RESEARCH PAPER

Correlation Between Blood Pressure Measurement by Non-invasive and Invasive Methods in Critically-ill Children

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Objective: To determine the correlation of non-invasive blood pressure obtained by auscultatory and oscillometric methods, with invasive blood pressure in critically ill children. **Methods**: We compared invasive with auscultatory and oscillometric blood pressures using paired t-test, Pearson's correlation coefficient and Bland-Altman plot in 50 children (age 1-12 y) admitted in Pediatric intensive care unit. **Results**: Systolic, diastolic, and mean arterial pressures of invasive methods significantly correlated with auscultatory and oscillometric methods (P<0.001). Auscultatory and oscillometric measurements under-estimated systolic arterial pressures [mean (SD) difference 5.4 (12.2) mmHg and 6.3 (14.0) mmHg, respectively; P<0.001] and overestimated diastolic arterial pressures [-4.1 (5.8) mmHg and -3.6 (7.2) mmHg; P<0.001] compared to invasive blood pressure. **Conclusion**: Mean arterial pressure obtained by NIBP measurement is more closer than systolic or diastolic pressures, when compared with invasive blood pressure measurement.

Keywords: *Arterial catheter, Auscultatory, Oscillometry, Sphygmomanometer*.

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Accurate blood pressure (BP) values are required for important diagnostic and therapeutic decisions in pediatric intensive care units (PICU). Arterial cannulation with continuous pressure transduction remains the reference standard for arterial BP. The manual auscultatory BP (ABP) technique is uncommonly used in critically ill children, except in emergencies or transports. Because of the frequent need for repeated BP monitoring in PICU, oscillometric non-invasive blood pressure (NIBP) measurements are more commonly used [1,2]. Oscillometric blood pressure (OBP) monitoring offers the advantage of automatic and direct measurement of mean arterial pressure (MAP). In view of scarce data, validation studies are needed to compare the precision of NIBP with invasive blood pressure (IBP) in critically ill children[3]. We, therefore, determined the correlation and reliability of NIBP obtained by auscultatory and oscillometric methods compared to IBP.

METHODS

We conducted the study at Dr BC Roy Post Graduate Institute of Paediatric Sciences, Kolkata, after Institutional ethics committee approval. Treating pediatricians took the decision to place an intra-arterial catheter, without any influence from the investigators. In the PICU, every child aged 1-12 years, and having a radial arterial catheter for continuous IBP monitoring was selected, till we enrolled 50 patients for the study (consecutive sampling technique) after obtaining written informed consent from guardians. Patients with contraindications to cuff application/inflation (arm injuries or wounds, limb edema), presence of arrhythmias, at high risk for intravascular thrombosis (diabetic ketoacidosis, nephrotic syndrome and hypercoagulable states), non-functional arterial catheter (defined as presence of overshooting or undershooting phenomenon following rapid flush test), absent pulses and having confounders of NIBP monitoring (chronic hypertension, obstructive airway disease and obesity) were excluded.

Accompanying Editorial: Pages 289-91

The investigators filled the study proforma including general details of children, history, general and systemic examination findings, diagnosis, and treatment being received. A single investigator measured BP in all participants to avoid inter-observer variability, initially recording the NIBP followed by the IBP, to avoid the bias introduced by the investigator being aware of IBP readings. We took 4 pairs of BP measurements from 50 patients, thereby collecting 200 pairs of BP measurements (100 comparisons between IBP and ABP and 100 between IBP and OBP).

For measuring IBP, the arterial catheter of proper size

(HMD KitKath, Germany) was inserted into the radial artery after performing the Allen test and was connected to a disposable pressure transducer (TruWaveTM, Edwards Lifesciences, Irvine, CA, USA) using rigid pressure tubing of identical length. The transducer was connected to the blood pressure module of the Phillips IntelliVue MP30 (Philips MedizinSysteme, Germany) bedside monitor and to a heparinized saline (2 units/mL) syringe running at the rate of 3 mL/h, to prevent clotting of the catheter. The pressure monitoring set had an Intraflo continuous flush element pigtail that could be pulled to allow rapid flush of the system. Before IBP measurements, the transducer position at the level of the patient's 4th intercostal space at the mid-axillary line, regulating the pressure reading to zero, ensuring absence of kinking or air bubbles in the tubing and transducer, flushing the tube and performing a "fast flush" test to verify optimal damping and the presence of a normal arterial waveform.

