Original Article

Comparison of intraoperative blood pressure values measured by noninvasive versus invasive methods during normotension, hypertension, and hypotension

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Abstract

Background and Aims: Monitoring of intraoperative blood pressure (BP) is essential. We aimed to compare BP values simultaneously recorded by invasive and noninvasive methods under general anesthesia (GA) during normotension, hypertension, and hypotension. Mean arterial pressure (MAP) values calculated by the automated technique were also compared to the values obtained using predefined formula.

Material and Methods: An observational, prospective study was conducted in 250 adult patients undergoing elective surgeries under GA. Before induction, noninvasive blood pressure (NIBP) was measured in the arm in a supine position using an automated oscillometer. Radial artery in the opposite arm was cannulated. NIBP and arterial BP (ABP) were recorded simultaneously during normotension, hypotension, and hypertension.

Results: During normotension and hypertension, systolic BP (SBP) measured by NIBP and ABP were comparable. Diastolic BP (DBP) and MAP during normotension were significantly higher with NIBP (73.65 ± 7.73 vs. 65.69 ± 8.39 and 87.79 ± 8.43 vs. 84.24 ± 8.82, respectively). During hypertension, DBP and MAP were significantly higher with NIBP (90.44 ± 11.61 vs. 78.59 ± 11.09 and 111.67 ± 10.43 vs. 105.63 ± 11.06, respectively). During hypotension, SBP was significantly higher in ABP (91.14 ± 6.90 vs. 86.24 ± 6.06), and DBP and MAP were comparable. Comparison of MAP measured by ABP and NIBP techniques with the MAP calculated using predefined formula in normotension showed significantly higher values with the automated technique.

Conclusions: During normotension and hypertension, DBP and MAP showed significantly higher values with the NIBP technique compared to ABP, with comparable SBP values. During hypotension, SBP showed significantly higher values with the ABP technique, with comparable DBP and MAP. MAP obtained using predefined formula and automated method in normotension was significantly higher with the automated technique.

Keywords: Blood pressure, general anesthesia, intraoperative, invasive, noninvasive

Introduction

One of the basic vital markers for determining a patient's hemodynamic condition is the blood pressure (BP). BP should be checked every 3–5 min in patients undergoing surgery under general anesthesia (GA) because both hypertension and hypotension might affect the functioning of critical organs like heart, brain, and kidneys.

The two main monitoring techniques, that is, intermittent automated oscillometric and continuous invasive methods,

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are used in different situations, but frequently yield discrete values. This is because different proprietary algorithms are used by oscillometric monitors to determine BP from cuff vibrations. As a result of this, it is thought that the accuracy of oscillometric and intra-arterial BP readings are highly varied.[1,2] It is not always practical to employ invasive BP monitoring in all patients. Mean arterial pressure (MAP) is usually calculated based on the values of systolic and diastolic BP (SBP and DBP, respectively). It is commonly observed that MAP values obtained from established formula are often different from what is displayed in the multichannel monitors. Hence, we planned this study to assess if there is a definite relationship between the BP values simultaneously recorded by invasive and noninvasive methods.

The primary objective of the present study was to compare the SBP values simultaneously recorded by invasive and noninvasive methods under GA during normotension. The secondary objectives were to compare the SBP values recorded by invasive and noninvasive methods during hypertension and hypotension. DBP and MAP recorded by invasive and noninvasive methods during normotension, hypertension, and hypotension were also compared. MAP values recorded by the automated technique were also compared to the values obtained using predefined formula.

Material and Methods

This prospective, observational study was conducted after obtaining approval from the institutional ethical committee (ECASM-AIMS-2022-044) and informed consent from patients. The study was registered in Clinical Trial Registry of India (CTRI/2022/03/046488). Two hundred and fifty patients between 20 and 70 years of age, belonging to American Society of Anesthesiologists Physical Status (ASA PS) 1–3, requiring invasive BP monitoring, and satisfying the criteria of cuff width/arm circumference = 0.4–0.5 were enrolled for the study. Patients who were morbidly obese, those having underlying cardiac conditions, those with previous history of mastectomy or axillary lymph node dissection were excluded.

Based on the mean ± standard deviation (SD) values obtained on comparison of intraoperative SBP values recorded by noninvasive (112.39 ± 7.96) versus invasive (115.9 ± 10.05) methods in normotensive surgical patients under GA in a pilot study conducted in 20 samples and with 95% confidence and 80% power, the minimum sample size was calculated to be 54. However, during our study period, we were able to include 250 patients.

