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RESEARCH

Blood pressure measurement in obese patients: non-invasive proximal forearm versus direct intra-arterial measurements

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Background: In obesity, accurate perioperative blood pressure measurement using upper arm, non-invasive blood pressure (NIBP) is technically challenging. Proximal forearm NIBP may be an acceptable substitute. Mean arterial blood pressures (MAP) estimated by proximal forearm NIBP were compared with direct intra-arterial measurements. It was hypothesised that the measurement techniques would be interchangeable if between-technique MAP differed ≤ 20% and MAP ratios were < 1.2 and > 0.8.
Method: A total of 30 adults with body mass index ≥ 30 kg/m² in whom perioperative intra-arterial blood pressure measurement was considered mandatory were enrolled. MAP measurements using the two techniques were obtained at three random intervals in each patient. Bland–Altman analyses were employed.
Results: Forearm mean NIBP MAP overestimated mean intra-arterial MAP by 2.2 (SD 8.1; range from 23.8 to −19.4 mmHg; *p* = 0.011, 95% CI 3.9 to 0.5). However, Bland–Altman analyses revealed a wide dispersion with several MAP differences and MAP ratios exceeding the pre-specified bounds for interchangeability.
Conclusion: Forearm NIBP could not be considered interchangeable with direct intra-arterial MAP measurements in obese patients.

Keywords: Blood pressure monitoring, comparative study, forearm, intra-arterial, obese

Introduction

Accurate perioperative blood pressure measurements are essential for the safe conduct of anaesthesia.[1–3] Perioperative hypotension has been independently associated with adverse postoperative outcomes such as ischaemic stroke and myocardial infarction.[3–5] On the other hand, severe hypertension may result in encephalopathy, haemorrhagic stroke, aortic dissection, arrhythmias and/or myocardial infarction.[6] The general approach is to maintain mean arterial pressure (MAP) within 20% of baseline values.[7] This is based on the principle of autoregulation, which assumes that vital organ blood flow is constant when MAP is maintained within certain limits, typically ± 20% of baseline MAP values.[7] These limits are based on Strandgaard and colleagues' research in which they studied cerebral autoregulation by inducing blood pressure changes in conscious hypertensive and normotensive patients. After a 25% MAP reduction, both groups trespassed the lower limit of cerebral blood flow autoregulation.[7]

Accurate, perioperative blood pressures measurements are particularly important in obese patients as they frequently suffer from multiple co-morbidities, particularly hypertension.[8] Unfortunately, non-invasive blood pressure (NIBP) measurements are difficult in obesity for several reasons:

(1) The regular adult cuff size is often too short for individuals with an upper arm circumference ≥ 32 cm. Obese patients will therefore often require large-sized cuffs, which over-estimate MAP. [9–11]

(2) Anatomical differences, particularly the conically shaped upper arm, common in obesity, make fitting the cuff difficult. This increases the likelihood of inaccurate blood pressure measurements.[10]

(3) The combination of very large arm circumferences and short upper arm lengths often coincide. The distal end of the large cuff may extend for several centimetres past the patient's elbow, interfering with cuff inflation and proper arterial occlusion.[10,11]

All of the above contribute to difficult NIBP cuff placement and inaccurate readings. Clinicians therefore may resort to alternative sites such as the forearm for NIBP cuff placement, although no studies confirm their accuracy.[10] A potential solution is to use direct intra-arterial blood pressure monitoring, which has been considered the 'gold standard' measurement technique.[12–15] Unfortunately radial artery catheterisation is associated with additional cost and complications, and may be difficult and time-consuming in the morbidly obese, precluding routine use.[16,]

We therefore decided to investigate the accuracy of forearm NIBP compared with direct intra-arterial measurements in obese patients.[13,14,17–19] We hypothesised that NIBP MAP measurements would be interchangeable with intra-arterial MAP measurements.

