP). On the right hand side, CO, PPV, and dP/dt max values over successive time points can be seen as a trend.

Arterial waveform scale was fixed at 1× with a sweep speed of 12 mm/s, and three pictures of the same screen (using three different smartphones with the Capstesia application installed) were analysed and averaged to obtain each CO, PPV, and dP/dtmax reading. A high speed internet connection and avoidance of artefacts or glare on the monitor screen was ensured. The smartphone screen was carefully held parallel to the monitor screen to avoid parallax error.

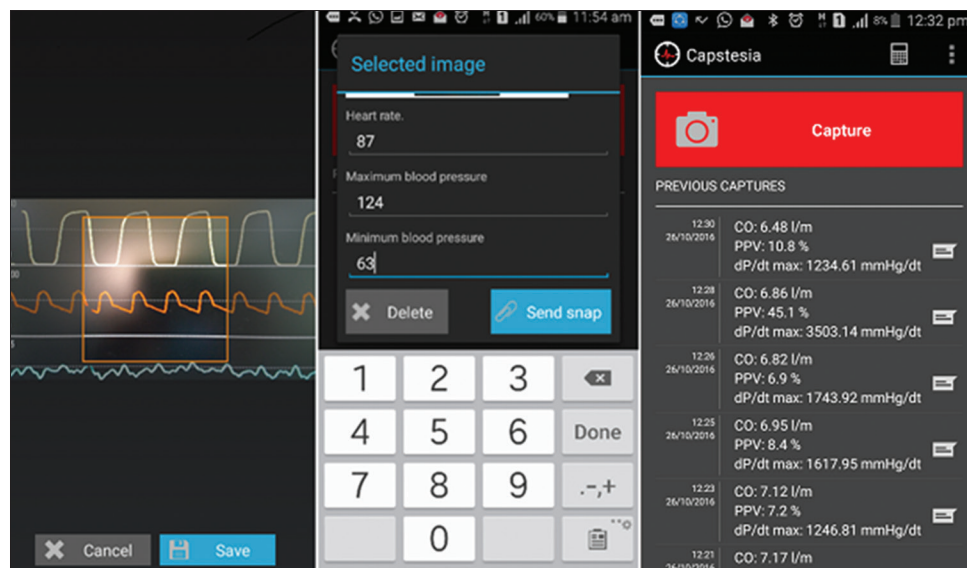


Figure 1: Three screenshots of android smartphone screen depicting the functioning of Capstesia application. The left side shows a red-margined selection box which is to be placed over the arterial waveform. In the centre is the image showing entry of data (heart rate, maximum, and minimum blood pressures). On the right hand side, cardiac output, pulse pressure variation, and dP/dt max values over successive time points can be seen as a trend

Sample size calculation was done for the number of paired readings as 538 based on a manuscript titled Sample size for assessing agreement between two methods of measurement by Bland–Altman method (Lu *et al.* 2015)^[10] with following assumptions: Different standardised difference limit was 0, different standardised agreement limit was 2.2, and power was 80%.

Student's *t*-test, intraclass correlation, and Pearson's correlation coefficient were used for normally distributed, continuous/quantitative variables (expressed as mean \pm SD), whereas Chi-square test was performed for categorical/qualitative variables (expressed as numbers and percentage). Mann–Whitney test was utilised for non-Gaussian data (expressed as median and range). IBM SPSS (International Business Machines; Statistical Package for the Social Sciences) statistics for windows (version 23.0; released 2015; Armonk, NY: IBM Corp.) was utilised and $P < 0.05$ was considered statistically significant. Bias, precision, and limits of agreement between Clvig and Cicap were calculated using Bland and Altman analysis^[11] in which bias was summarised as the mean difference between Clvig and CI cap and precision the standard deviation (SD) of this difference. The upper and lower limits of agreement were calculated as the bias \pm 2 SD. 95% limits of agreement were denoted by the interval defined by the observed bias \pm 1.96 the observed SD of the observed differences. Clinical significance of the difference was analysed using the Morey's Error Grid Zone Analysis^[12] after plotting paired CI values provided by the two cardiac output monitors. The Mountain plot (folded empirical cumulative distribution plot) provided a graphical representation of the distribution of differences between Clvig and CI cap for 530 observations taken together. Microsoft Excel 2010 (Microsoft Corp., Redmond, WA, USA) was utilised for the analysis of descriptive statistics.

