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REPORTS OF ORIGINAL INVESTIGATIONS

The impact of blood pressure cuff location on the accuracy of noninvasive blood pressure measurements in obese patients: an observational study

Impact de l'emplacement du brassard pneumatique sur la précision des mesures non invasives de la tension artérielle chez les patients obèses: une étude observationnelle

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Abstract

Purpose *Obesity presents many challenges to the anesthesiologist, including poorly fitting blood pressure (BP) cuffs due to the conical shape of the upper arm. The aim of this study was to determine the accuracy of noninvasive BP readings, obtained from a noninvasive BP cuff using various cuff locations and wrapping techniques, compared with invasive intra-arterial BP readings.*

Methods *Thirty American Society of Anesthesiologists physical status I-III obese (body mass index > 30 kg·m^{-2}) individuals undergoing non-cardiac surgery were enrolled in this observational study. Serial oscillometric noninvasive BP (NIBP) measurements were taken in the patients' forearm and upper arm with two different wrapping formations (one following the contour of the upper arm, the other keeping cuff edges parallel). These NIBP measurements were compared with invasive arterial blood pressure (ABP) measurements taken from the ipsilateral radial artery. The precision and bias of the NIBP and ABP measurements were determined using Bland-Altman analysis. Analysis of variance and Welch's t test were used to determine between-group differences in bias.*

Results *There was poor agreement between the ABP measurements and all types of NIBP measurements. Each of our study participants had a least one NIBP parameter (mean arterial pressure, systolic BP, or diastolic BP) that was > 10 mmHg different than the corresponding ABP parameter. Upper arm BP measurements showed a statistically insignificant trend toward underestimating ABP. For all cuff positions and wrapping techniques, systolic BP offered the best agreement between NIBP and ABP measurements.*

Conclusions *All the forms of NIBP cuff orientation studied had unacceptable precision and bias compared with invasive ABP measurements. When patient and/or surgical conditions necessitate accurate BP monitoring, direct arterial measurement should be considered over NIBP measurements in obese patients.*

Résumé

Objectif *L'obésité pose de nombreux défis à l'anesthésiologiste, notamment des brassards pneumatiques difficiles à ajuster en raison de la forme conique du bras. L'objectif de cette étude était de déterminer la précision des mesures non invasives de la tension artérielle (TA) obtenues à l'aide d'un brassard pneumatique non invasif placé à différents niveaux et ajusté différemment, et de les comparer à des mesures invasives intra-artérielles de la TA.*

Author contributions *Nicolas Anast* and *Megan Olejniczak* collected all the data and shared the primary authorship role. *Jerry Ingrande* performed the statistical analysis. All the authors shared manuscript preparation. *Jerry Ingrande* and *John Brock-Utne* served as advisors and editors.

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Méthode *Trente personnes obèses de statut physique I-III selon la classification de l'American Society of Anesthesiologists (indice de masse corporelle > 30 kg·m^{-2}) subissant une chirurgie non cardiaque ont participé à cette étude observationnelle. Des mesures de la TA non invasives (TA-NI) réalisées par oscillométrie en série ont été prises au niveau de l'avant-bras et du bras des patients en plaçant le brassard de deux façons différentes (l'une en suivant le pourtour du bras, l'autre en gardant parallèles les bords du brassard). Ces mesures TA-NI ont été comparées aux mesures intra-artérielles de la tension artérielle invasives (TA-I) prises au niveau de l'artère radiale ipsilatérale. La précision et le biais des mesures TA-NI et TA-I ont été déterminés à l'aide d'une analyse de Bland-Altman. L'analyse de la variance et le test t de Welch ont été utilisés pour déterminer les différences de biais entre les groupes.*

Résultats *Les mesures TA-I et TA-NI, tous types confondus, concordaient peu. Chacun des participants à l'étude avait au moins un paramètre de TA-NI (tension artérielle moyenne, TA systolique ou TA diastolique) qui était différent de plus de 10 mmHg au paramètre TA-I correspondant. Lors des mesures de TA au niveau du bras, on a observé une tendance non significative d'un point de vue statistique vers une sous-estimation de la TA-I. Quelle que soit la position du brassard et la technique de placement, la TA systolique était celle affichant le plus de concordance entre les mesures TA-NI et TA-I.*

Conclusion *Toutes les méthodes de positionnement du brassard pour mesurer la TA de façon non invasive étudiées ont donné des mesures dont la précision et le biais étaient inacceptables par rapport aux mesures invasives de la TA. Lorsque les conditions liées au patient et/ou à la chirurgie nécessitent un monitorage précis de la TA, une mesure artérielle directe doit être envisagée plutôt que des mesures non invasives chez les patients obèses.*

A recent study in the United States found that one-third of all adults are obese,[1] making obesity one of the most common comorbidities among surgical patients. Obesity presents a number of challenges to the anesthesiologist and is often associated with obstructive sleep apnea, hyperlipidemia, hypertension, insulin resistance, and cardiovascular disease. Appropriate and accurate monitoring is necessary when caring for these patients in the perioperative period.

