Blood Pressure Measurement in Severely Obese Patients: Validation of the Forearm Approach in Different Arm Positions

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BACKGROUND

Blood pressure measurement in severe obesity may be technically challenging as the cuff of the device may not fit adequately around the upper arm. The aim of the study was to assess the agreement between intra-arterial blood pressure values (gold standard) compared with forearm blood pressure measurements in severely obese patients in different arm positions.

METHODS

Thirty-three severely obese patients and 21 controls participated in the study. Pairs of intra-arterial blood pressures were compared with simultaneous forearm blood pressure measurement using an oscillometric device in 4 positions: (i) supine, (ii) semi-fowler with the forearm resting at heart level, (iii) semi-fowler with the arm downward, and (iv) semi-fowler with the arm raised overhead. Degree of agreement between measurements was assessed.

RESULTS

Overall, correlations of systolic and diastolic blood pressure measurements between the gold standard and forearm blood pressure were 0.95 (n = 722; P < 0.001) and 0.89 (n = 482; P < 0.001), respectively. Systolic blood pressure measured using the forearm approach in the supine and the semi-fowler positions with arm downward showed the best agreement when compared with the gold standard (−4 ± 11 (P < 0.001) and 2 ± 14 mm Hg (P = 0.19), respectively). In the control group, better agreement was found between the supine and semi-fowler positions with the arm resting at heart level (1 ± 9 mm Hg (P = 0.29) and −3 ± 10 mm Hg (P = 0.01), respectively).

CONCLUSIONS

Forearm systolic blood pressure consistently agreed with the gold standard in the supine position. This method can be of use in clinical settings when upper-arm measurement is challenging in severe obesity.

Keywords: blood pressure; blood pressure measurement; hypertension; severe obesity.

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Systemic hypertension is a common comorbidity associated with severe obesity.[1–3] To properly manage hypertension, it is mandatory to accurately measure blood pressure in clinical and ambulatory settings.[4–6] This is important because severe obesity affected 184 million adults worldwide[7] and knowing that the prevalence of systemic hypertension being more than 60% in obese patients while it is 36% in nonobese.[2] Nevertheless, the reported prevalence of hypertension in severely obese patients is probably undermined by the technical challenges encountered with blood pressure measurement in this population. Indeed, accurate blood pressure measurement is challenging in the severely obese population; the upper arms being frequently short, large, and conical.[8–10] An upper-arm blood pressure measurement alternative, the forearm method, has recently been validated in severe obesity in the supine position.[11] This approach may be considered valid and comparable with the intra-arterial measure (gold standard).[11] Subsequent analyses conducted on the same set of patients revealed a high sensitivity (0.98) and a strong predictive positive value (0.93) of hypertension diagnosis with the forearm approach in the supine position.[12] There are no validation studies or guidelines regarding blood pressure forearm measurements. Recently, the Canadian hypertension guidelines recommended wrist

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blood pressure measurement as an alternative to upper arm in obesity.[4] In the meta-analysis cited[13] in guidelines, the only report included studying blood pressure in severely obese was from our group, and we measured forearm not wrist blood pressure.[11] Undoubtedly, forearm blood pressure is a promising avenue in severe obesity but remains to be validated in different body and arm positions before clinical and ambulatory use.

The aim of this study was to validate forearm blood pressure measures in severely obese patients in different body and arm positions. We hypothesized that forearm systolic and diastolic blood pressure measurements would (i) closely agree with the intra-arterial values when patients rested in the supine or semi-fowler position, forearm supported at heart level and (ii) not agree with the gold standard when patients rested in the semi-fowler position with arm downward or arm raised overhead.

METHODS

Study population

Patients that were to undergo surgical procedures under general anesthesia with radial catheter arterial pressure monitoring were recruited preoperatively. Thirty-three severely obese and 21 nonseverely obese patients aged ≥18 years old were enrolled in the study at the *Institut Universitaire de Cardiologie et de Pneumologie de Québec* (IUCPQ). Severely obese patients were included if they had a body mass index (BMI) ≥40 kg/m^2 or ≥35 kg/m^2 with associated comorbidities and if they were scheduled for bariatric surgery. Nonseverely obese patients (control group) patients were included if they had a BMI <35 kg/m^2 and if they were scheduled for cardiac surgery, including coronary artery bypass grafting and/or valve replacement procedures. Exclusion criteria were significant arrhythmia (i.e., atrial fibrillation), pacemaker, and inter-arm systolic blood pressure difference ≥20 mm Hg[14] as determined during preoperative blood pressure measurements. Patients were recruited during the preoperative admission at the surgery department by a convenient sampling method. The ethic committee of the IUCPQ research center approved the research protocol. Each participant provided written informed consent before inclusion in the study.