All values are mentioned as “mean \pm standard deviation.”

RESULTS

Out of sixty potentially eligible patients examined for eligibility, 55 were found to be eligible. Two eligible patients were excluded since a radial artery catheter could not be placed and their dorsalis pedis artery was cannulated instead. The demographic and surgical profile of 53 adult patients included and analysed in the study has been tabulated [Table 1].

The first patient was enrolled in April 2017. The trial ended in September 2017 after the requisite number of cases was successfully completed. 69.8% of the patients underwent urogynecological oncosurgeries (radical hysterectomy, ovarian laparotomy, radical cystoprostatectomy with neobladder) whereas 15.1% each underwent gastro-oncosurgeries and thoracic oncosurgeries.

Table 2 displays the range, mean, and SD for the parameters studied. CI was obtained by dividing CO values by BSA. The mean and standard deviation values for Clvig were 3.07 ± 0.77 , whereas those for CI cap were 3.04 ± 0.72 which is comparable. Clvig was found to have a positive correlation with CI cap using the intraclass correlation for raters, the Cronbach's alpha (strength of correlation) being 0.76 (P value 0.0001). A Bland–Altman plot was charted between the CI values obtained by the two devices to measure the agreement [Figure 2]. As per the Bland–Altman plot, plotted between CI cap and

Table 1: Patient characteristics

Characteristic	Range/n (%)	Mean \pm SD
Age (years)	22-70	56.6 \pm 10.3
Weight (kg)	41-107	63.7 \pm 12.5
BSA (m ²)	1.32-2.09	1.69 \pm 0.177
Gender (male/female)	26 (49.1)/27 (50.9)	
ASA Grade (II/III)	38/15	
Surgery type		
Uro-Gynae oncosurgery	37 (69.8)	
Gastro-oncosurgery	8 (15.1)	
Thoracic-oncosurgery	8 (15.1)	

SD – Standard deviation; BSA – Body surface area; ASA – American Society of Anaesthesiologists

Table 2: Range, mean and standard deviation (descriptive statistics) for the parameters studied

Haemodynamic parameter	n	Minimum	Maximum	Mean \pm SD
COvig	530	2.10	9.60	5.18 \pm 1.35
Clvig	530	1.18	4.94	3.07 \pm 0.77
SVVvig	530	3.00	31.00	10.53 \pm 4.83
COcap	530	2.16	8.13	5.12 \pm 1.05
Cicap	530	1.28	4.97	3.04 \pm 0.72
PPVcap	530	0.00	50.40	10.63 \pm 7.76
Dp/dt max	530	16.58	4559.76	968.78 \pm 498.26
HR	530	41.00	120.00	73.47 \pm 17.15
SBP	530	72.00	179.00	118.67 \pm 18.57
DBP	530	36.00	92.00	63.22 \pm 9.92
MAP	530	52	111	81.70 \pm 11.30

COvig – Cardiac Output Vigileo™; COcap – Cardiac Output Capstesia™; Clvig – Cardiac Index Vigileo™; Cicap – Cardiac Index Capstesia™; SVVvig – Stroke Volume Variation Vigileo; PPVcap – Pulse Pressure Variation Capstesia; Dp/dt max – Pressure Differential over Time; HR – Heart Rate; SBP – Systolic Blood Pressure; DBP – Diastolic Blood Pressure; MAP – Mean Arterial Pressure; SD – Standard deviation

