RESEARCH PAPER

Agreement Between Non-Invasive (Oscillatory) and Invasive Intra-Arterial Blood Pressure in the Pediatric Cardiac Critical Care Unit

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Objective: We assessed the agreement between non-invasive (oscillatory) blood pressure (NIBP) measurements and invasive intra-arterial blood pressure (IBP) in the pediatric cardiac critical care unit. **Methods:** Children with intra-arterial lines as per standard management protocol were enrolled. NIBP was measured every 4 hourly and the corresponding IBP reading was recorded. **Results:** A total of 839 brachial NIBP, 834 IBP femoral (IF), and 137 IBP radial (IR) readings were noted on 45 participants. The mean difference (95% CI) for agreement between NIBP and IF was -2.3 (-27.1, 22.5) mmHg for systolic, 0.9 (-21.3, 23.1) mmHg for diastolic and 0.3 (-23.3, 23.9) mmHg for mean BP. Similar results were found between NIBP and IR and between IF and IR. The interrater agreement [Kappa (95% CI)] was fair between NIBP and IF [0.54 (0.48, 0.61)], and IF and IR [0.62 (0.48, 0.76)] but lower between NIBP and IR [0.37(0.20, 0.55)] when values were classified as hypotensive, normotensive, and hypertensive. **Conclusions:** NIBP cannot replace but can supplement IBP in the pediatric cardiac critical care setting.

Keywords: *Accuracy, Comparison, Indirect blood pressure, Femoral blood pressure.*

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Blood pressure (BP) recording is an integral part of hemodynamic monitoring for quick therapeutic decisions in an intensive care setting. Non-invasive BP (NIBP) monitoring by an oscillatory automated device is an accepted modality in most clinical settings. Alternatively, invasive monitoring after placing an intra-arterial catheter is considered the gold standard as it provides continuous, reliable, and beat to beat monitoring of the BP [1,2]. Invasive BP (IBP) monitoring is the norm in pediatric post-cardiac surgery settings [3]. The NIBP measurement is affected by multiple factors including accuracy of the equipment, observer bias, position and movement of the arm, and the child's cooperation [4]. Determination of the appropriate BP cuff size is also crucial in pediatric patients. IBP reading is affected by movement artifact, altered pulse traveling in case of arterial dissection or stenosis, calibration errors, or overdamping and under-damping phenomena due to inappropriate dynamic response of the fluid-filled monitoring systems [5]. It is technically cumbersome and requires trained manpower to insert and maintain an arterial catheter, which may not be readily available at all facilities. IBP monitoring systems have known complications such as local tissue injury, excessive bleeding, hematoma formation, blood-stream infection, thrombosis or embolism, distal ischemia, and pseudoaneurysms of the vessels [6].

NIBP is easy, cost-effective, and avoids potential harms caused by invasive arterial line. Several studies have compared the accuracy of NIBP to IBP in intensive clinical care settings [3,7,8]. There are fewer such studies in the pediatric cardiac critical care setting [3]. This observational study assessed the agreement between NIBP by an automated oscillatory method with IBP in the pediatric cardiac critical care setting.

METHODS

This study was conducted in the pediatric cardiac critical care unit on post-operative patients who had undergone cardiothoracic surgeries. As per the protocol of the unit, the patient was induced on a radial arterial line by the anesthetic team in an operating room. Later, central venous and femoral arterial lines were inserted. Hemodynamics in the intra-operative and post-operative period were monitored via the femoral line. The radial line was not preferred for the peri-operative monitoring, particularly for the surgeries involving cardio-pulmonary bypass and was less stable in the pediatric age group due to frequent de-lining. The study was approved by the institutional ethics committed with a waiver of informed consent.

All consecutive patients with an intra-arterial line (radial and/or femoral) were selected for this study. The decision of placing an arterial line was made by the treating team. All lines were placed without ultrasound guidance. Radial and femoral lines used in the same patient were connected to the same transducer via a three-way stopcock. The radial line was usually removed on the next day of surgery, whereas the femoral line was kept as long as required. NIBP measurement was done by the oscillatory method within one hour of admission to the post-operative care unit and then repeated every four hourly. Patients with contraindications to NIBP cuff application/inflation (arm injuries or wounds, limb edema) were excluded from the study. Patients with uncorrected or inadequately corrected coarctation/ interruption of aorta were also excluded. IBP reading was concurrently noted at each instance of NIBP recording in a patient. Age, weight, height, primary diagnosis, type of surgery/intervention, and current clinical condition of all participants were recorded.