Methods

Approval for the study was obtained from the Stellenbosch University Human Research Ethics Committee (project number S15/05/099). Informed consent was obtained before enrolment. Inclusion criteria comprised obese patients with body mass index ≥30 kg.m^{-2} and in whom intraoperative direct intra-arterial blood pressure measurement was considered mandatory by the attending anaesthesiologists. Exclusion criteria included patients with a MAP difference of more than 20 mmHg between their upper arms as measured by automated oscillometric NIBP, a history of or concurrent known arterial vascular occlusive diseases such as thromboangiitis obliterans, Takayasu's disease, Raynaud's disease, lupus, scleroderma, rheumatoid arthritis,

Table 1: Recommended cuff size for the non-invasive blood pressure[24]

Arm circumference	NIBP cuff size
22 to 26 cm	12 × 22 cm
27 to 34 cm	16 × 30 cm
35 to 44 cm	16 × 36 cm
45 to 52 cm	16 × 42 cm

thoracic outlet syndrome, and a history of upper extremity embolisation.[20,21] Contraindications for intra-arterial catheterisation including a negative Allen test, a history of Raynaud's phenomenon or brachial artery injury, which were also not considered for enrolment.[21] Patients with contra-indications to non-invasive blood pressure cuff placement such as the presence of an upper limb arteriovenous fistula for renal dialysis, previous lymph node removal and lymphoedema were also not considered for enrolment. Patients with dysrhythmias and pre-existing hypotension were also excluded as NIBP is potentially inaccurate in these circumstances.[22]

Radial intra-arterial catheterisation was performed using a 20-gauge (1.10 mm inner diameter), 45 mm-long arterial cannula (Floswitch Arterial Cannula; Becton Dickinson (BD), Franklin Lakes, NJ, USA). The disposable arterial transducers (Biometrix®, Breda, The Netherlands) were zeroed relative to atmospheric pressure at the 4th intercostal space, at the anterior axillary line. The 160 cm catheter tubing and transducer hubs were carefully flushed and inspected for bubbles or clots. Patients with visually over- or underdamped arterial line waveforms, as evaluated by the flush test, were excluded from the study. Underdamping was judged to be present if the flush test was followed by more than two oscillations ('ringing'). Overdamping was judged to be present if there was no obvious dicrotic notch on the pulse wave and if the response to the flush test did not include at least one oscillation.[21,23]

The forearm NIBP cuff was positioned on the contralateral arm so that its upper border was in the crease of the anterior cubital fossa. Cuff size was individualised based on mid-forearm circumference measured halfway between the medial epicondyle and the lunate. As forearm blood pressure cuff sizes have never been specified, the cuff was sized according to recommendations for upper arms (Table 1). These specifications require that the air

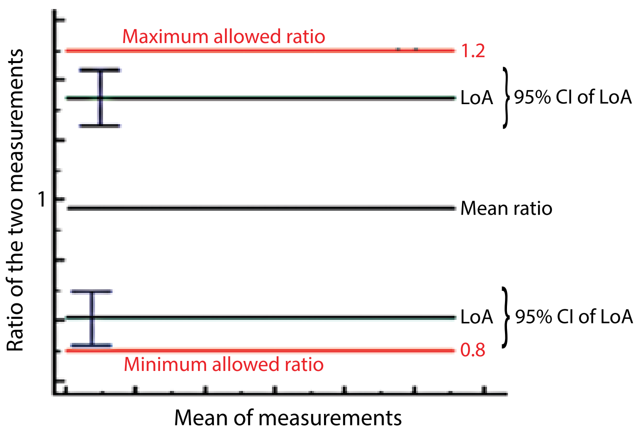

Figure 1: Example of a Bland–Altman plot illustrating two interchangeable methods of measurement. LoA = limits of agreement; 95% CI = 95% confidence interval. Maximum/minimum allowed ratio = ±20%

bladder should fit round at least 80% but not more than 100% of the arm. To ensure an air-tight system, the tubing was inspected before use in each patient.[24]

Both invasive and NIBP were performed using the GE Datex Ohmeda S/5 (General Electric Healthcare, Little Chalfont, UK), and Nihon Kohden Life Scope (Nihon Kohden Corporation, Tokyo, Japan) monitors. These monitors are re-calibrated annually by our hospital's department of clinical engineering according to the manufacturer's standards.

Data recorded included body mass index (BMI), mid-upper arm circumference and forearm circumference, the latter defined below. Pressures were measured on three randomly chosen intraoperative occasions at a time when patients were considered to be haemodynamically stable. Haemodynamic stability was defined as when blood pressure was maintained within 20% of baseline intra-arterial MAP with no change in vasopressor infusion rate (if any).[6] Intra-arterial measurements were annotated within five seconds of the NIBP display.