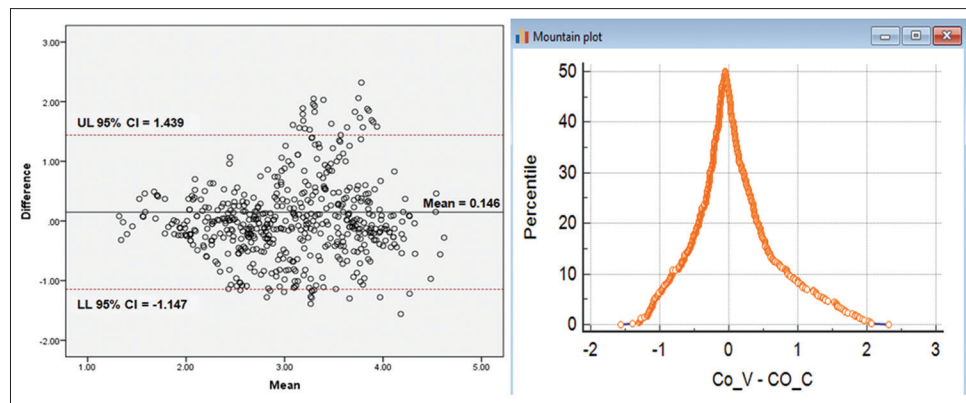


Figure 2: (left) Bland–Altman Plot – The line above the Xaxis depicts the upper limit of agreement (1.43 l/min/m²). The line below shows the lower limit of agreement (–1.14 l/min/m²); the line just adjacent to Xaxis depicts the bias (0. 14 l/min/m²). LL: Lower limit; UL: Upper limit; Right: Mountain plot

CIvig, the bias was 0.14 l/min/m², precision was 0.84 (95% CI of limit of agreement were – 2.91 to 2.94) and the upper and lower limits of agreement were 1.43 l/min/m² and – 1.14 l/min/m², respectively. The mountain plot [Figure 2] had a peak centred almost at zero (0.14) with short tails, the tail on the negative (left) side being slightly shorter than the tail on the positive (right) side.

The Morey's error grid analysis figure [Figure 3] is divided into four zones: Zone A (green) is the maximum agreement area, Zone B (orange) is the better agreement area, Zone C (yellow) is the error area, and Zone D (red) is the danger area (Xaxis represents CIvig while the Yaxis denotes CIcap). It showed 514 data points to be lying within the green zone while 16 values were in the yellow zone bordering the green zone. These belong to two obese patients where, even though there was a relatively large difference between the CO values obtained, the difference was proportionate over all 10 readings in each patient (bias was proportionate, *P* value = 0.003).

COcap showed a statistically significant positive correlation with the SBP, DBP, and MAP, whereas no significant positive correlation was seen between COvig and the systolic, diastolic, and mean arterial pressures [Table 3].

Mean \pm SD for SVVvig was 10.53 ± 4.86 , that for PPV cap was 10.55 ± 5.08 , while that for dP/dt max was found to be $968.78 (498.26)$ [Table 2]. A positive Pearson's correlation was found between SVVvig and PPVcap. The strength of this correlation was 0.732 which is statistically highly significant (*P* value < 0.001). A statistically significant positive correlation was observed between SVVvig and HR,

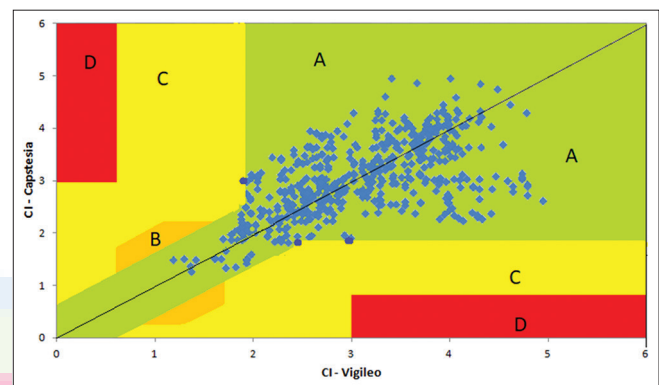


Figure 3: Morey's error grid analysis

(*r* = 0.501; *P* value < 0.001). PPVcap was found to have a stronger positive correlation with HR (*r* = 0.679; *P* value < 0.0001) compared to SVVvig.