IBP measurement was performed with an appropriately sized arterial catheter (Leader-Flex, Vygon, GmbH & Co) inserted into the radial/femoral artery and connected to a disposable pressure transducer (iPeX, B L Lifesciences Pvt Ltd) using rigid pressure tubing of identical length. In neonates, a 24 G cannula (Jelco) was used to obtain a radial line. The transducer was connected to the blood pressure module of the Drager, Infinity Vista XL (Dragerwerk AG & Co) bedside monitor. The catheter was flushed with heparinized saline (2 units/mL) at the rate of 3 mL/hour to prevent clotting. However, in neonates, the rate of flow was kept at 1 mL/hour via syringe pump to reduce their fluid intake. As both radial and femoral lines were connected to the same transducer by a three-way stopcock, the flush was entering one arterial line at a time. The IBP measurements were documented every hour by rotating the valve. Four hourly IBP values for invasive femoral (IF) and invasive radial (IR) were taken to coincide with the NIBP measurements. The pressure monitoring set had a continuous flush element pigtail that could be pulled to allow the rapid flush of the system. The transducer position was at the level of the patient's 4th intercostal space at the mid-axillary line, ensuring the absence of kinking or air bubbles in the tubing and transducer. Zeroing and fast-flush test to verify optimal damping was done in every nursing shift. Oscillatory BP (NIBP) in the upper limb was measured by using Drager, NIBP cuff (Dragerwerk AG & Co) of appropriate sizes and connected to the BP module of the Drager, Infinity Vista XL – Multi-para monitor via BP cable. The NIBP was measured in a different limb to that with the arterial line.

The blood pressure measurements by all the three methods were classified as hypotensive, normotensive, and hypertensive based on age and height by systolic value [9-11]. Fifth percentile cut off was used to label hypotension in our patient population [9].

Statistical analysis: Bland-Altman analysis was performed to assess agreement amongst NIBP, invasive femoral (IF), and invasive radial (IR) recordings. Kappa statistic with quadratic weights was used to assess agreement amongst the three methods at a crude level. The analysis was performed using STATA 14.2.

RESULTS

During a period of nine months, a total of 45 (33 male) patients [median (IQR) age 12 (4,84) months] were enrolled in the study. A total of 839 upper limb NIBP measurements, 834 femoral line, and 137 radial line blood pressure readings were available. The primary diagnosis and age group of the patients are mentioned in **Table I**. All the patients were on ventilatory and inotropic support during the initial post-operative period. The median (Q1,Q3) duration for ventilatory and inotropic support was 36 (7,74) and 57 (24,80) hours, respectively. None of the patients had pre-existing hypertension or features of vasculitis. The mean difference (95% CI) for agreement between NIBP and IF line was -2.3 (-27.1, 22.5) mm Hg for systolic, 0.9 (-21.3, 23.1) mmHg for diastolic and 0.3 (-23.3, 23.9) mm Hg for mean blood pressure. The mean difference (95% CI) for agreement between NIBP and IR line was -0.5 (-23.2, 22.3) mmHg for systolic, 2.1 (-19.6, 23.8) mmHg for diastolic and 2.3 (-19.1, 23.6) mmHg for mean blood pressure. The

Table I Age Group and the Primary Diagnosis of the Patients (*N*=45)

Characteristics	*No. (%)*
Age	
<1 mo	7 (15)
1-12 mo	20 (44)
1-5 y	5 (11)
5-10 y	7 (15)
10-18 y	6 (13)
Diagnosis[a]	
Ventricular septal defect	10 (22)
Atrial septal defect	9 (20)
Tetrology of fallot	8 (18)
Total anomalous pulmonary venous return	4 (09)
Double outlet right ventricle	4 (09)

[a]*Patent ductus arteriosis and transposistion of great arteries in two children each; and anomalous origin of left coronary artery from pulmonary artery, atrio-ventricular canal, coarctation of aorta,* single *right ventricle, tricuspid atresia, severe mitral regurgitation were seen in one child each.*

Table II Agreement in Classification of Blood Pressure by NIBP and IBP

	Invasive femoral	*Invasive radial*
Hypotensive	14/37	6/7
Normotensive	558/649	90/109
Hypertensive	103/147	5/20

Numerator denotes values agreed by NIBP and IBP and denominator denotes values by NIBP alone; IBP: invasive arterial blood pressure; NIBP: non-invasive blood pressure.

agreement between IF and IR line had a mean difference (95% CI) 0.3 (-21.5, 22.2) mm Hg for systolic, -0.6 (-15.8, 14.7) mmHg for diastolic and 0.7 (-13.7, 15.1) mm Hg for mean blood pressure.