Blood pressure (BP) monitoring is one of the standard intraoperative monitors universally recommended by numerous guidelines for the practice of anesthesia.[2,3] Automated devices that use oscillometric techniques for noninvasive blood pressure (NIBP) measurement are widely used in clinical practice. Nevertheless, validation protocols for NIBP systems set forth by the American Association for the Advancement of Medical Instrumentation may not be adequate in obese individuals.[4] These validation protocols require only a minimum of 10% of a validation study population to have an arm circumference > 35 cm. It is recognized that oscillometric NIBP monitors passing established validation protocols may fail to provide accurate blood pressure measurements in certain patients.[5] Thus, any limitations of these NIBP devices deserve close attention and thorough investigation.

In addition to the inherent equipment limitations, obese patients present additional challenges due to their anthropometric changes, specifically with the conical shape to their upper extremity anatomy. Accordingly, NIBP measured with an upper arm BP cuff may be difficult to accomplish due to the size and shape of the arm,[6] resulting in uncertainty in the accuracy of the measurements obtained.[7] An alternative method is invasive blood pressure monitoring using a direct arterial cannula, but this can be a challenge to place in the obese patient and does have some, albeit very low, risk.[8]

In obese individuals, the conical shape of the upper arm is exaggerated compared with that of the forearm. As a result, conventional cylindrical BP cuffs may fit poorly on the upper arm but may often be easier to place on the less conical forearm in morbidly obese patients. Nevertheless, studies validating BP cuff placement on the forearm *vs* the upper arm provide little information relating to obese participants or specific body mass index (BMI) measurements.[9-13]

The purpose of our study was to determine the accuracy of oscillometric NIBP measurements, using cuffs at different locations and with various wrapping techniques, compared with intra-arterial measurements in obese patients undergoing surgery.

Methods

The Stanford University School of Medicine Institutional Review Board granted approval for this prospective observational study in November 2011. All the subjects provided written informed consent prior to study enrolment. Thirty obese (BMI > 30 kg·m^{-2}) individuals, American Society of Anesthesiologists physical status I-III and scheduled for surgery, were enrolled in the study from January 24, 2012 to June 17, 2014. Patients undergoing intra-abdominal, bariatric (gastric sleeve or gastric bypass), orthopedic, urologic, gynecologic, plastic, neurologic, or ear, nose, and throat procedures were included for enrolment. Exclusion criteria included patients requiring cardiac or vascular surgery; those with a history of significant cardiopulmonary disease, uncontrolled hypertension, or diseases affecting the adrenocortical axis; those with the potential for significant intraoperative fluid shifts or blood loss; and emergency surgery. Eligible study participants were identified by chart review. Invasive blood pressure monitoring was used at the discretion of the attending anesthesiologist. No patient received an arterial catheter solely for inclusion in our study. To ensure reliability and consistency in how the measurements were taken, recruitment was also dependent on the availability of one of two authors (N.A. or M.O.) to collect data.

Prior to surgery, each patient's arm circumference was measured at three positions: (1) proximal upper arm at the axilla, (2) distal upper arm just above the elbow, and (3) forearm midway between the elbow and the wrist, and the results were recorded. An appropriately sized (20.5 × 28 cm, 27 × 35 cm, or 34 × 43 cm) NIBP cuff (Philips Comfort Care Adult; Philips Medical Systems, Andover, MA, USA) was selected based on American Heart Association recommendations (i.e., optimal bladder length and width should be 80% and 40% of the patient's arm circumference, respectively).[14] The NIBP cuff selected for the forearm was based on the same sizing requirements as suggested for the upper arm. For many patients, this resulted in using a cuff one size smaller on the forearm than that used on the upper arm. For some patients, however, there was limited size difference between the upper arm and the forearm; consequently, the same cuff size was used for both measurements.