Anthropometric and blood sample measurements

For both groups, blood samples were drawn after a 12-hour overnight fast. Routine laboratory analyses were performed through standard methods. Within 1 day before surgery, body weight (kg) and height (cm) were measured on calibrated scales; a Detectomedical-scale (Brooklyn) or a Healthometer-scale (Bridgeview) was used for patients for body weight <140 kg, and a Toledo-scale (Model 4181–8140, Canada) was used for body weight ≥140 kg. BMI was calculated using body weight in kg divided by height in meter squared (kg/m^2). Arm length was measured from the acromion process of the scapula to the olecranon.[15] Arm circumference was defined at a midpoint distance between these anatomical references.[11,15] Forearm length was measured from the olecranon to the styloid apophysis.[15] Forearm circumference was defined at a midpoint distance between these anatomical references.[15] Length and circumference were measured to the nearest 0.1 cm.[11,15]

Preoperative blood pressure measurements

Baseline blood pressure measurements were performed according to the Canadian Hypertension Education program (CHEP) guidelines[16] using the same oscillometric device for all participants (Welch Allyn, Life sign monitor 5200 Series NY).[17] After a 5-minute rest in sitting position, duplicate blood pressure measurements were randomly taken on left and right upper arms and forearms to assess inter-arm differences, with a 1-minute delay between measures. As recommended in hypertension guidelines, cuff size (small cuff (20.0–26.0 cm), standard cuff (25.4–40.6 and 25.0–34.0 cm) and large cuff (32.0–43.0 cm)) was selected according to participant's arm circumference.[5] Cuff was similarly selected according to forearm circumference. The same cuff size was used at the moment of the experimentation. For participants with arm circumference exceeding 43.0 cm, the large cuff was used.

Blood pressure measurement validation

This forearm blood pressure measurement validation study was carried out in the recovery room following surgery (cardiac or bariatric) in all *a priori* recruited patients with an intra-arterial cannula in place. Intra-arterial blood pressure measurement was the reference method (gold standard), while forearm and upper-arm measures were the methods evaluated. Blood pressure measurements were taken in a pair fashion in this specific sequence: (i) intra-arterial vs. contra lateral forearm and (ii) intra-arterial vs. contra lateral upper arm with a minimum of 2-minute delay between each set of measurements.

Intra-arterial blood pressure method. An intra-arterial catheter was inserted in the left or right radial artery of each patients by an anesthesiologist, as usual care, before surgery (Catheter: BD Insyte Autoguard BC, Mississauga, Canada; Pressure captor: Edwards Lifesciences, Irvine, États-Unis; Tubing between catheter and pressure captor: Microbore Angiography Set MEDXL, Montréal, Canada). Accuracy of arterial waveform was carefully monitored during blood pressure measurement using the arterial monitoring system (Phillips MX700 and MX800, Markham, Canada)[18] with the catheter sensor positioned at heart level following mobilization.[19]

Forearm oscillometric blood pressure measurement method. We arbitrarily determined the forearm position for cuff installation. We refer precisely to the lower edge of the cuff (where the tube is connected) which was located 6 cm proximal to the styloid process of the ulna, palpable at the wrist, contralateral to the intra-arterial catheter. The same ambulatory-setting oscillometric device was used (Mobil-O-graph I.E.M. GmbH, Stolberg, Germany)[20] throughout the study for forearm blood pressure measurements. Forearm cuff size was selected as detailed above.

Upper-arm oscillometric blood pressure method. Upper-arm blood pressure was measured with bedside mural calibrated oscillometric devices (Phillips MX600 and MX700, Markham, Canada).[18] This device is routinely used in the intensive care department for usual noninvasive blood pressure monitoring at the upper-arm level. Using 2 different devices for forearm and upper-arm methods allowed us to leave both cuffs in place during the experimentation. Upper-arm cuff size was selected as detailed above.

Body and arm positions

Body and arm positions evaluations were performed in the same pattern for severely obese and control groups (Figure 1). The same investigator (M.E.L.) performed all measurements.

The sequence was performed when patients were in the supine position (position 1; Figure 1a) with the arm and forearm resting at heart level. The second sequence was completed with the head of patient's bed lifted at 45° in the semi-fowler position, using the hospital bed's automatic system indicating the precise degree of head level angle. Measurements were taken, with the arm and forearm in 3 different positions: (i) arm supported at heart level (position 2; Figure 1b), (ii) arm in a downward position (position 3; Figure 1c), and (iii) arm raised overhead (position 4; Figure 1d). When the arm was positioned at heart level or raised overhead (positions 2 and 4), the arm was resting on a pillow installed on an adjustable bedside table. For position 4, the whole arm was positioned at 45° with reference to the shoulder using an international standard manual goniometer (Cat. No. 238, Rajowalt T Company, Atwood, Indiana).