After adequate nil per oral (NPO), patients were taken to the operation theater on the day of surgery and preinduction monitors like electrocardiogram and pulse oximeter were attached. Arm circumference was measured at the midpoint of acromion process of scapula and olecranon process of ulna proximal to the antecubital fossa on one arm. A BP cuff that was appropriate according to the arm circumference, mostly of adult size 27 × 35 cm, was chosen as per the recommendation of the American Heart Association (AHA). Noninvasive BP (NIBP) was measured in the supine position before induction with Philips IntelliVue MP20 automated oscillometer to record the baseline BP. In accordance with the manufacturer's advice, calibration of these monitors was done every 2 years. Before the trial began, no additional calibration was performed.

After confirming collateral flow by employing the modified Allen's test, the contralateral arm radial artery was cannulated under local anesthesia. The arterial tubings were connected to a pressure transducer, which was then leveled in line with the heart level of a supine lying patient, corresponding to 5 cm behind the sternum. The transducer was "zeroed" before monitoring.

After adequate preoxygenation with 100% oxygen 6 L/min through a tight-fitting face mask, patients were premedicated with intravenous midazolam 2 mg, glycopyrrolate 0.2 mg, fentanyl 2 μg/kg, and propofol 2–3 mg/kg and paralyzed with atracurium 0.5 mg/kg, following which they were intubated with cuffed endotracheal tubes of internal diameter 8.0 and 7.0 mm in males and females, respectively. Patients were mechanically ventilated with a respiratory rate of 12–14 per minute and tidal volume 6–8 mL/kg body weight, and end-tidal CO_2 was maintained between 30 and 35 mmHg. Maintenance of anesthesia was established with isoflurane 1%–1.5% in oxygen:air mixture (1:1).

During the intraoperative period, NIBP and arterial BP (ABP) were recorded simultaneously at a minimum time interval of 5 min at different ranges of BP, namely, hypotension, normotension, and hypertension. A maximum of three values were recorded in each subset of BP range. Hypertension was defined as per the standard AHA/American College of Cardiology guidelines as SBP ≥140 mmHg and/or DBP ≥90 mmHg.[2] For the conduct of this study, we defined hypotension as SBP ≤90 mmHg and/or DBP ≤60 mmHg.[3]

Automated MAP values displayed on the multichannel monitor by both invasive and noninvasive methods were also simultaneously recorded during the intraoperative period. The SBP and DBP values recorded by both the methods were used to manually calculate the MAP values by using the predefined formula:

MAP = DBP + 1/3(SBP – DBP).

The calculated and automated values of MAP by both NIBP and ABP were then compared.

Statistical analysis was done using IBM Statistical Package for the Social Sciences (SPSS) 20 (SPSS Inc, Chicago, IL, USA). All continuous variables are presented as mean ± SD and categorical variables as frequency and percentage. To test the statistically significant relationship between continuous variables such as intraoperative, SBP, DBP, MAP, automated MAP and MAP calculated using predefined formula by both methods during hypertension and hypotension recorded by noninvasive versus invasive methods in normotensive patients, Pearson correlation coefficient was computed and its statistical significance was tested using linear Reg *t* test. A *P* value of <0.05 was considered as statistically significant.

Results

Data was obtained from 250 subjects. Their mean age was 54.12 ± 14.94 years. Of these, 158 patients were males and 92 were females, comprising 63.2% and 36.8% of the study population, respectively. The mean body mass index (BMI) was 25.32 ± 3.60 kg/m^2 [Table 1].

Table 1: Demographic and BMI details of patients

Variable	Mean±SD
Age	54.12±14.94
BMI	25.32±3.60
	***n* (%)**
Male	158 (63.2)
Female	92 (26.8)

BMI=body mass index, SD=standard deviation

During normotension, SBP values measured by NIBP and ABP were comparable (*P* < 0.990). SBP comparison during hypertension also yielded similar results (*P* = 0.416). DBP during normotension showed significantly higher NIBP values compared to ABP (73.65 ± 7.73 vs. 65.69 ± 8.39, *P* < 0.001). During normotension, MAP values were noted to be significantly high with NIBP measurement (87.79 ± 8.43 vs. 84.24 ± 8.82, *P* < 0.001). During periods of hypertension, DBP values were found to be significantly higher with NIBP measurement (90.44 ± 11.61 vs. 78.59 ± 11.09, *P* < 0.001). MAP during hypertension was also significantly higher with NIBP (111.67 ± 10.43 vs. 105.63 ± 11.06, *P* < 0.001). SBP readings were significantly higher in ABP (91.14 ± 6.90 vs. 86.24 ± 6.06, *P* < 0.002) during periods of hypotension, whereas DBP and MAP were comparable (*P* = 0.857 and 0.376, respectively) [Tables 2-4]. MAP values measured by the ABP and NIBP techniques when compared to MAP calculated using predefined formula during normotension showed significantly higher values with the automated technique [Table 5].