Statistical analysis

Statistical analyses were performed using MedCalc for Windows, version 17.9.6 (MedCalc Software, Ostend, Belgium). An alpha value ≥ 0.05 was regarded as indicating statistical significance. Bland–Altman analysis was used to determine whether between-technique measurements differed by more than 20%.[25] Because three measurements per subject were recorded at different times and at different blood pressures, the Bland–Altman method modified for multiple measurements per subject was used.[26] Limits of agreement (LoA) were calculated as 1.96 standard deviations from the mean value. The 95% confidence intervals (95% CI) for the Bland–Altman limits of agreement with multiple observations per individual were calculated according to the MOVER method described by Zou.[27] For the methods to be interchangeable, a plot of the ratios between the two measures on the ordinate versus the mean of the two measurements on the abscissa would need to comply with the appearance of the example depicted in Figure 1.

In other words, the two methods would be considered to be interchangeable when a pre-defined maximum allowed difference (Δ) was larger than the upper bound of the 95% confidence interval of the higher limit of agreement, and –Δ was lower than the lower bound of the 95% confidence interval of the lower limit of agreement. For this study where Δ = 20%, the upper allowed ratio was ≤ 1.2 and the lower allowed ratio was ≥ 0.8 according to the physiologic principles defined above. We also performed a standard Bland–Altman analysis, plotting the MAP differences on the ordinate.

Sample size calculation

We decided to obtain 90 measurement pairs from 30 patients. Using the Medcalc procedure that employs the method of Lu *et al.*,[28] we calculated that for a method comparison study using a Bland–Altman plot with an alpha value of 0.05, aiming for 80% power, assuming an expected mean of differences of 5% with an expected standard deviation of 6% and a maximum allowed difference between methods of 20%, a minimum number of 86 paired measurements would be required.

Results

Patient demographics are presented in Table 2. Intra-arterial (Aline) MAP measurements ranged between 65 and 118 mmHg; mean 97 mmHg; standard deviation (SD) 13 mmHg). Overall, the

Table 2: Patient demographics

Factor	Units	Mean (SD)	Range
Age	Years	34.7 (13.9)	19 to 79
Body mass index (BMI)	(kg.m^{-2})	41.3 (8.8)	32 to 69
Upper arm circumference	cm	38 (5.9)	29 to 50
Forearm circumference	cm	27.5 (2.8)	23 to 32

Table 3: Bland–Altman analysis of mean arterial pressures

Factor		MAP(95% CI)
MAP ratios	Geometric mean	0.98 (0.97 to 1.00)
	Upper limit of agreement	1.17 (1.12 to 1.24)
	Lower limit of agreement	0.83 (0.77 to 0.86)
MAP differences (mmHg)	Arithmetic mean	−2.2 (−3.9 to −0.5)
	Upper limit of agreement	13.8 (9.9 to 19.4)
	Lower limit of agreement	−18.3 (−23.8 to −14.4)

MAP = mean arterial pressure; 95% CI = 95% confidence interval.
MAP differences = intra-arterial MAP minus NIBP MAP.
MAP ratio = intra-arterial MAP:NIBP MAP.