Statistical analyses

Patients' characteristics are reported as mean ± SD unless stated otherwise. Unpaired t-tests and chi-square tests were used to assess differences in baseline continuous and categorical variables between groups. Histograms with superimposed Gaussian curve were used to visually assess whether differences or bias between methods were normally distributed. Differences between the mean of all readings were calculated for systolic and diastolic blood pressure. Results were compared by paired t-tests for each position and reported as "bias" (mean difference between methods) with respective *P* value and 95% confidence intervals (95% CI). Scatter plots for systolic and diastolic blood pressure were used to assess correlations for the different positions. Pearson correlation coefficient was estimated for systolic and diastolic blood pressure measurements to assess the strength of the relationship between paired methods: (i) intra-arterial vs. forearm blood pressures and (ii) intra-arterial vs. upper-arm blood pressures. Bootstrapping was used to derive 95% CI[21] for Pearson correlations coefficient. Bland–Altman graphics were used to illustrate agreement of differences between methods for systolic and diastolic blood pressure, separately for each group in each position. The mean differences between methods and their respective limits of agreement (bias ± 1.96 × SD) and 95% CI are presented as recommended.[22–24] To explore the possibility of a between group difference in systolic blood pressure amplification across the brachial–radial territory, we used generalized estimating equation to take into account repeated measurements and position of measurements. The maximum acceptable difference between the new method and the gold standard (bias) is ≤5 mm Hg with a maximal SD of ≤8 mm Hg.[25] A multivariate linear regression model was used to determine the extent to which independent variables (age, sex, forearm/upper-arm circumferences) could explain differences between methods for systolic and diastolic blood pressure measures, for each group, in all positions. A 2-sided level

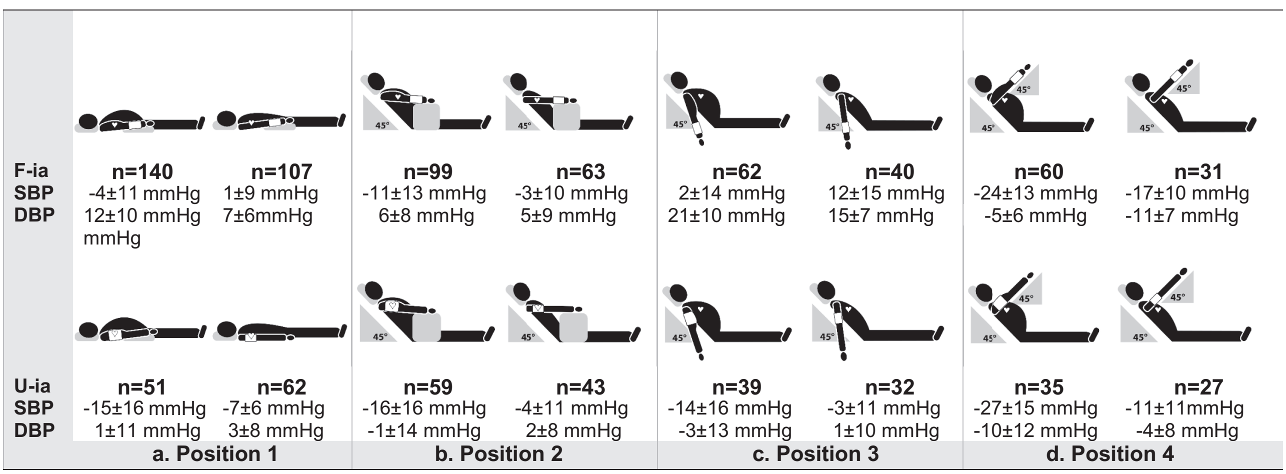

Figure 1. Body and arm positions (forearm method at the top and upper-arm method at the bottom) for the severely obese group (left side) and the control group (right side) of each column. (**a**) Position 1: supine, forearm or arm resting at heart level; (**b**) Position 2: semi-fowler, forearm, or arm resting at heart level; (**c**) Position 3: semi-fowler, forearm, or upper-arm downward; (**d**) Position 4: semi-fowler, forearm, or upper arm overhead. Abbreviations: DBP, crude mean bias for diastolic blood pressure with SD; F-ia, forearm compared with intra-arterial method; *n*, number of pairs of readings; SBP, crude mean bias for systolic blood pressure with SD; U-ia, upper arm compared with intra-arterial method.

<5% was considered statistical significance. Analyses were conducted using IBM SPSS (version 24).