Discussion

Invasive ABP monitoring is considered the gold standard and the values obtained are deemed superior to those obtained using noninvasive technique. However, very often, there is a gross difference in the simultaneous ABP and NIBP values recorded, resulting in a dilemma among healthcare professionals as to which values represent the actual BP of the patient. Though there are many trials which investigated this extensively, there is no consensus yet.

Techniques of BP monitoring can be categorized into noninvasive and invasive methods. The three most used methods for measuring BP are intermittent oscillometry, continuous noninvasive, and continuous intra-arterial.[4] It is

Table 2: Comparison of SBP, DBP, and MAP during normotension

	Normotension				
Variable	**ABP (Mean±SD)**	**NIBP (Mean±SD)**	***P***	**Correlation coefficient (*r*)**	***P***
SBP	114.728±10.857	114.736±8.921	0.990	0.440	<0.001
DBP	65.69±8.39	73.65±7.73	<0.001	0.381	<0.001
MAP	84.24±8.82	87.79±8.43	<0.001	0.481	<0.001

ABP=arterial blood pressure, DBP=diastolic blood pressure, MAP=mean arterial pressure, NIBP=noninvasive blood pressure, SBP=systolic blood pressure

Table 3: Comparison of SBP, DBP, and MAP during hypertension

	Hypertension				
Variable	**ABP (Mean±SD)**	**NIBP (Mean±SD)**	***P***	**Correlation coefficient (*r*)**	***P***
SBP	147.49±14.566	148.61±10.084	0.416	0.591	<0.001
DBP	78.59±11.093	90.44±11.614	<0.001	0.592	<0.001
MAP	105.63±11.061	111.67±10.435	<0.001	0.591	<0.001

ABP=arterial blood pressure, DBP=diastolic blood pressure, MAP=mean arterial pressure, NIBP=noninvasive blood pressure, SBP=systolic blood pressure

Table 4: Comparison of SBP, DBP, and MAP during hypotension

	Hypotension				
Variable	**ABP (Mean±SD)**	**NIBP (Mean±SD)**	***P***	**Correlation coefficient (*r*)**	***P***
SBP	91.14±6.906	86.24±6.065	0.002	−0.007	0.965
DBP	54.61±8.533	54.37±4.970	0.857	0.331	0.034
MAP	66.77±6.512	65.57±6.108	0.376	0.022	0.890

ABP=arterial blood pressure, DBP=diastolic blood pressure, MAP=mean arterial pressure, NIBP=noninvasive blood pressure, SBP=systolic blood pressure

Table 5: Comparison of automated and calculated MAP during normotension

Variable	Automated (Mean±SD)	Calculated (Mean±SD)	*P*	Correlation coefficient (*r*)	*P*
ABP	84.24±8.82	82.04±8.25	<0.001	0.967	<0.001
NIBP	87.79±8.43	87.34±7.24	0.035	0.921	<0.001

ABP=arterial blood pressure, MAP=mean arterial pressure, NIBP=noninvasive blood pressure

critical to understand the benefits, drawbacks, and restrictions of the many measurement modalities that are currently available, as well as some of the technical principles that underpin these modalities. The most frequently employed modality is the intermittent oscillometric measurement with an inflatable cuff.[5] The benchmark for monitoring BP is still continuous intra-arterial method using an indwelling catheter since it is thought to be the most accurate and represents beat-to-beat variability of BP.[6,7] Continuous noninvasive methods like the finger cuff technique using the volume clamp method allows continuous monitoring of the blood arterial waveform without catheterizing the artery.[8] As a relatively new technique, it has not been extensively adopted in routine practice.

Most of the published data includes studies conducted in the intensive care unit (ICU) setting in critically ill patients on various inotropic supports and in pediatric population. In our study, we had observed that during periods of normotension, the SBP values measured by NIBP and ABP techniques were comparable. Similar observations were made by Kaufmann *et al.*,[9] Kaur *et al.*,[10] Holt *et al.*,[11] and Takci *et al.*[12] However, in case of DBP measurement during normotension, we observed significantly higher values of NIBP compared to ABP. This was against the result of the above studies where the DBP values were comparable when measured by both techniques. The reasons for the contradictory observations could be that the study populations were different. Kaufmann *et al.*,[9] Holt *et al.*,[11] and Takci *et al.*[12] performed their studies in an intensive care setting in awake, critically ill pediatric population on inotropic supports. Kaur *et al.*,[10] on the other hand, studied critically sick adult patients on inotropes in a patient transport setting. Observations made by Lalan and Blowey[13] showed greater DBP values with noninvasive methods. Their result was similar to our study observations. Similar results were obtained with MAP, where NIBP showed a significantly higher reading than ABP in our study. However, this study population included neonates and accuracy of oscillometric method was evaluated with that of ABP monitoring.