We measured all ABP in the brachial artery using a well-calibrated aneroid sphygmomanometer (Smart Care, Indore, India) with proper cuff sizes [4]. We chose an appropriately sized cuff following a measurement of the arm circumference (at the midpoint between the acromion and the humeral epicondyle). The investigator positioned to see the dial of the manometer perpendicularly at eye level. In case of persistence of the fifth Korotkoff tone, attenuation of the fourth tone determined the diastolic arterial pressure (DAP). To calculate the MAP from the values obtained by the sphygmomanometer, we used the formula (SAP + 2DAP)/3 [systolic arterial pressure is abbreviated as SAP]. We measured all the OBP in the brachial artery using Phillips EasyCare cuffs (Philips Medical Systems, Andover, MA, USA) of appropriate sizes [4] and connected with the NIBP pressure cable into the BP module of the Phillips MP30 monitor. The NIBP was measured in a different limb to the one with the arterial line. A 5-minute interval separated one assessment from the other to avoid the compression applied to the arm possibly affecting the measurements.

Statistical analysis: Data were entered into a Microsoft Excel spread sheet and analyzed using SPSS version 20.0 [IBM Corp., NY, USA]. The correlations of systolic, diastolic and mean pressures of ABP and OBP *versus* IBP were investigated using Pearson's correlation coefficient, and agreement with Bland-Altman analysis [5]. Paired t-test was used for comparisons between means. The criterion for statistical significance was $P<0.05$.

RESULTS

We screened 248 children; 198 were excluded (no arterial line 153, arterial line not working 4, presence of arrhythmias 24, contra-indication to cuff application/ inflation 1, and refusal of consent 16). Finally we enrolled 50 (28 girls) children for the study.

The primary diagnosis of the study children were as follows: 1 with acute gastro-enteritis and severe dehydration, 10 with acute encephalitis syndrome, 4 with acute pancreatitis, 4 Congestive cardiac failure (2 myocarditis, and 2 dilated cardiomyopathy), 1 disseminated tuberculosis, 2 near drowning, 3 empyema thoracis with septicemia, 4 Guillain-Barre syndrome, 1 hanging, 1 head injury, 2 post-operative complications (perforated appendix), 5 pyogenic meningitis, 3 pneumonia, 3 septicemia, 1 status asthmaticus, 4 status epilepticus and 1 tubercular meningitis. Mean (SD) age of studied children was 4.8 (3.2) years; 23 (46%) were 1-3 years, 11(22%) were 3-6 years, 12 (24%) were 6-9 years, and rest were >9 years. Fourteen children (28%) received vaso-active drugs to treat hypotension; 4 each received only dopamine or dobutamine, 3 received dopamine and epinephrine, and rest 3 received dopamine and nor-epinephrine. None had hypertension.

The differences between means of SAP, DAP and MAP of IBP *versus* ABP and OBP, and results of paired *t*-test were shown in ***Table* I** and **II**. We found a statistically significant correlation between SAP, DAP, and MAP measurements of IBP *versus* ABP, and OBP. Comparing IBP *versus* ABP, the Pearson's coefficients for SAP, DAP and MAP were 0.914 ($P<0.001$), 0.920 ($P<0.001$), 0.944 ($P=0.0001$). Comparing IBP *versus* OBP, the Pearson's coefficients for SAP, DAP and MAP were 0.908 ($P<0.001$), 0.866 ($P<0.001$), 0.916 ($P<0.001$). The Bland-Altman analysis (***Table* III**) showed wide limits of agreement between SAP, DAP and MAP of IBP *versus* ABP and OBP.

DISCUSSION

Both ABP and OBP significantly underestimated SAP and overestimated DAP compared to IBP. The

TABLE I BLOOD PRESSURE DIFFERENCES USING IBP VS ABP

Pressures	*IBP Mean (SD)*	*ABP Mean (SD)*	*IBP-ABP Mean (SD) (95% CI)*	*P value*
Systolic	91.6 (24.3)	86.2 (15)	5.4 (12.2) (3.0; 7.9)	<0.001
Diastolic	51.2 (14.3)	55.3 (11.7)	-4.1 (5.8) (-5.3; -3.0)	<0.001
Mean	64.4 (17.3)	65.6 (12.2)	-1.2 (7.0) (-2.6; 0.18)	0.086

IBP: *invasive blood pressure; ABP*: *auscultatory blood pressure.*

WHAT THIS STUDY ADDS?