While a negative correlation was found between the systolic blood pressure and SVVvig, the strength of correlation being -0.385 (*P* = 0.004), no significant correlation was observed between the SVVvig and the DBP or between SVVvig and MAP.

A statistically insignificant, positive correlation was found between Dp/dt Max and CO cap. dP/dt max had a statistically significant negative correlation with SVVvig (*r* = -0.466 (*P* < 0.001) and also with PPVcap (*r* = -0.286 (*P* < 0.05). Dp/dt Max was found to have a strong positive correlation with SBP (*r* = 0.562 (*P* < 0.001) and MAP (*r* = 0.403 (*P* < 0.005), but not with DBP. Here *r* is the coefficient of correlation and denotes the strength of correlation.

COcap is quicker (10–15 s) to sense changes in CO than COvig. In clinical settings of rapidly changing cardiac output, COcap matches better with the COvig readings produced 10–15 s later in the timeline.

Table 3: Correlation analysis

Factor	CO-Vigileo	SVV-Vigileo	CO-Capstesia	PPV-Capstesia	HR	SBP	DBP	MAP
CO-Vigileo	1	-0.309*	0.570*	-0.136	0.093	0.140	0.118	0.172
P		0.024	0.0001	0.331	0.506	0.316	0.401	0.217
SVV-Vigileo		1	-0.321*	0.732*	0.501*	-0.385*	0.097	-0.213
P			0.019	0.000	0.000	0.004	0.489	0.126
CO-Capstesia			1	-0.029	0.258	0.461*	0.458*	0.574*
P				0.838	0.062	0.001	0.001	0.000
PPV-Capstesia				1	0.679*	-0.272	0.164	-0.120
P					0.000	0.049	0.240	0.391
HR					1	-0.337*	0.211	-0.078
P						0.014	0.130	0.577
Dp/dt max	0.229	-0.466*	0.269	-0.286*	-0.120	0.562*	0.067	0.403*
P	0.099	0.000	0.051	0.038	0.392	0.000	0.634	0.003

*Correlation is significant at the 0.05 level (two-tailed). CO – Cardiac output; SVV – Stroke volume variation; PPV – Pulse pressure variation; HR – Heart rate; Dp/dt max – Pressure differential over time; SBP – Systolic blood pressure; DBP – Diastolic blood pressure; MAP – Mean arterial pressure

DISCUSSION

We compared two pulse contour devices, Vigileo™ (already validated by several studies^[13-18]) and Capstesia™ (latest in the bandwagon) and found good agreement between the CO measured by the two devices. The SVV and PPV values correlated well too. While Vigileo™ requires a peripheral/central arterial line, Capstesia™ requires just a snapshot of the arterial waveform which may be obtained from either an invasive arterial line or from noninvasive finger probes.^[4] Both do not require external calibration.

The arterial waveform scale and sweep speed were selected based on a precision and accuracy study for Capstesia™ based PPV by Dessebe *et al.*^[3] in simulated environmental conditions. Capstesia™ identifies the peaks and nadirs of the arterial waveform curve and calculates the PPV, CO, and dp/dt max from the same.