The size of each NIBP cuff used was recorded along with the participants' BMI and presence of pertinent comorbidities. A 20G radial arterial catheter (Arrow International Teleflex®, Morrisville, NC, USA) was inserted for arterial blood pressure (ABP) measurement either pre- or post-induction at the discretion of the attending anesthesiologist. Transpac IV® disposable pressure transducers (**icu**medical, San Clemente, CA, USA) were zeroed at the patients' heart level. Both ABP and NIBP measurements were taken using the integrated Philips IntelliVue MP90 patient monitoring system.

All BP measurements for our study were taken with the patient under general anesthesia during a period of hemodynamic stability. When access to the patient's arm was limited due to surgical positioning, the patient was kept anesthetized at the completion of the procedure to complete the BP measurements. None of the patients received an infusion of vasoactive medication at the time of BP measurement. With patients in the supine position, BP measurements were taken at least two minutes apart with both the intra-arterial pressure transducer and the patient's arm with the NIBP cuff placed at heart level. The NIBP measurements were taken on the ipsilateral arm as the arterial catheter.

The NIBP measurements were taken using three different cuff positions: (1) cuff placed cylindrically around the upper arm, (2) cuff placed conically around the upper arm, and (3) cuff placed cylindrically around the forearm with the cuff body centred midway between the wrist and the elbow (Fig. 1). The NIBP measurements were taken twice in each of these positions. With each cycle of the BP cuff, systolic blood pressure (SBP), diastolic blood pressure (DBP), and mean arterial pressure (MAP) were recorded individually. The ABP (with its corresponding SBP, DBP, and MAP) in the ipsilateral arm was recorded ten seconds following deflation of the cuff from the preceding NIBP measurement.

Statistical analysis

Power analysis determined that 22 subjects were required to detect a 10 mmHg difference between arterial and NIBP measurements with an $\alpha = 0.05$ and a power of 0.9. A 10 mmHg difference between ABP and NIBP measurements was selected as being clinically significant because it represents twice the current standard difference in blood pressure (i.e., 5 mmHg) required for NIBP system accuracy by the Association for the Advancement of Medical Instrumentation.[15] Histograms of the data confirmed normality. Precision and bias were measured using the Bland-Altman method.[16,17] Mixed-effects models were used to account for within subject variability, and models were compared using analysis of variance. Analysis of variance, followed by the Welch's *t* test, was used to determine between-group differences in bias. Linear regression (continuous data) and logistic regression (categorical data) were used to determine relationships between patient characteristics and the difference between arterial and noninvasive blood pressure measurements. All statistical analysis was performed using R (R Development Core Team, 2008).[18]

Results

Thirty subjects were enrolled in the study (Table 1). Each subject contributed six different NIBP measurements (a single forearm and two different upper arm cuff measurements, with the three measurements taken twice) with six corresponding ABP measurements. This produced 18 comparative data sets of the three blood pressure parameters (SBP, DBP, and MAP) between the NIBP and ABP for each patient.

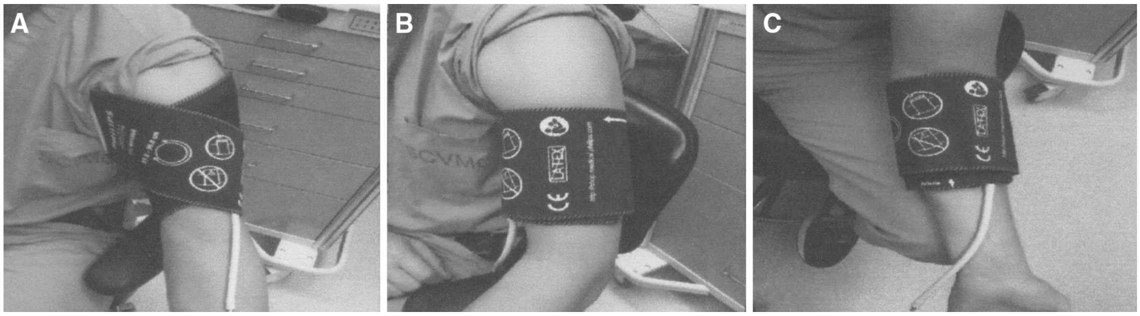

Fig. 1 Oscillometric noninvasive blood pressure cuff positions. A) Conical wrap: Blood pressure cuff wrapped around upper arm so that the contour of the cuff is identical to the contour of the arm, even if the ends of the cuff crisscross. B) Cylindrical wrap: Blood pressure cuff wrapped around upper arm so that the edges of the cuff are parallel to one another, even if this results in a large gap between the distal arm and the cuff. C) Forearm wrap: Blood pressure cuff placed on the forearm midway between the elbow and the wrist with the edges of the cuff parallel to one another