- Non-invasive methods significantly under-estimate systolic blood pressure and over-estimate diastolic pressure; mean arterial pressure obtained by non-invasive methods is more valid than either.

TABLE II DIFFERENCES BETWEEN SAP, DAP, MAP USING IBP VS OBP

Pressures	*IBP Mean (SD)*	*OBP Mean (SD)*	*IBP-OBP Mean (SD) (95% C.I.)*	*P-value*
Systolic	92.0 (25.0)	85.6 (13.3)	6.3 (14.0) (3.6; 9.1)	<0.001
Diastolic	50.6 (14.1)	54.2 (10.5)	-3.6 (7.3) (-5.0; -2.1)	<0.001
Mean	64.1 (17.3)	64.5 (10.7)	-0.5 (8.6) (-2.2; 1.2)	0.571

IBP: *invasive blood pressure; OBP*: *oscillometric blood pressure.*

TABLE III BLAND-ALTMAN ANALYSIS SHOWING MEAN DIFFERENCES (95% LIMITS OF AGREEMENT) BETWEEN IBP *VERSUS* ABP AND OBP

Differences	*Systolic*	*Diastolic*	*Mean*
IBP-ABP(95%	5.4	-4.1	-1.2
limits of agreement)	(29.3; -18.6)	(7.2; -15.4)	(12.6; -15)
IBP-OBP(95%	6.34	-3.58	-0.5
limits of agreement)	(33.8; -21.1)	(10.6; -17.8)	(16.4; -17.4)

IBP: *invasive blood pressure; ABP*: *auscultatory blood pressure; OBP*: *oscillometric blood pressure.*

differences between mean MAP of both ABP and OBP with IBP were small and not significant, but with wide variability in individual differences. These differences depend on the site of BP measurement as brachial IBP monitoring tends to be closer to central BP than radial IBP. Inappropriateness of cuff sizes and rapid deflation also contribute to discrepancies in auscultatory method [3,6]. However, these factors were minimized by following the proper method strictly. The overestimation of diastolic pressure by non-invasive methods may be due to cuff inflation. When cuff pressure exceeds venous pressure, it occludes venous return, resulting in increased blood volume in the arm distal to the cuff. This impairs diastolic run-off of blood and elevates diastolic pressure [7]. The oscillometric methods are not standardized and measuring algorithms differ among manufacturers and devices, resulting in differences in OBP measurements [8,9].

The major limitation of the study is the comparison of only non-invasive intermittent manual and automated techniques with IBP, and inability to compare non-invasive automated continuous techniques, due to unavailability of those devices in our institute. The formula used for the calculation of MAP with the auscultatory method is inaccurate in bradycardic or tachycardic patients, due to the length of the systole changing with heart rate [10]. Unfortunately, no formula of MAP adjusts for the heart rate. Analysis based on age- and sex-specific normotensive, hypotensive and hypertensive criteria was not done.

Joffe, *et al.* [11] studied the difference (NIBP–IBP) of SAP, DAP and MAP in 100 children. The mean difference was usually small and significantly correlated. There was wide variability in the differences between NIBP and IBP, and this varied even in the same patient on the same day. Holt, *et al.* [12] compared IBP, OBP, ABP and Doppler ultrasound measurements in 40 children. In the normotensive range, there was no significant difference between systolic pressures of NIBP and IBP, whereas mean and diastolic IBP measurements significantly exceeded NIBP measurements [ΔMAP 2.6, ΔDAP 5]. Outside the normotensive range, the automated readings were higher during hypotension and lower during hypertension compared with the invasive and Doppler ultrasound methods. Other researchers [13,14] described the under-estimation of SAP and over-estimation of DAP by NIBP techniques compared to IBP in adults. However, a study in neonates testing the accuracy of NIBP device using SuperSTAT algorithm [15], contradicted our results. They found that NIBP and IBP comparisons for SAP, DAP and MAP met the 1992 US Association for the Advancement of Medical Instrumentation accuracy standards, thereby concluding that NIBP measurements taken with the new algorithm were accurate when compared to IBP in neonates [15].

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