RESULTS

Baseline characteristics

Initially, we recruited a total of 39 patients in the severely obese group and 35 in the control group. Following their surgery, 6 severely obese and 14 patients in the control group were excluded as they withdrew consent, had unusual intra-arterial cannula sites (humeral or femoral), or were pacemaker-dependent. Characteristics of participants are presented in Table 1. Of note, there were 11 severely obese patients whose upper-arm circumference exceeded the limit of available cuffs in the recovery room, making it technically impossible to properly adjust the cuff to measure blood pressure at the upper arm. For 2 patients in the control group, upper-arm measurement was impossible because of hemodynamic instability. The ranges of intra-arterial systolic and diastolic blood pressures were 102–217 and 49–127 mm Hg, respectively in severely obese patients and 79–140 and 34–75 mm Hg, respectively in the control group. Body and arm positions illustrations are given the crude mean bias for systolic and diastolic blood pressure separately, for each method compared 2-by-2, and for each group (Figure 1).

Severely obese group

Forearm blood pressure compared with intra-arterial measurements. The 722 data (361 systolic and 361 diastolic blood pressure measurements) were closely correlated in all positions (overall: $r \geq 0.95$, $P < 0.001$). Forearm systolic blood pressure measurements in the supine position (position 1; Figure 2a) and supine with arm downward (position 3; Figure 3a) were more closely associated with

Table 1. Baseline characteristics of participants

Characteristics			Severely obese *n* = 33	Control group *n* = 21	*P*
Age (years)			49.2 ± 10.9	54.8 ± 8.1	0.05
Men/women (%)			58/42	71/29	0.30
Body weight (kg)			135.7 ± 30.2	77.1 ± 12.7	<0.001
Height (m)			1.7 ± 0.1	1.7 ± 0.1	0.33
Body mass index (kg/m^2)			48.5 ± 8.9	26.9 ± 3.8	<0.001
Waist circumference (cm)			140.3 ± 17.7	97.0 ± 9.9	<0.001
Upper-arm blood pressure	Systolic	mm Hg	122 ± 11	116 ± 11	0.04
	Diastolic	mm Hg	75 ± 8	72 ± 8	0.19
Forearm blood pressure	Systolic	mm Hg	128 ± 15	121 ± 13	0.09
	Diastolic	mm Hg	73 ± 10	74 ± 10	0.76
Length (cm)	Right arm		34.4 ± 2.9	34.8 ± 2.8	0.80
	Left arm		34.3 ± 3.2	34.5 ± 3.0	0.82
	Right forearm		27.6 ± 2.8	26.3 ± 1.7	0.09
	Left forearm		28.0 ± 2.5	26.8 ± 2.0	0.50
Circumference (cm)	Right arm		43.0 ± 6.1	30.7 ± 3.1	<0.001
	Left arm		42.3 ± 5.8	30.8 ± 3.0	<0.001
	Right forearm		27.9 ± 3.3	23.9 ± 2.3	<0.001
	Left forearm		27.8 ± 3.1	23.6 ± 2.2	<0.001
Comorbidities	Systemic hypertension (%)		58	76	0.16
	Diabetes (%)		45	24	0.11
	Dyslipidemia (%)		52	62	0.45
	Sleep apnea (%)		55	10	<0.001
Blood test	Glycemia (mmol/l)		7.0 ± 2.0	5.9 ± 1.1	0.02
	Lipid profile	TC (mmol/l)	4.2 ± 0.8	4.0 ± 1.1	0.44
		TG (mmol/l)	1.5 ± 0.5	1.4 ± 0.7	0.54
		LDL (mmol/l)	2.3 ± 0.8	2.2 ± 0.9	0.73
		HDL (mmol/l)	1.2 ± 0.2	1.2 ± 0.4	0.68

Abbreviations: HDL, high-density lipoprotein; LDL, low-density lipoprotein; TC, total cholesterol; TG, triglycerides.