Table 1 Patient characteristics

		n (%)
Study participants		30
Male		11 (37)
Hypertension		18 (60)
Peripheral Vascular Disease		1 (3)
Coronary Artery Disease		5 (17)
	mean (SD)	Range
BMI (kg·m^{-2})	39.9 (9.7)	30-70
Age (yr)	54.6 (15.6)	29-76
Arm circumference (cm)		
Axilla	44 (6)	33-62
Elbow	33 (4)	27-41
Forearm	27 (3)	23-33
Arterial Blood Pressure (mmHg)		
Systolic Blood Pressure (SBP)	124(24)	81-198
Diastolic Blood Pressure (DBP)	68(13)	34-94
Mean Arterial Pressure (MAP)	85(16)	45-123

BMI = body mass index

Table 2 shows the mean (SD) value for each blood pressure parameter according to NIBP cuff position and the corresponding ABP. Bland-Altman plots showed the imprecision of NIBP *vs* ABP measurements (Figs. 2-4). We defined *a priori* a 10 mmHg difference between NIBP and ABP measurements as clinically relevant. For each study participant, a least one NIBP parameter (MAP, SBP, or DBP) was "clinically different" from the corresponding ABP parameter. The number of clinically different NIBP parameters for each patient ranged from 1-16 (out of 18 total data sets as defined above). Analysis of Bland-Altman plots also showed that the 95% limits of agreement (dotted lines) were beyond the *a priori* 10 mmHg (ABP-NIBP) difference for all cuff orientations (Figs. 2-4).

Linear models showed no significant relationship between BMI, total body weight, or lean body weight and the NIBP to ABP differences. There were no significant relationships between patient comorbid conditions (hypertension, peripheral or coronary vascular disease) and age, arm circumference, or cuff size.

The mean (SD) MAP measured with the NIBP cuff in the conical position was the only significantly different measurement from the corresponding ABP measurement [77.2 (15.5) mmHg *vs* 84.4 (16.5) mmHg, respectively; mean difference, −7.2; 95% confidence interval, −12.1 to 26.5; $P = 0.027$]. Measurements of both SBP and DBP did not show significant differences from ABP measurements across all NIBP cuff positions (Table 2).

All the NIBP parameters (MAP, SBP, and DBP) for all the positions (cylindrical, conical, and forearm) showed poor precision compared with the ABP measurements (Figs. 2-4). Although only one measurement showed statistically significant bias (ABP MAP *vs* conical NIBP MAP), our data suggest that both upper arm cuff orientations systematically underestimate blood pressure. The forearm cuff location showed the least bias. There was no significant difference between the ABP measurements taken for each NIBP position.

Discussion

As the number of obese patients presenting for surgery increases, anesthesiologists must have confidence in the accuracy of their monitoring equipment for these patients. The difficulty in properly fitting many obese patients with an NIBP cuff has led practitioners to attempt measuring BP using a variety of blood pressure cuff wrapping techniques and locations, e.g., the forearm. Currently, there is no consensus regarding the accuracy of measurements obtained at these different locations. Accordingly, the

Table 2 Comparison of mean NIBP *vs* ABP parameters

Measurement	NIBP	ABP	ABP-NIBP difference	95% Limits of Agreement	*P* value
Conical Upper Arm vs Arterial					
MAP	77.2 (15.5)	84.4 (16.5)	7.2	(−12.1 to 26.5)	0.027
SBP	119.5 (25)	125.3 (27.2)	5.8	(−14.4 to 26.0)	0.275
DBP	62.5 (12.3)	67.1 (13.2)	4.6	(−12.8 to 22.0)	0.080
Cylindrical Upper Arm *vs* Arterial					
MAP	79.9 (14.4)	85.1 (15.5)	5.2	(−11.2 to 22.2)	0.084
SBP	120 (22.1)	125.7 (25.2)	5.7	(−11.5 to 22.9)	0.247
DBP	65 (13)	68 (12.9)	3	(−18.3 to 24.3)	0.263
Forearm *vs* Arterial					
MAP	83.1 (15.7)	86.2 (15.3)	3.1	(−14.6 to 20.9)	0.324
SBP	125.4 (22.3)	123.2 (21.1)	−2.2	(−19.7 to 15.3)	0.616
DBP	68.6 (14.1)	68.7 (12.1)	0.1	(−20.7 to 20.9)	0.983

Data are represented as mean (SD). ABP = arterial blood pressure; DBP = diastolic blood pressure; MAP = mean arterial pressure; NIBP = noninvasive blood pressure; SBP = systolic blood pressure

current study was conducted to determine the accuracy of these alternate positioning techniques for blood pressure monitoring in obese patients.