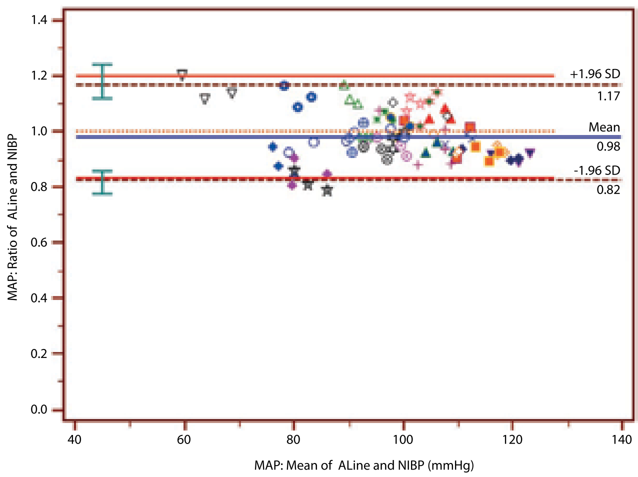

Figure 2: Mean arterial blood pressure measurements—Bland–Altman ratio plot for multiple measurements per subject: direct arterial versus non-invasive blood pressure measurements (maximum allowable difference between measurements = 20%).
Notes: MAP = mean arterial pressure; ALine = direct arterial blood pressure measurements; NIBP = non-invasive blood pressure measurements.Abscissa: mean of Aline and NIBP measurement pairs. Ordinate: ratio of Aline:NIBP pairs. Orange dotted line = line of agreement (ratio =1). Blue solid line = mean ratio ALine:NIBP.Brown dashed lines = upper and lower limits of agreement (1.96 standard deviations from the mean ratio). Red solid lines = maximum and minimum allowable ratios between the methods. Green error bars: 95% confidence intervals for the limits of agreement.

measurement differences were normally distributed. The mean MAP difference (ALine minus NIBP) was −2.2 mm Hg (SD 8.1 mmHg; 95% confidence interval (95% CI) −3.9 to −0.5 mmHg; $p = 0.011$). Expressed as percentage differences in relation to ALine values, the MAP means differed by −2.5% (SD 9%; 95% CI −4.3% to −0.6%).

Results of the Bland–Altman analysis of ratios as well as analysis of pressure differences are presented in Table 3 and in Figures 2 and 3. The overall NIBP:Aline MAP ratio was 0.98 ± 0.09 (95% CI 0.97 to 1.00); however, the 95% CI of the upper limit of agreement (1.24) and the 95% CI of the lower limit of agreement (0.86) exceeded the predetermined acceptable bounds.

Discussion

In a clinical setting we investigated whether there was acceptable agreement with regard to MAP, between forearm NIBP and intra-arterial measurements in obese patients. Mean values differed statistically significantly ($p = 0.011$), but the difference between means was clinically unimportant (95% CI −3.9 to −0.5 mmHg). Nevertheless, Bland–Altman analysis of the ratios between the measurements revealed a wide dispersion with several ratios exceeding the pre-specified interchangeability bounds (see Figure 2).

Previous similar studies have reported conflicting results. Le Blanc and co-workers concluded that forearm systolic NIBP was acceptable and preferable to upper arm NIBP in severe obesity.[13] Anast and co-workers compared direct radial intra-arterial measurements with NIBP using various cuff locations in obese patients. They reported unacceptably poor between-technique agreements.[19]

There are a number of possible reasons for the differences obtained by the differing measurement techniques. Structural differences in the obese forearm can adversely affect proper cuff fit and negatively impact NIBP accuracy.[9–11,13,19] Obese patients with upper arm circumferences ≥ 32 cm represent problems for NIBP measurements. They require greater cuff inflation pressures because more soft tissue overlies the artery and needs to be compressed.[29] This causes MAP to be overestimated. Discrepancies when NIBP is measured at different anatomical sites can also be attributed to differences in blood vessel size and depth in relation to the overlying subcutaneous tissue.[29] Arm circumferences ≥ 32 cm also require the use of oversized cuffs, which can result in inaccurate blood pressure measurements.[9–11] The obesity-related increase in upper arm circumference is also associated with short, conical upper arms which contributes to poorly fitting cuffs and inaccurate NIBP measurements.[9,13,14,19]

Furthermore, the two techniques estimate blood pressures in fundamentally different ways. Oscillometric NIBP devices sense arterial pulsation of the underlying artery, the peak pulsation amplitude agreeing very well with directly measured MAP. However, oscillometric NIBP devices derive systolic and diastolic pressures using proprietary, manufacturer-determined algorithms, which are less accurate than direct intra-arterial measurements.[24,30,31] We limited our study to patients with normal vasculature who were haemodynamically stable. Our results cannot be extrapolated to unstable or vasoconstricted patients, for example patients in cardiogenic shock or those receiving high-dose vasopressor infusions. NIBP measurements are adversely affected by peripheral vessel vasoconstriction as the decreased arterial pulsation and pulse amplitude results in MAP underestimation. Conversely, decreased arterial compliance (e.g. severe atherosclerosis and calcification) increases cuff inflation pressure, with MAP overestimation.[21]