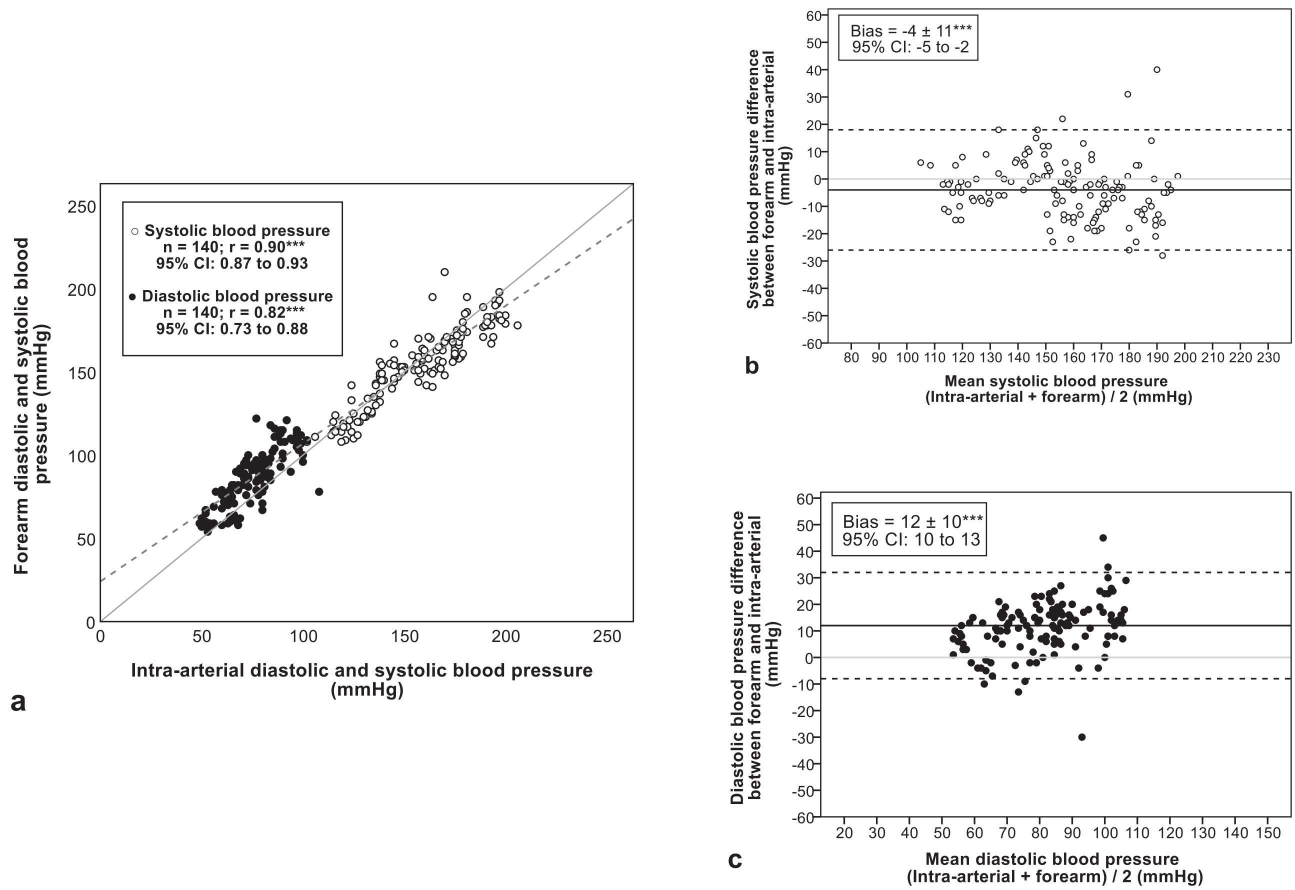

Figure 2. Forearm method and intra-arterial diastolic and systolic measures in the severely obese group in the supine position (position 1). (**a**) Correlation for systolic and diastolic blood pressure measurements between methods. Solid line represents a theoretical correlation of 1, while dash line represents the estimated correlation. (**b**) Bland–Altman representation between methods for systolic and (**c**) diastolic blood pressure. *r*, Pearson correlation coefficient. *n*, number of data sets. 95% CI, confidence interval is the range of values within which we are 95% confident that the true population parameter lies. In (b) and (c): solid line represents the measured bias between methods; dash line represents twice the SD around the mean and bias in the box is in mm Hg. *$P < 0.005$, **$P < 0.01$, ***$P < 0.001$.

intra-arterial readings than sitting position 2 and position 4 (Supplementary Figures S1a and S2a of Supplementary material). Bland–Altman shows the pressure differences (in mm Hg) in position 1 (Figure 2b) for intra-arterial vs. forearm; the latter slightly underestimated systolic intra-arterial. Regarding position 3 (Figure 3b), forearm systolic oscillometric readings slightly overestimated intra-arterial measures. In positions 2 and 4, forearm measures clearly underestimated systolic intra-arterial readings. Diastolic blood pressure measures in positions 1 and 3 (Figure 2c and Figure 3c) were overestimated. In position 2, forearm method modestly overestimated diastolic intra-arterial readings. Of note, only 29 of 722 (4%) data points exceeded the limits of agreement. Correlations and Bland–Altman graphics for positions 2 and 4 are shown in Supplementary material in Supplementary Figures S1 and S2a–c.