Current recommendations for sizing a blood pressure cuff for upper arm measurement specify selecting a bladder width and a bladder length equal to 40% and 80% of the upper arm circumference, respectively.[14] Current recommendations do not specify the size of blood pressure cuff for use in the forearm location. For this study, we used the same criteria to select both the upper arm and the forearm NIBP cuff.

Prior studies comparing NIBP measurements on the forearm with measurements on the upper arm (with an appropriately sized cuff) have shown a trend for overestimation of systolic, diastolic, and mean pressures in the forearm location.[9-13,19] Although these studies were based on NIBP measurements alone, our results show a similar trend toward forearm overestimation. In our study, the NIBP measurements taken on the upper arm showed a tendency toward underestimating ABP. The MAP measurements taken on the forearm underestimated the ABP MAP, while the SBP measurements taken on the forearm overestimated the ABP MAP. There was good agreement between the NIBP DBP and the ABP DBP measurements taken on the forearm.

Recently, Leblanc *et al.*[20] compared NIBP measurements obtained from the upper arm and forearm of morbidly obese patients with intra-arterial control measurements from the contralateral arm. The investigators found that the NIBP measurements from both the upper arm and forearm locations resulted in SBP and DBP measurements that closely correlated with those obtained from the intra-arterial measurements. While correlation is a good indication of *association* between measurements, it does not indicate *agreement* between measurements. The Bland-Altman plot, as shown in our study, is a better and more reliable method of illustrating precision and bias in a measurement. Although there are no differences in mean measurements for many of our measurement groups (SBP and DBP for upper arm measurements and MAP, SBP, and DBP for forearm measurements) (Table 2), there is a lack of precision demonstrated by the Bland-Altman plots and a bias toward underestimating ABP (Figs. 2-4).

The poor agreement between ABP and NIBP measurements observed in our study may be related to equipment validation methods. The American Association for the Advancement of Medical Instrumentation validation protocol requires 10% of a validation study population to have an arm circumference > 35 cm.[4] In our study population, nine of 30 patients (30%) had a distal upper arm circumference (just proximal to the elbow) > 35 cm, and this may have influenced the accuracy of NIBP measurements.

In an attempt to address current limitations in the sizing of blood pressure cuffs for large and obese patients, GE Healthcare recently released a conical blood pressure cuff for use on the forearm. In the validation study, Hersh *et al.*[21] compared intra-arterial pressures taken at the radial artery with ipsilateral oscillometric NIBP measurements taken at the forearm in 34 patients with a mid-arm circumference > 40 cm and an average BMI of 33 $kg \cdot m^{-2}$. They found good agreement between the intra-arterial measurements and the measurements made with the conical forearm cuff for SBP, DBP, and MAP (reported mean errors −0.82, 1.53, and 2.58 mmHg, respectively). Importantly, the NIBP cuff used in this study was designed to fit a conically shaped forearm. Ideally, the cuff shape