The inter-rater agreement [Kappa with quadratic weights (95% CI)] for readings classified as hypotensive, normotensive, or hypertensive was fair between NIBP and IF [0.54 (0.48, 0.61)] and between IF and IR [0.62 (0.48, 0.76)] but slightly lower between NIBP and IR [0.37(0.20, 0.55)]. IF and IR classified 109/133 (81.2%) records correctly (6 hypotensive, 89 normotensive, 14 hypertensive). The correct classification between NIBP and IF and IR is shown in **Table II**.

DISCUSSION

The mean difference between NIBP and IBP among systolic, diastolic, and mean BP readings were marginal in the present study but wide 95% confidence limits made both these methods non-comparable and irreplaceable.

NIBP gave lower readings for systolic and higher for diastolic in comparison with both IF or IR as expected norms [1] but with a minimal difference, unlike wide mean difference reported earlier [8]. Higher systolic readings with NIBP were seen in few studies [3,12]. As per our unit policy of placing the femoral line for better stability, NIBP was compared against both invasive femoral (IF) and invasive radial (IR) unlike studies which compared radial lines only [5,7,8]. Both brachial NIBP and femoral IBP in this study represent central BP, unlike, radial readings which represents peripheral BP [8]. Physiologically, a slightly elevated lower limb BP reading than the upper limb is expected. The present study did not find significant difference between upper limb (NIBP or IR) and lower limb (IF) blood pressure, as also seen in a similar study [3].

IBP should be preferentially used when patient is hemodynamically stable or deviations can be detrimental in setting like pediatric cardiac intensive care [13]. Invasive and non-invasive (oscillatory) methods have entirely different principles. IBP monitoring has a column of fluid connecting an arterial catheter to a pressure transducer [1,7]. Oscillatory devices track oscillations of the pressure in a cuff during its progressive deflation. The maximal oscillation corresponds to MAP and systolic and diastolic readings are calculated which results in different accuracy with different devices [7]. Improper cuff size and poor cooperation and movement of the pediatric subject can affect NIBP reading [4].

Though the mean difference between IF and IR readings was insignificant, a wide range existed among; systolic, diastolic, and mean BP. Invasive measurements give different values depending upon the site of measurement [7,14] and state of shock where peripheral radial pressure value may not accurate [14].

Clinically significant discrepancies in systolic blood pressure values can be present between invasive and oscillometric non-invasive methods during hypotension [2]. Outside the normotensive range, the automated readings were higher during hypotension and lower during hypertension compared to the arterial BP [15]. However, such specific trends were not seen in this study. IBP reading is affected by underdamping/resonance phenomena in a significant number of events where NIBP measurement along with IBP is beneficial [5]. A clinician should remain cautious and check for the accuracy of both the instruments if in doubt; before undertaking any treatment [7]. Thus, the use of NIBP along with IBP results in lower use of vasopressors, transfusions, and antihypertensive when compared with IBP alone [16].

There are certain limitations to the study. This study enrolled participants from neonatal age to 18 years, representing diverse body mass and stature. The agreement between NIBP and IBP in age and height related subgroups was not assessed due to the small sample size. Almost all the patients were on inotropic support during the initial post-operative period, which might have affected the actual representation of BP readings. We could not separate the readings in the presence and absence of shock (compensated or non-compensated).

To conclude, the agreement between NIBP and Invasive BP readings was not optimal, while inter-rater agreement was fair for different categories of blood pressure. Considering IBP monitoring as the gold standard in the pediatric post-cardiac surgical setting, it cannot be replaced with NIBP, but rather should supplement with NIBP when in doubt.

Ethics clearance: Institutional ethics committee; No IEC/HMPCMCE/114/Faculty/11/ dated October 1, 2019. Considering the nature of the study, a waiver of informed consent was approved.

Contributors: JT: conceptualized and designed the study, guided

WHAT THIS STUDY ADDS?

- Non-invasive blood pressure measurement should supplement intra-arterial blood pressure measurement in pediatric cardiac critical care settings.

and supervise data collection, drafted the manuscript, and approved the final manuscript; SN: conceptualized and designed the study, critical review of the manuscript, and approved the final manuscript; AK; critical inputs for design of the study and manuscript preparation, drafting the manuscript, guided and supervise data collection, and approved the final manuscript; MC; helped in study planning and execution, continued onsite data collection and interpretation, and approved the final manuscript; AP: conceptualized and designed the study, data analysis, critical input for manuscript preparation, and approved the final manuscript.

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