Upper arm vs. intra-arterial blood pressure measurements. The 368 values obtained (184 systolic and 184 diastolic blood pressure measurements) were closely correlated in all positions (overall: $r \geq 0.95$, $P < 0.001$). Upper-arm systolic blood pressure was underestimated compared with the gold standard in all positions (Supplemental Figures S5–S8). Regarding diastolic blood pressure, measurements were similar in positions 1, 2, and 3 while underestimated in position 4.

Control group

Forearm vs. intra-arterial blood pressure measurements. The 482 values obtained (241 systolic and 241 diastolic blood pressure measurements) were closely correlated in all position (overall: $r \geq 0.89$, $P < 0.001$). Correlations for systolic and diastolic blood pressure measures are illustrated for the positions with better agreement (position 1, Figure 4a and position 2, Figure 5a). Forearm systolic oscillometric readings were similar to intra-arterial readings in position 1 (Figure 4b) and in position 2 (Figure 5b). Forearm method significantly overestimated intra-arterial systolic blood pressure in position 3 while significantly underestimated it in position 4. Regarding diastolic blood pressure, forearm method overestimated intra-arterial readings in position 1 (Figure 4c), in position 2 (Figure 5c), and in position 3. In position 4, forearm method underestimated

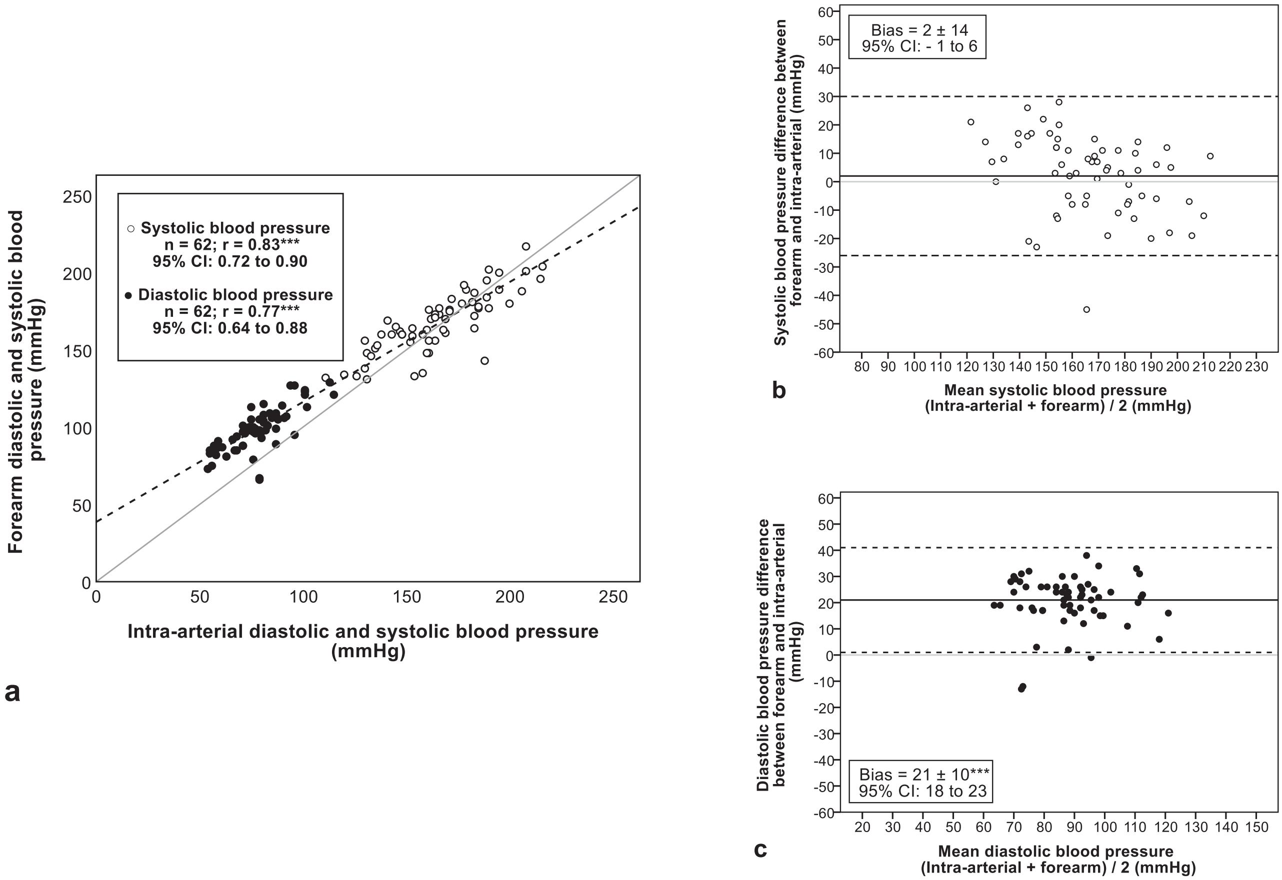

Figure 3. Forearm and intra-arterial diastolic and systolic measures in the severely obese group in the semi-fowler position, arm downward (position 3). (**a**) Correlation for systolic and diastolic blood pressure measurements between methods. Solid line represents a theoretical correlation of 1, while dash line represents the estimated correlation. (**b**) Bland–Altman representation for methods for systolic and (**c**) diastolic blood pressure method. *r*, Pearson correlation coefficient. *n*, number of data sets. 95% CI, confidence interval is the range of values within which we are 95% confident that the true population parameter lies. In (b) and (c): solid line represents the measured bias between methods; dash line represents twice the SD around the mean and bias in the box is in mm Hg. *$P < 0.005$, **$P < 0.01$, ***$P < 0.001$.