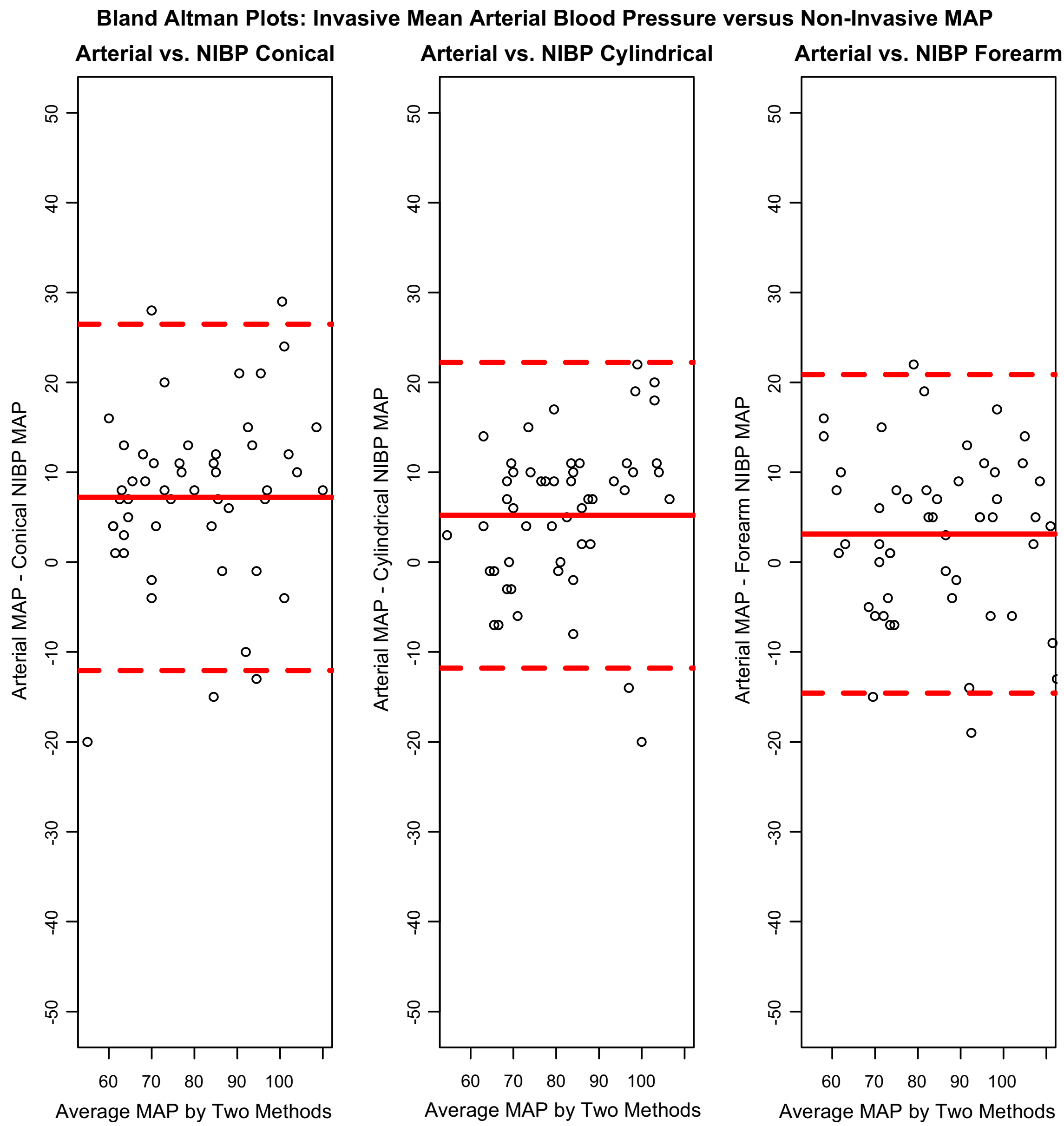

Fig. 2 Bland-Altman plots of arterial blood pressure (ABP) *vs* noninvasive blood pressure (NIBP) mean arterial pressure (MAP) measurements

mirrored the arm shape, making appropriate contact with the skin and minimizing gaps between skin and cuff along the entire length of the cuff. This suggests that properly fitting conical forearm cuffs can produce accurate blood pressure readings. Nevertheless, based on our data, currently available cylindrical cuffs do not accurately measure blood pressure when placed on the forearm.

The mean blood pressure value is accepted as the most accurate value derived from NIBP measurements because it correlates directly with the maximum oscillations detected by the system. In contrast, the systolic and diastolic values are determined using a mathematical algorithm.[22] For this reason, one might expect to find the best agreement between mean blood pressure measurements obtained with the NIBP cuff and the intra-arterial measurements in obese subjects. The fact that our results show better agreement with systolic pressures than with mean pressure suggests that the current algorithm in use for NIBP measurements may not be applicable to all patients. Indeed, this remains an area of active research in the biomedical engineering community.[23]

In addition to providing inaccurate BP readings, NIBP measurement systems are occasionally unable to provide *any* reading in obese patients. This results in prolonged time between measurements and can put patient safety at risk. During our study, we did encounter this problem.

