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INTERNATIONAL REVIEW OF HUMANITIES AND SCIENTIFIC RESEARCH
By International Scientific Indexing
ISSN: 2519-5336

COMPARISON OF OSCILLOMETRIC NON-INVASIVE AND INVASIVE ARTERIAL BP MEASUREMENTS IN CRITICALLY ILL CHILDREN

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Abstract
In a prospective observational study the agreement between invasive and oscillometric non-invasive BP measurements in 93 critically ill children of age less than 15 years having radial arterial catheter for continuous BP monitoring was studied in Pediatric ICU of a tertiary level care hospital.

A total of 1060 paired measurements of invasive and oscillometric non-invasive BP (IBP and NIBP) were taken in pediatric ICU of a selected tertiary care facility simultaneously on each subject at the time of enrolment and then every 3-4 hourly for 7 days or till the arterial catheter was in place, whichever occurred earlier. The oscillometric NIBP was taken on right arm if arterial line was on left and vice-versa using a BP cuff appropriate to the child's arm. The agreement using Bland Altman analysis revealed the mean (±SD) differences between the IBP and oscillometric NIBP for systolic, diastolic and mean arterial BP measurements -3.6 ± 5.6, -3.4 ± 5.5 and -3.4 ± 5.5 mm Hg respectively ($p<0.05$). The Bland Altman analysis showed fairly wide limits of agreement. When analyzed using age specific normo-, hypo- and hypertensive criteria, among normotensive group, the difference of invasive and non-invasive systolic (dSBP), diastolic (dDBP) and mean (dMAP) arterial BP measurements group were -2.96, -3.17, -2.89 mm Hg respectively($p<0.05$). The dSBP among hypotensive group (-3.4 ± 3.93 mm Hg) and dMAP among hypertensive group (-4.24 ± 5.37 mm Hg) also showed significant difference ($p<0.05$). A good correlation was found between both methods.

As the limits of agreement were wide and oscillometric readings were overestimated, invasive method of BP monitoring should be used for monitoring critically ill children to get accurate blood pressure, whenever feasible.

Key words: Invasive blood pressure (IBP), Non-invasive blood pressure (NIBP), critically ill children.

Contributor's statement page

Ms. Liah Raju had primary responsibility for protocol development, analytical framework, enrolment of participants, and writing the manuscript.

Dr. Poonam Joshi, Dr. Manju Vatsa, Dr. SK Kabra, and Dr. Rakesh Lodha helped in execution of the study, and contributed to the writing of the manuscript. Dr Poonam Joshi would act as the corresponding author and the overall guarantor of the manuscript.

Introduction

Hemodynamic monitoring is a central component of intensive care. Blood pressure (BP) is one of the most important hemodynamic indices in critically ill children for their optimal management. Absolute blood pressure measurements frequently trigger therapeutic interventions in critically ill children. [1] In order to avoid unnecessary use of volume overloads or inotropy, a correctly measured blood pressure is essential. [2]

BP measurement techniques generally involve non-invasive measurements with a cuff (oscillometric) or invasive measurements through an arterial catheter. Invasive measurement from an arterial line (invasive arterial blood pressure -IBP) is generally considered to be the gold standard, despite recognition that errors may be introduced by over/under damping, calibration errors, and movement artifacts. The automated noninvasive blood pressure systems (NIBP) using oscillometric techniques have advantages over invasive arterial lines as they avoid bleeding and infection risk, and can be used outside the ICU. [3, 4] But it is important that guidelines are followed in selecting the correct arm cuff based on mid-upper arm circumference and that calibration is done properly according to the manufacturer's specifications.