A weakness of our study is the uncertainty regarding the accuracy of our NIBP devices, and this may have contributed to the data dispersion. Despite NIBP devices being accurate on delivery by the manufacturer, subsequent regular recalibration is

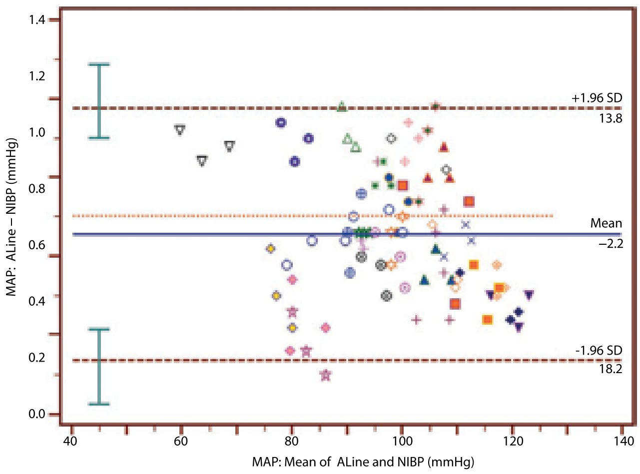

Figure 3: Mean arterial blood pressure measurements—Bland–Altman data plot for multiple measurements per subject: direct arterial versus non-invasive blood pressure measurements.
Notes: MAP = mean arterial pressure; ALine = direct arterial blood pressure; NIBP = non-invasive blood pressure measurements.Abscissa: mean of Aline and NIBP measurement pairs. Ordinate: difference between ALine and NIBP pairs. Orange dotted line = line of agreement (difference = 0). Blue solid line = mean difference (ALine-NIBP). Brown dashed lines = upper and lower limits of agreement (1.96 standard deviations from the mean difference). Green error bars: 95% confidence intervals for the limits of agreement.

needed. De Greef *et al*. demonstrated that 25% of NIBP devices in use at a large teaching hospital have unacceptable calibration errors.[32] Our hospital's Clinical Engineering Department performs annual, onsite recalibration of all NIBP monitors, but it is uncertain whether our machines require more frequent checking. In this respect, our use of the available monitors and cuffs represents the 'real world' of clinical monitoring with all its inherent pitfalls. A strength of our study was that our population comprised mostly obese, young obstetric patients with low likelihood of vascular disease. It is therefore unlikely that pathophysiological reasons contributed to the observed between-technique MAP differences.

Another weakness is that we did not formally assess the dynamic responses of the catheter, tubing and transducer intra-arterial measuring system. Although the adequacy of the dynamic responses of direct intra-arterial blood pressure measurement systems cannot be determined by visual inspection alone, we specifically excluded obvious underdamping and overdamping. Furthermore, MAP measurements are acceptably accurate in moderately over- and underdamped systems.[21] This emphasises our primary purpose, which was to compare MAP. For the sake of completeness, we also compared systolic and diastolic pressures and these Bland–Altman graphs are available at https://doi.org/10.1080/22201181.2018.1461323 for interested readers to peruse.

An additional weakness is the limited range of MAP measurements and especially the paucity of lower pressures where a 20% overestimation by NIBP would be of clinical importance for decision-making (see Figure 3). Inspection of Figure 3 reveals that individual patient measurements tend to be clustered around a small MAP range. This results from our limiting measurements to periods of haemodynamic stability and when MAP was within 20% of preoperative measurements. Figure 3 also reveals that very few data points actually exceeded the a priori determined limits of agreement. This prompts speculation that a larger study could possibly indicate that the forearm NIBP technique would provide acceptable measurements.

Conclusions

We conclude that in obese adults with stable haemodynamics, forearm NIBP MAP is not interchangeable with direct intra-arterial MAP measurements. This leaves the clinician with difficult, imperfect choices, particularly in short cases where the risks, costs and difficulties associated with arterial cannulation outweigh the benefits. Further studies that employ larger sample sizes, compare both upper arm and lower arm MAPs, that include a wide range of blood pressures, and that investigate trends over extended periods are needed to determine the wisest courses of action.

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Supplementary material

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