intra-arterial readings. Correlations and Bland–Altman for positions 3 and 4 are shown in Supplementary materials (Supplementary Figures S3 and S4). Of note, 16 of 482 (3%) data points exceeded the limits of agreement.

Upper arm vs. intra-arterial blood pressure measurements. The 328 data (164 systolic and 164 diastolic blood pressure measurements) were closely correlated in all positions (overall: $r \geq 0.92$, $P < 0.001$). Correlations and Bland–Altman for positions 1, 2, 3, and 4 are shown in Supplementary materials (Supplementary Figures S9–S12).

Upper-arm systolic blood pressure significantly underestimated intra-arterial systolic blood pressure readings in all positions. For diastolic blood pressure, upper arm overestimated intra-arterial readings in positions 1, 2, and 3 but underestimated intra-arterial readings in position 4. Of note, 19 of 328 (6%) data points exceeded the limits of agreement.

Contribution of independent variables on differences between methods

Differences between intra-arterial systolic and diastolic blood pressure measurement compared with forearm method are marginally explained by age (<4% in the supine position; $P < 0.05$) and, globally not explained by forearm circumference or sex, in both groups.

Systolic blood pressure amplification

The amplification of systolic blood pressure from upper arm to the radial artery (ratio of intra-arterial systolic/upper-arm systolic blood pressure) was 1.12 (95% CI = 1.08–1.16) in the severely obese group compared with 1.06 (95% CI = 1.01–1.10) in controls ($P = 0.04$), suggesting a higher amplification in the obese group. The forearm to radial amplification (ratio of intra-arterial systolic/forearm systolic blood pressure) was 1.05 (95% CI = 1.04–1.078) in the severely obese group compared with 1.02 (95% CI = 0.98–1.05) in controls ($P = 0.07$).

DISCUSSION

In this validation study, we demonstrated that all forearm systolic and diastolic blood pressure measurements were significantly associated with the gold standard namely