Continuous arterial blood pressure monitoring is of great importance in many clinical situations, including emergency and critical care medicine. The continuously measured invasive BP shows variations according to the patient's movements, pain, procedures, etc. whereas an oscillometric measurement just gives a snapshot. The reliability of these measures is extremely important to avoid under or overtreatment. [1]

Despite the fact that invasive blood pressure monitoring is considered the clinical gold standard, in small children intra-arterial catheter may be difficult to insert and may require specific medical skills. [4] Contrary to the earlier reports showing that non-invasiveblood pressure measurements are generally lower than arterial pressures [5] studies by Holt TR [1] noted that Philips automated monitors gives higher cuff pressures than direct arterial pressures when BP is lower than normal. This is also similar to the difference demonstrated by Chia et al using Dinamap non-invasive BP measurement device in critically ill children. [6] So the correct method of BP measurement remains debatable in critically ill children. Due to these reasons, we planned this study to determine the reliability of the non-invasive oscillometric method compared with the invasive technique in critically ill children admitted in Pediatric ICU.

Materials and methods

This prospective observational study was approved by the Ethics Committee of the Institute. All children admitted to the PICU during this period were screened for enrollment. The critically ill children <15 years admitted in pediatric ICU, having an indwelling radial arterial catheter in either of the limbs and whose parents were willing to give consent for the study were included. Children having arterial line other than in radial/ulnar artery and/or those with any structural abnormality of heart were excluded.The reasons for admission to our PICU were mainly respiratory, renal and neurological problems. Written informed consent was obtained from the parents/ guardians. Oscillometric non-invasive measurement was taken on right arm if the arterial line was on the left and vice-versa using a BP cuff that was appropriate to the child's arm. Invasive and oscillometric non-invasive systolic, diastolic and mean arterial BP measurements were taken on different arms of the enrolled subject simultaneously. As the differences between right and left arm BP values are unsubstantial, both arms were used. [7] NIBP measurements were performed with the use of appropriate cuffs with cuff width-to-arm

circumference ratio of 0.40-0.80 by measuring the child's mid upper arm circumference (MUAC). [8] When NIBP reading appeared on the monitor, the corresponding arterial BP was recorded on the observation checklist. BP was measured at the time of enrolment and every 3-4 hour interval for 7 days or until the catheter was in place, whichever occurred earlier. Multiple measurements were obtained from a single subject.

The arterial line was connected to a transducer, connected to MindrayBeneView T5, which was calibrated every 6 months. The catheter was maintained by infusion of heparinized isotonic normal saline solution for continuous invasive monitoring and zeroed to atmospheric pressure at the mid-axillary line. The subjects were categorized according to their age (<1yr, 1-5yr, and >5 yr), cuff size based on MUAC(<9cm, 10-19cm and 20-27cm) and presence/absence of edema. The readings were categorized on the basis of the child's age, sex and height as per the Fourth Report on the Diagnosis, Evaluation and Treatment of High Blood Pressure in Children and Adolescents, given by the U.S. Department of Health And Human Services [9].

Analysis: Statistical analysis was performed using Bland Altman plot and paired t-test to compare the mean IBP and NIBP. Differences between invasive and non-invasive measurements were plotted against the average of each pair being compared which showed the visual assessment of the bias between the two measurements. Pearson correlation coefficient was used to determine the relation between invasive and non-invasive readings.The observations were further categorized into normo-, hypo- and hypertensive groups comprising of 639, 50 and 371 paired readings respectively, based on the percentile charts.

Results: We enrolled 93 critically ill children (48 boys); 1060 paired observations were obtained. Among them, 54.8% had arterial line on left upper limb, 31.2 % and 30.1% had edema on their upper right and left limb respectively. The mean duration of ICU stay at the time of enrolment in the study was 2.72 ± 2.38 days with a median of 14 days. An average of 11 paired readings was taken on each child.

The measurement deviance when plotted against the average of invasive and oscillometric non-invasive measurements also showed that the agreement between invasive and oscillometric non-invasive systolic, diastolic and mean blood pressure measurements was wide. The non-invasively measured blood pressure measurements were overestimated as compared to the invasive blood pressure measurements (Table1).