On analyzing the simultaneous readings obtained by both methods during periods of hypertension, SBP measured by NIBP and ABP did not show significant difference. Studies by Wax *et al.*[14] and Marouane *et al.*[15] reported higher SBP with invasive intra-arterial technique when compared to the oscillometric cuff method. The possible reason for this difference in results could be that firstly, they were retrospective studies and secondly, the measurements were made using a different oscillometer and the size of the NIBP cuff was not documented. We observed that diastolic pressures during hypertension were significantly higher with NIBP. Similar conclusions were made by Manios *et al.*[16] who observed elevated BP values in a setting of acute stroke. Wax *et al.*[14] and Holt *et al.*[11] found higher ABP readings than NIBP in their studies. The possible explanations for the differing results have been already mentioned earlier. In other studies by Zhang *et al.*[17] and Marouane *et al.*,[15] the diastolic pressures were found to be comparable. The reason for the conflicting results could be that Zhang *et al.*[17] conducted an ICU study enrolling women with peripartum hypertensive disorders treated with intravenous nicardipine and used a MX450 automatic monitor (Philips, Boblingen, Germany) for recording the BP values. Similar observations were made for the mean arterial pressures of during hypertension in our study. This result was different from the results obtained by Wax *et al.*,[14] Marouane *et al.*,[15] and Zhang *et al.*,[17] where the mean pressures were higher with the invasive method than the noninvasive modality. The probable reasons for the different conclusions have been discussed already.

In our study, significantly higher readings of SBP were found in ABP during periods of hypotension. This result was different from the studies of Wax *et al.*,[14] Holt *et al.*,[11] and Takci *et al.*,[12] who obtained higher NIBP values, whereas Zhou *et al.*[18] got comparable SBP readings. The studies by Takci *et al.*[12] and Zhou *et al.*[18] were conducted in premature neonates in NICU using an umbilical artery catheter and Infinity Vista XL (Draeger Medical Systems Inc., Telford, PA, USA) monitor for invasive monitoring. The DBP values recorded during hypotensive episodes were comparable with the NIBP and ABP modalities in the present study. This was in agreement with a previous study conducted by Holt *et al.*[11] However, the conclusions were different from those reported by Wax *et al.*[14] and Takci *et al.*,[12] in which both DBP and MAP values were found to be higher with the NIBP method. In our study, the MAP values recorded in both methods during hypotension were almost comparable. This was also against the analysis by Zhou *et al.*[18] that resulted in higher ABP-recorded values.

We also compared the MAP values measured by ABP and NIBP techniques with MAP calculated using predefined formula in normotension. This was a major difference of our study, which could be pointed out from most of the previous trials. It was observed that the mean values measured with automated technique showed significantly higher values than the mean values obtained with predefined formula. However, the automated mean values measured with NIBP were clinically more relatable to the mean values obtained by calculating with the predefined formula than the mean values measured with ABP.

By generating the linear regression equation for each category of BP, that is, normotension, hypertension, and hypotension, we also attempted to estimate ABP roughly with NIBP in this study, allowing a scope for prediction of ABP in its absence.

$$\text{ASBP during normotension} = (\text{NISBP} \times 0.536) + 53.250$$

$$\text{ADBP during normotension} = (\text{NIDBP} \times 0.414) + 35.220$$

$$\text{ASBP during hypertension} = (\text{NISBP} \times 0.854) + 20.555$$

$$\text{ADBP during hypertension} = (\text{NIDBP} \times 0.566) + 27.416$$

$$\text{ADBP during hypotension} = (\text{NIDBP} \times 0.568) + 23.699$$

(ASBP = arterial SBP, ADBP = arterial DBP, NISBP = noninvasive SBP, NIDBP = noninvasive DBP). As there was a negative low degree of correlation for SBP during hypotension, we were not able to derive any formula for prediction of arterial SBP from noninvasive values.

We did not induce hypotension or hypertension deliberately during the study period. The range of BP values to be considered as hypotension, normotension, or hypertension has been already defined. The values were collected whenever the patient developed BP variations in the predefined ranges. Our study had several limitations. It was a single-center study. BP values were recorded only during the intraoperative period. We included patients aged 20–70 years in the trial. Subgroup analysis of BP values based on age was not performed, which is a drawback of our study. We did not examine other factors that might influence the differences between ABP and NIBP readings, such as specific disease states, BMI, waist hip ratio, brachial artery intimal thickness, vasoactive drugs, and others. Since just one manufacturer's oscillometric device was employed in this investigation, our findings might not be generalized to other oscillometric devices.

Conclusions

It is concluded that during normotension and hypertension, DBP and MAP showed significantly higher values with the NIBP technique compared to ABP, with comparable SBP values. During hypotension, SBP showed significantly higher values with ABP technique, with comparable DBP and MAP values. MAP calculated using predefined formula in normotension was significantly higher with the automated technique.

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Conflicts of interest

There are no conflicts of interest.

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