It is vital to ensure that the dicrotic notch is clearly visible and the arterial waveform is not damped (by pulling the pigtail of the transducer to flush the arterial line) and purely reflective of forward SV to prevent wrong calculation of values. Any distortion due to artefacts or physiologic phenomenon (intra-aortic balloon counterpulsation, aortic regurgitation) causes inaccuracies. Natural frequency and damping coefficient of pressure-transducer kits affect the monitoring accuracy. A damping device, Resonance Over-Shoot Eliminator device (ROSE™, Argon Medical Devices, TX, USA) was utilised to increase the damping coefficient to between 0.5 and 0.7, thereby optimizing frequency characteristics.

As per the Bland–Altman plot charted between the CO measured by the two devices, the upper and

lower 95% confidence limits were 1.43 l/min/m² and –1.14 l/min/m² which implies that in 95% of the cases there would be a maximum discrepancy of roughly 1.4 l/min/m² between the CI measured by the two devices. Capstesia™ values for CO coincided with Vigileo flotracs CI in 15 patients. In others there was a fixed proportionate difference between the two values. For each unit rise in CIvig, there was a proportionate rise in CIcap and for each unit decrease in former the latter decreased proportionately. This proportionate bias was seen to be 0.014 in the Bland–Altman plot. For instance, during HIPEC in both ovarian laparotomy patients, 7–7.4 L/min was the range for COvig (3.14–3.99 CIvig) while 5.71–5.96 L/min was the range for COcap (2.34–2.79 CIcap). Both increased/decreased in the same direction and by the same amount but within their own range. Similarly, in 3 patients undergoing radical cholecystectomy with wedge resection of liver the CIvig values were proportionately higher than CIcap values. This may be attributed to the low SVR in these patients.^[19]

The mountain plot had a peak centred almost at zero (0.14) indicating a negligible bias between the two methods. Both tails (reflecting distribution of differences) were short reflecting narrow differences between the two methods. The tail on the negative side was slightly shorter than the tail on the positive side indicating that Capstesia over-calculates slightly more commonly than it under-calculates.

The density of data points lying closer to the line of agreement is higher. As 97% of the paired values lie in the green zone or the zone of maximal agreement in the Morey's error grid analysis chart, it implies that there is a good agreement between the two CO monitoring devices. Ours is the first reported study

comparing the CO measured by Capstesia and Vigileo. In a study by Marque *et al.*,^[18] with simultaneous measurements of CO by three methods (FloTrac/Vigileo, bioactance-based system and thermodilution method) in stable conditions, correlations of bioactance method and Vigileo with pulmonary artery catheter thermodilution method were 0.77 and 0.69, respectively. The variability of measurements around the trend line (precision) was almost similar for the three methods ($8 \pm 3\%$, $8 \pm 4\%$ and $8 \pm 3\%$ for Vigileo, bioactance, and thermodilution methods, respectively). We obtained similar values for the two techniques compared by us.

COcap showed a statistically significant positive correlation with the systolic, diastolic, and mean arterial pressures, whereas no significant positive correlation was seen between COvig and the same parameters. This important finding explains why the discrepancy between COvig and COcap increases at extremes of blood pressure. At higher blood pressure readings the COcap values are higher than COvig whereas at lower blood pressure readings COcap readings are lower than corresponding COvig readings. The algorithm of Capstesia™ necessitates feeding the HR, SBP, and DBP values manually into the smartphone whereas the same manual inputs are not required by the Vigileo™ device to provide CO values.

The mean SVVvig and PPVcap were almost the same (10.53 and 10.55, respectively) and both displayed a strong positive correlation ($r = 0.73$) implying that both can be useful for ascertaining fluid responsiveness and goal-directed fluid therapy.^[20] Both PPVcap and SVVvig showed a positive correlation with HR with PPVcap showing a stronger positive correlation ($r = 0.679$; P value < 0.001). This implies that PPVcap values are more affected by HR. Higher the heart rate, higher the PPV and SVV vig but there is a greater rise in PPVcap values compared to SVVvig values. This again maybe explained by a difference in the proprietary algorithms. Capstesia requires the HR to be fed (while Vigileo does not) and probably gives greater weightage to the HR.