The data was further categorized to normo-, hypo- and hypertensive groups as per the percentile charts. A statistically significant difference was found among the normotensive group and for systolic BP in hypotensive and mean arterial pressure in hypertensive group except for hypotensive diastolic and MAP and systolic and diastolic pressure in hypertensive group which showed no significant difference (Table 2). A similar difference was noticed among the three groups also.

The data was analyzed further to find the agreement of invasive and oscillometric non-invasive BP measurements with selected variables i) cuff size based on mid upper arm circumference (MUAC), ii) age and iii) edema on upper limbs. The limits of agreement appeared to be similar among the three categories. No age specific difference could be found. The use of different cuffs based on mid upper arm circumference did not make any significant difference between the invasive and non-invasive BP measurements.

The correlation coefficient ® for invasive and oscillometric non-invasive systolic was 0.96 and for both diastolic and mean arterial blood pressure measurements it was 0.95 showing good correlation between the two ($p<0.001$).

Discussion

Accurate measurement of BP is essential for the rational hemodynamic management of all critically ill children. Although both invasive and non-invasive methods are being used for blood pressure measurement, invasive method of BP monitoring is preferred over non-invasive method in hemodynamically unstable children to get accurate blood pressure, while in acutely ill children with stable hemodynamic status one can continue using non-invasive method of BP monitoring. While studies have been performed earlier in neonates and children, our study had an advantage of having more than a thousand paired readings for comparisons.

Overestimation of blood pressure by non-invasive measurements has been reported earlier in studies in newborns [6, 11, 16] and children. [1, 20, 21] Considering the studies in newborns, overestimation of non-invasive monitoring as approximately 7.6 mmHg higher than invasive measurements was found in the studies of Dannevig et al [11] O'Shea and Dempsey [23] also reported monitor specific overestimation of mean BP levels ranging from 3.3 to 8.4 mmHg in new-born infants. This finding is also similar to the findings of Diprose GK (1986) [12] and Pilossoff V (1985) [13]. However, it is in contrast to the findings of Meyer et al [14] that they found no significant difference between invasive and non-invasive readings even in extremely low birth weight infants. This may be attributable to the use of optimal cuff size, with which it is possible to obtain agreement between invasive and non-invasive measurements, as was used in our study.

Bland altman analysis was used to find the agreement between the two methods. It showed that the limits of agreement between IBP and NIBP were wide. Therefore, the invasive method of blood pressure measurement, which is the gold standard, could not be replaced by the oscillometric non-invasive method of blood pressure measurement. This finding is supported by the findings of Gevers M et al (1996)[16] that the limits of agreement for SAP, DAP and MAP were wide: 18.8 mm Hg, 17.2 mm Hg and15.2 mm Hg respectively which showed that care should be taken when interpreting the oscillometrically derived values in critically ill new born infants. It is also similar to the findings of Yigit S et al (2011) [6] that the accuracy of oscillometric BP measurement fails in preterm infants with BP within the lower limits. The findings of Araghi A et al (2006) [17] also shows that both oscillometric and auscultatory methods underestimated IABP measurements among patients with a SBP>140 mmHg ($p < 0.001$) which showed that when critical therapeutic decisions are required, IABP monitoring may be the preferred monitoring method.

We used age and anthropometry specific charts for the classification into the three groups [9] normo-, hypo- and hypertensive groups. We also evaluated the agreement between IBP and NIBP hypotensive and hypertensive readings. The trends were similar to that observed in normotensive readings. However, few authors have reported no significant differences between the two methods in the normotensive group. Findings of other studies show that outside normotensive range, the automated readings were higher during hypotension and lower during hypertension. [1] However, the number of readings of hypotensive group was only 50 compared to 639 and 371 in normotensive and hypertensive groups respectively.

Age did not appear to have an influence on the results in our study. The findings of the present study are also in concordance with the findings of Holt T R et al (2011) [1] that there is no significant difference between the methods of blood pressure measurement based on age.