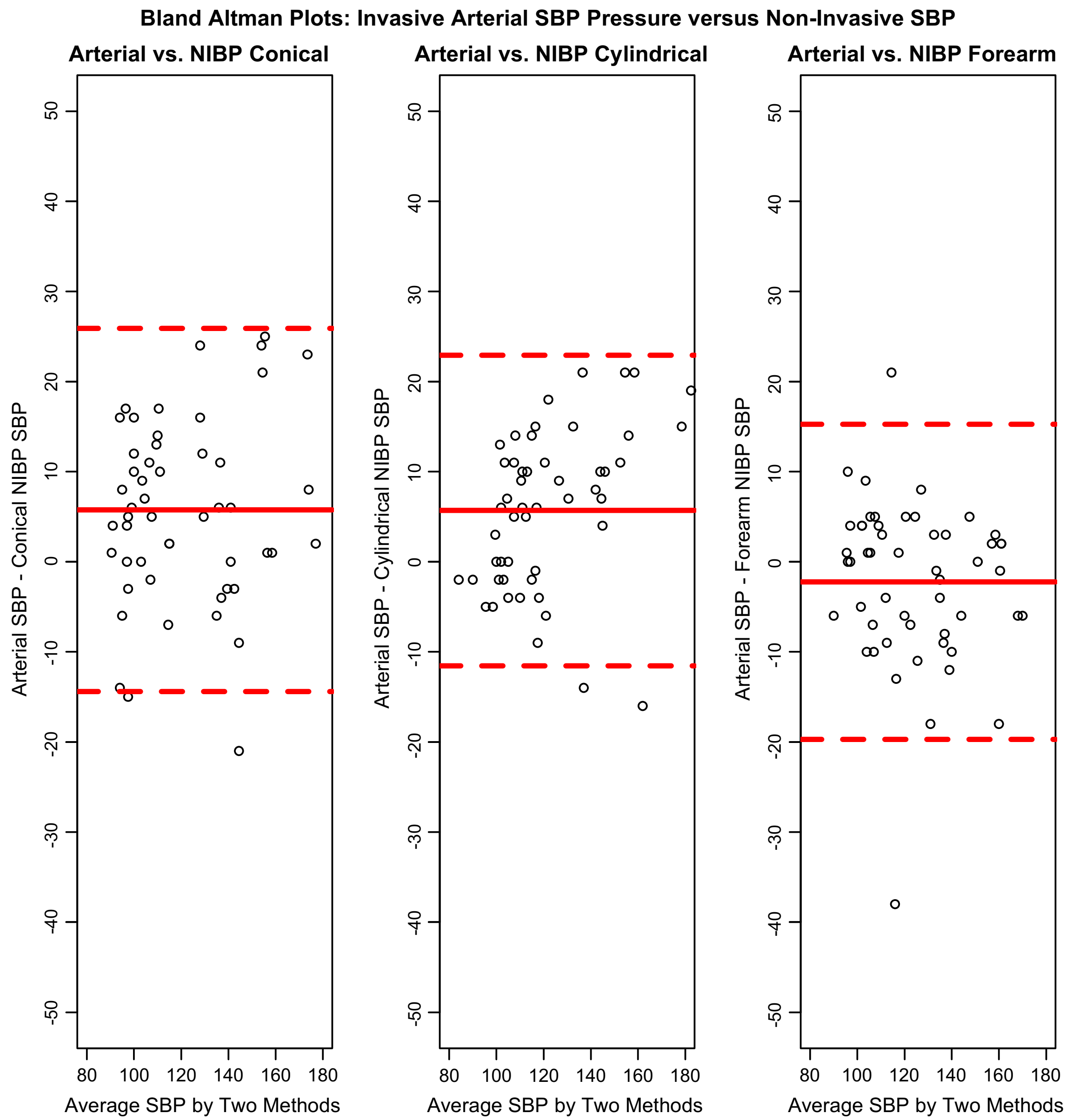

Fig. 3 Bland-Altman plots of arterial blood pressure (ABP) *vs* noninvasive blood pressure (NIBP) systolic blood pressure (SBP) measurements

When the NIBP cuff failed to produce a reading, a repeat measurement was taken. Though infrequent, we did not record the actual number of times we encountered this problem. These data would be helpful in further establishing the limitations of NIBP measurement systems in obese patients and should be included in future studies.

There were other limitations to our study. For example, two investigators were responsible for recording the blood pressure values, thereby rendering them non-blinded. Nevertheless, we do not consider recorder bias a limitation to this study. Although the recorders (N.A. and M.O.) were not blinded to the BP site being recorded, the investigator performing the data analysis (J.I.) was blinded and took no part in the actual data recording.