Maximal rate of rise of left ventricular (LV) systolic pressure is calculated from the radial artery pressure waveform by Capstesia™. After conversion into its first derivative (dp/dt) max with respect to time, it is expected to be a good indicator of LV contractility. Peripheral (dp/dt) max calculations from the brachial

artery using a sphygmomanometer cuff were found to be in good agreement ($r = 0.87$) with invasive measurements of left ventricular (dp/dt) max.^[21] Peripheral arterial dp/dt max from femoral artery was compared to end-systolic elastance, the gold standard for assessing LV contractility by Morimont *et al.*^[22] They found arterial dp/dtmax to be more accurate for assessing LV contractility when adequate vascular filling ($PPV \leq 11\%$), was achieved ($r = 0.51$ and $r = 0.77$ for volume depleted and volume repleted conditions, respectively). However, we found a statistically insignificant positive correlation between Dp/dt Max and CO cap ($r = 0.269$; $P = 0.051$). This maybe because Capstesia was supplied a radial artery waveform snapshot for deducing dp/dt max in our study. A brachial/femoral artery waveform might give a better correlation with COcap. Ventricular loading conditions represent the second variable (besides myocardial contractility) on which dp/dt max depends. Change in LV loading conditions in some patients in our study may also have weakened this correlation.

One drawback of the existing Capstesia™ version is that it may prove hard to endorse the quality of the arterial waveform image clicked. Distorted images taken from an angle give a falsely elevated value of CO as compared to regular images taken by keeping the smartphone screen parallel to the monitor screen.^[2] After a short learning curve, we could avoid 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 while taking the snapshot. Even though both cardiac output monitors are minimally invasive and easy to use, Capstesia™ is operator dependent to this extent.

A limitation of our study is that it was conducted only on oncosurgery patients and can only be extrapolated to include other patients. Capstesia application uses external libraries including Action Bar Sherlock, Achar Engine, Crop image, and Google Analytics. The only input required is the systolic and diastolic blood pressures and the heart rate. Vigileo only takes the sex, height, and weight of the patient. Neither requires race to be entered.

Second, till such time the agreement between minimally invasive CO monitors improves, it is imperative that each device has its own clinical efficacy validated. A stronger correlation might have been observed had we compared COcap with COvig

taken 10–15 s after the snapshot for COcap calculation. Further studies need to be undertaken in this regard under conditions of massive blood loss and rapidly changing CO. Another limitation is that there exists a possibility of some error creeping in despite making the best attempt to keep the two screens (monitor and smartphone) parallel.

CONCLUSION

The statistically significant positive correlation and agreement between Cicap and Cividig makes Capstesia™ application a promising alternative to Vigileo™ for intraoperative advanced haemodynamic monitoring in surgical patients.

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Nil.

Conflicts of interest

There are no conflicts of interest.