Cuff size is one of the most important factors for the accuracy of the non-invasive measurements. In the present study, the agreement of invasive and oscillometric non-invasive blood pressure readings with cuff sizes based on MUAC showed that the limits of agreement appeared to be similar for different cuff sizes based on MUAC. Appropriate cuffs with cuff width-to-arm circumference ratio of 0.40-0.80 were used by measuring the child's MUAC. [8] The limits of agreements were similar which showed that use of proper cuff sizes do not make significant differences between invasive and non-invasive blood pressure measurements. Kimle et al [8] demonstrated that accurate results were obtained with a cuff width-to-arm circumference ratio of 0.45-0.70. This study finding is also similar to the findings of Soneson and Broberger [18] in which they found that mean blood pressure was overestimated by 6.2 ±7.2 mmHg ($p<0.001$) when a small cuff with width to arm circumference ratio of 0.33-0.42 was used. In the present study, by using optimal cuff size, a mean difference of 3-4 mmHg was seen between the two methods, which were not statistically significant, when the whole study group was considered. However, when the hypotensive and hypertensive groups were evaluated, a statistically significant difference between invasive and oscillometricnon-invasive measurements were found for systolic ($p= 0.016$) and mean arterial pressures ($p= 0.002$. Studies by Dannevig et al [11] showed birth weight and arm circumference affected the deviance strongly.

Most of the studies that compared IBP and NIBP showed good correlation between the two [1, 2], the accuracy of the oscillometric method is under debate because a good correlation does not guarantee clinically useful prediction.

Other studies have not examined this relationship of presence of edema on the limbs and the difference of measurement between the two methods. We did not find any influence of presence of edema and the measurement deviance.

Falsely low/high readings by the non-invasive monitors may lead to unnecessary use of volume and inotropic therapy, while over-reading may lead to under-use of vasopressors. As per the study findings, the limits of agreement are wide and oscillometric readings were overestimated. Hence, the invasive method of BP monitoring should be used in hemodynamically unstable children to get accurate blood pressure, which is the gold standard.

The strength of the study was that same catheter insertion sites were used in order to avoid bias between various catheter insertion sites. We also had a large numbers of paired readings; however, we had taken multiple observations in each patient. We used the currently followed centile charts that are based on non-invasive BP measurement. [9]
Based on our observations and previously published work, we suggest that blood pressure in critically ill children should be monitored using invasive arterial BP measurements

Acknowledgement
Authors acknowledge the contribution of the critically ill children and their parents in the study.

Table 1: Difference between invasive and oscillometricnon-invasive blood pressure

measurements n=1060

Variables		Mean ± SD	Mean difference ± SD (IBP-NIBP)	Limits of agreement	CI	p-value
Systolic blood pressure (mm Hg)	Invasive	98.38 ± 20.11	-3.60 ± 5.62	-14.84 to 7.64	-3.94 to -3.26	<0.001*
	Non-invasive	101.98 ± 19.75				
Diastolic blood pressure (mm Hg)	Invasive	58.69 ± 16.86	-3.58 ± 5.11	-14.60 to 7.44	-3.91 to -3.25	<0.001*
	Non-invasive	62.27 ± 16.85				
Mean arterial pressure (mm Hg)	Invasive	71.87 ± 17.02	-3.35 ± 5.50	-15.14 to 8.44	-3.70 to -2.99	<0.001*
	Non-invasive	75.25 ± 17.09				

IBP : Invasive blood pressure, NIBP: Oscillometric non-invasive blood pressure

Table 2: Difference between invasive and oscillometric non-invasive BP among groups

n=1060

Variable	NORMOTENSIVE Group 1 (n_1=639)		HYPOTENSIVE Group 2 (n_2=50)		HYPERTENSIVE Group 3 (n_3=371)	
	Mean ± SD	p-value	Mean ± SD	p-value	Mean ± SD	p-value
dSBP (mm Hg)	-2.96 ± 6.26	<0.001*	-3.4 ± 3.93	0.016*	-4.73 ± 4.34	0.912
dDBP (mm Hg)	-3.17 ± 5.91	0.005*	-3.04 ± 3.99	0.592	-4.36 ± 4.87	0.413
dMAP (mm Hg)	-2.89 ± 5.63	<0.001*	-3.2 ± 3.82	0.176	-4.24 ± 5.37	0.002*