Based on the results of this study, we cannot recommend a best orientation for obtaining noninvasive blood pressure measurements. All NIBP cuff orientations show poor precision and bias when compared with the ABP measurement. More research is needed to determine the appropriate size for a forearm blood pressure cuff, the optimal location for making noninvasive blood pressure cuff measurements in the obese, and validation protocols for NIBP cuff measurements at the extremes of blood pressure. In patients where accurate blood pressure monitoring and blood pressure control is necessary, use

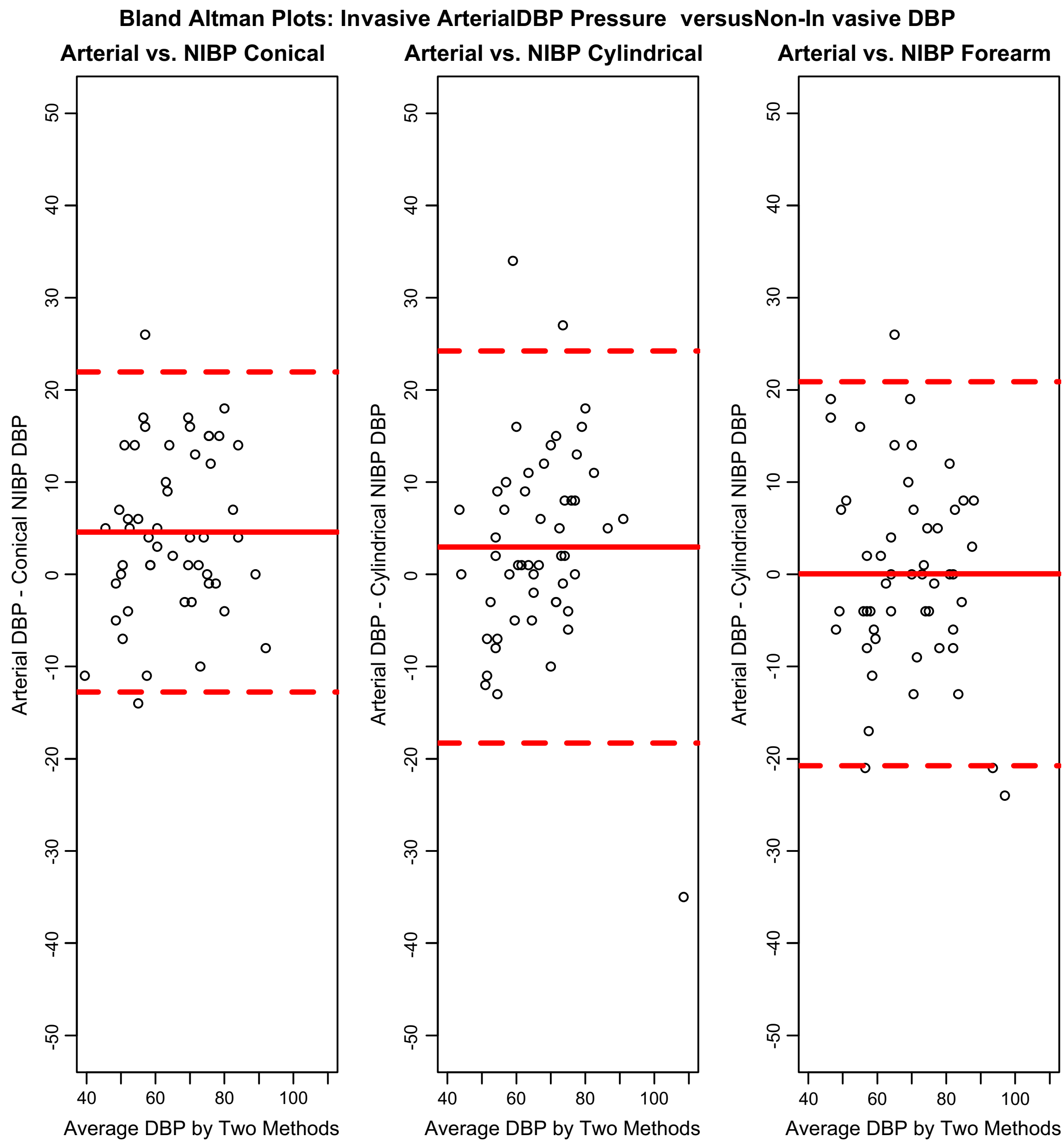

Fig. 4 Bland-Altman plots of arterial blood pressure (ABP) *vs* noninvasive blood pressure (NIBP) diastolic blood pressure (DBP) measurements

of invasive blood pressure monitoring is likely the best approach.

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Conflicts of interest None declared.

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