REFERENCES

- Barrachina Larraza B, Alvarez Guerras O, Lopez-Picado A. Capstesia, a new APP for advanced hemodynamic monitoring. *Rev Esp Anestesiol Reanim* 2014;61:535-6.
- Shah SB, Hariharan U, Bhargava AK. Capstesia™: The smart hemodynamic monitor! *Trend Anaesth Crit Care* 2016;10:15-9.
- Desebbe O, Joosten A, Suehiro K, Lahham S, Essiet M, Rinehart J, et al. A novel mobile phone application for pulse pressure variation monitoring based on feature extraction technology: A method comparison study in a simulated environment. *Anesth Analg* 2016;123:105-13.
- Montenij LJ, de Waal EE, Buhre WF. Arterial waveform analysis in anesthesia and critical care. *Curr Opin Anaesthesiol* 2011;24:651-6.
- van Lieshout JJ, Wesseling KH. Editorial II: Continuous cardiac output by pulse contour analysis? *Br J Anaesth* 2001;2:467-8.
- Chamos C, Vele L, Hamilton M, Cecconi M. Less invasive methods of advanced hemodynamic monitoring: Principles, devices, and their role in the perioperative hemodynamic optimization. *Perioper Med (Lond)* 2013;2:19.
- Critchley LA, Critchley JA. A meta-analysis of studies using bias and precision statistics to compare cardiac output measurement techniques. *J Clin Monit Comput* 1999;15:85-91.
- Peyton PJ, Chong SW. Minimally invasive measurement of cardiac output during surgery and critical care: A meta-analysis of accuracy and precision. *Anesthesiology* 2010;113:1220-35.
- Jarvis MA, Jarvis CL, Jones PR, Spyt TJ. Reliability of Allen's test in selection of patients for radial artery harvest. *Ann Thorac Surg* 2000;70:1362-5.
- Lu MJ, Zhong WH, Liu YX, Miao HZ, Li YC, Ji MH, et al. Sample size for assessing agreement between two methods of measurement by Bland-Altman method. *Int J Biostat* 2016;12. pii: /j/ijb. 2016.12.issue-2/ijb-2015-0039/ijb-2015-0039.xml.
- Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 1986;1:307-10.
- Morey TE, Gravenstein N, Rice MJ. Let's think clinically instead of mathematically about device accuracy. *Anesth Analg* 2011;113:89-91.
- Mayer J, Boldt J, Schöllhorn T, Röhm KD, Mengistu AM, Suttner S, et al. Semi-invasive monitoring of cardiac output by a new device using arterial pressure waveform analysis: A comparison with intermittent pulmonary artery thermodilution in patients undergoing cardiac surgery. *Br J Anaesth* 2007;98:176-82.
- Manecke GR. Edwards floTrac sensor and vigileo monitor: Easy, accurate, reliable cardiac output assessment using the arterial pulse wave. *Expert Rev Med Devices* 2005;2:523-7.
- McGee WT, Horswell JL, Calderon J, Janvier G, Van Severen T, Van den Berghe G, et al. Validation of a continuous, arterial pressure-based cardiac output measurement: A multicenter, prospective clinical trial. *Crit Care* 2007;11:R105.
- Opdam HI, Wan L, Bellomo R. A pilot assessment of the FloTrac™ cardiac output monitoring system. *Intensive Care Med* 2007;33:344-9.
- Pittman J, Bar-Yosef S, SumPing J, Sherwood M, Mark J. Continuous cardiac output monitoring with pulse contour analysis: A comparison with lithium indicator dilution cardiac output measurement. *Crit Care Med* 2005;33:2015-21.
- Marqué S, Cariou A, Chiche JD, Squara P. Comparison between floTrac-vigileo and bioreactance, a totally noninvasive method for cardiac output monitoring. *Crit Care* 2009;13:R73.
- Biancofiore G, Critchley LA, Lee A, Yang XX, Bindi LM, Esposito M, et al. Evaluation of a new software version of the floTrac/Vigileo (version 3.02) and a comparison with previous data in cirrhotic patients undergoing liver transplant surgery. *Anesth Analg* 2011;113:515-22.
- Rathore A, Singh S, Lamsal R, Taank P, Paul D. Validity of pulse pressure variation (PPV) compared with stroke volume variation (SVV) in predicting fluid responsiveness. *Turk J Anaesthesiol Reanim* 2017;45:210-7.
- Brinton TJ, Cotter B, Kailasam MT, Brown DL, Chio SS, O'Connor DT, et al. Development and validation of a noninvasive method to determine arterial pressure and vascular compliance. *Am J Cardiol* 1997;80:323-30.
- Morimont P, Lambermont B, Desai T, Janssen N, Chase G, D'Orio V, et al. Arterial dp/dtmax accurately reflects left ventricular contractility during shock when adequate vascular filling is achieved. *BMC Cardiovasc Disord* 2012;12:13.

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