Bland Altman Analysis
IBP: Invasive blood pressure
NIBP: Oscillometric non-invasive blood pressure
dSBP: Difference between invasive and oscillometric non-invasive systolic BP.
dDBP: Difference between invasive and oscillometric non-invasive diastolic BP.
dMAP: Difference between invasive and oscillometric non-invasive mean arterial pressure.

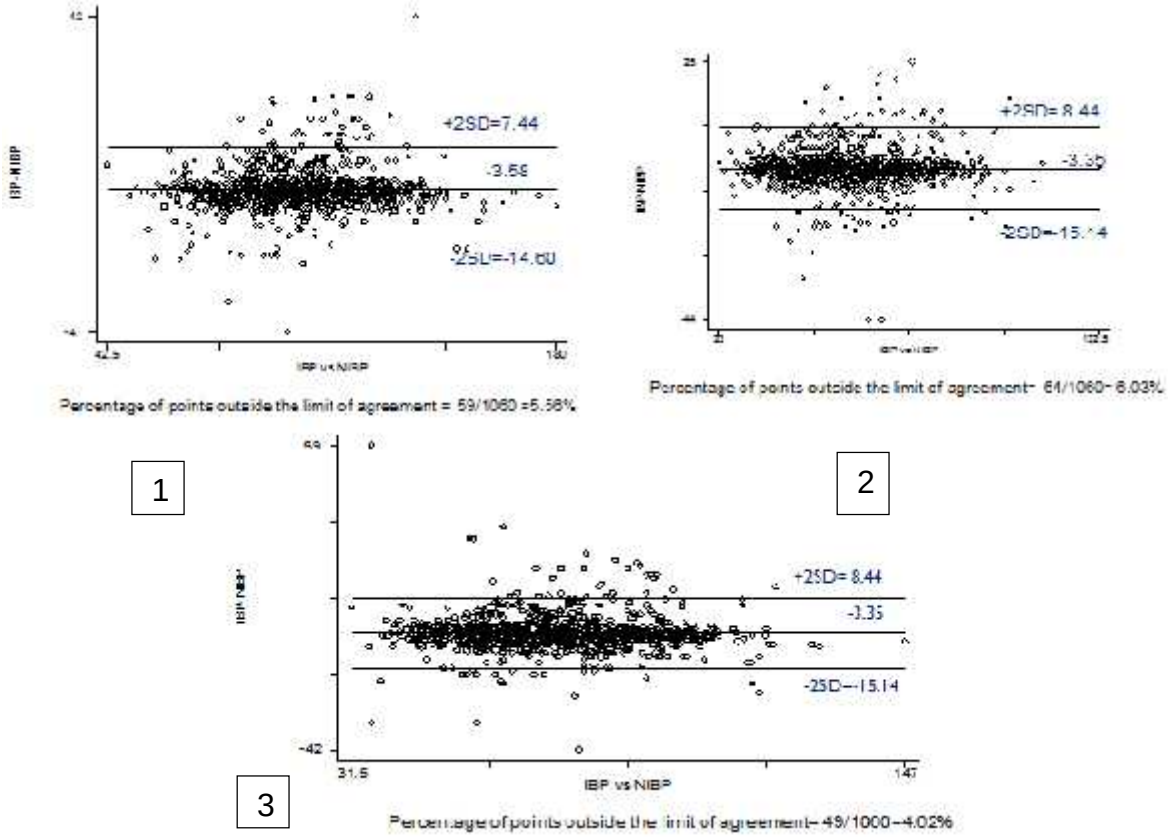

Fig 1: Agreement between invasive and oscillometric

non- invasive 1) systolic 2) diastolic and 3) mean arterial pressures

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