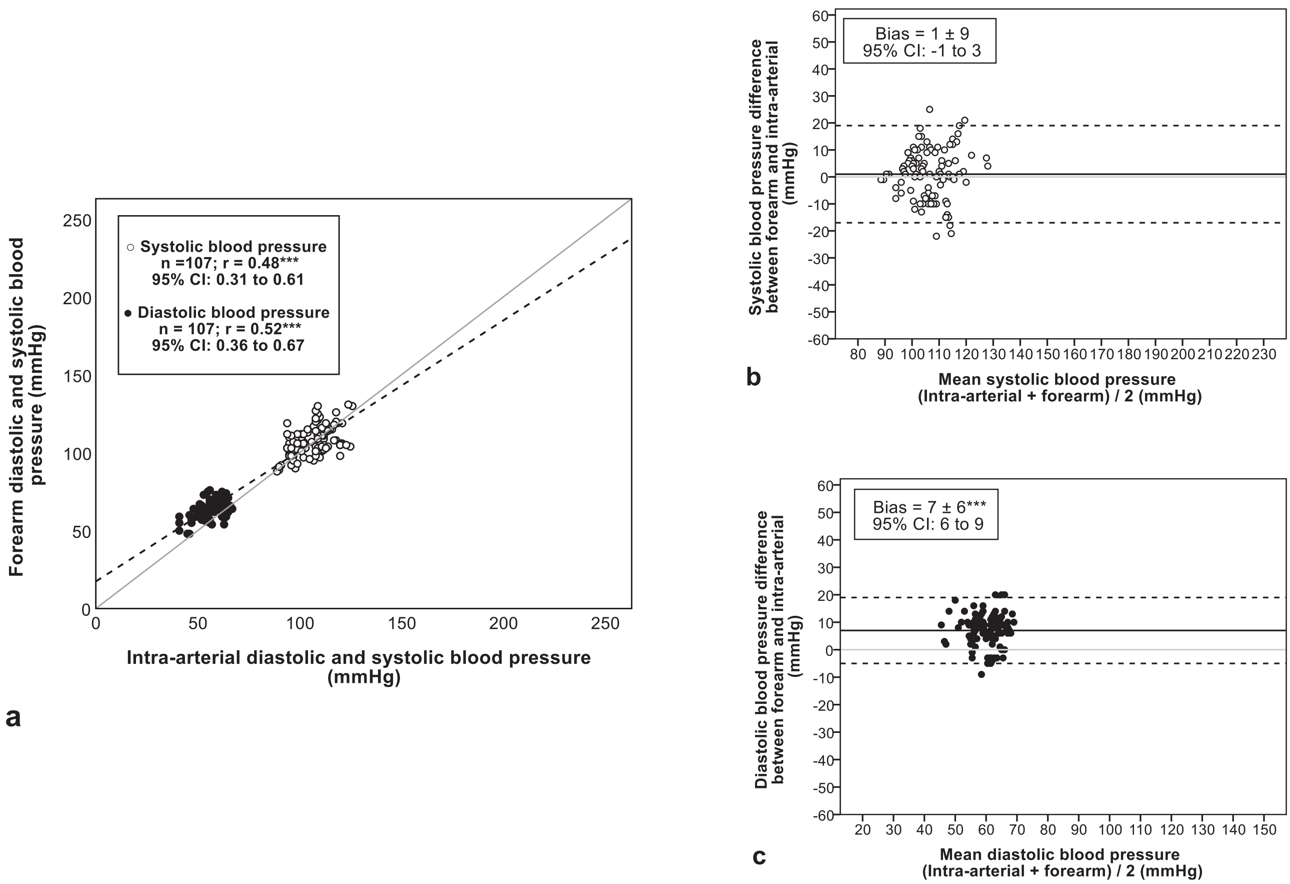

Figure 4. Forearm method and intra-arterial diastolic and systolic measures in the control group in the supine position (position 1). (**a**) Correlation for systolic and diastolic blood pressure measurements between methods. Solid line represents a theoretical correlation of 1, while dash line represents the estimated correlation. (**b**) Bland–Altman representation between methods for systolic and (**c**) diastolic blood pressure. *r*, Pearson correlation coefficient. *n*, number of data sets. 95% CI, confidence interval is the range of values within which we are 95% confident that the true population parameter lies. In (b) and (c): solid line represents the measured bias between methods; dash line represents twice the SD around the mean and bias in the box is in mm Hg. **P* < 0.005, ***P* < 0.01, ****P* < 0.001.

the intra-arterial blood pressure measurement ($r \geq 0.91$, $P < 0.001$) in severely obese and nonseverely obese patients. For severely obese patients, the comparison between methods showed a clinically acceptable difference in the supine position for systolic blood pressure (−4 ± 11 mm Hg) but not for diastolic blood pressure (12 ± 10 mm Hg). The magnitude of differences of systolic blood pressure between forearm and intra-arterial methods was also clinically acceptable in semi-fowler with the forearm unsupported (2 ± 14 mm Hg), but this finding remains to be further studied taking into consideration the variability of difference between methods reflected by the large SD of the mean difference. At most, only 4% data points exceeded the limits of agreement using the Bland–Altman plots. Clearly, clinicians can use forearm systolic blood pressure measurement in a severely obese patient in the supine position.

Differences between methods: effect of body and arm positions

Agreement between methods varied according to different body and forearm positions, with higher impact for diastolic than systolic blood pressure measurements. Discrepancy between the forearm and intra-arterial methods could be explained by different mechanisms. First, in the supine position, better agreement between methods in both groups is probably due to reduced gravitational and hydrostatic effects on blood pressure. Blood pressure measured in the supine position is usually higher for systolic and lower for diastolic, compared with values measured in the sitting position.[26] This phenomenon involved physiological components at the vascular level following positional hemodynamic perturbation. Obesity is associated with higher cardiac output[1,27–29] and an altered/decreased vascular resistance[27,29], conditions inducing blood pressure variations and, consequently, potentially explaining increased differences between methods. In the semi-fowler position, lower venous return results in a drop in cardiac output as blood accumulates in lower extremities and abdominal vasculature.[30] These mechanisms are potentially amplified in obesity, especially with forearm supported at heart level instead of downward. It is also possible that vascular responses to postsurgery drugs (e.g., vasodilators) accentuated differences between methods despite synchronization during simultaneous pairs of measurements.

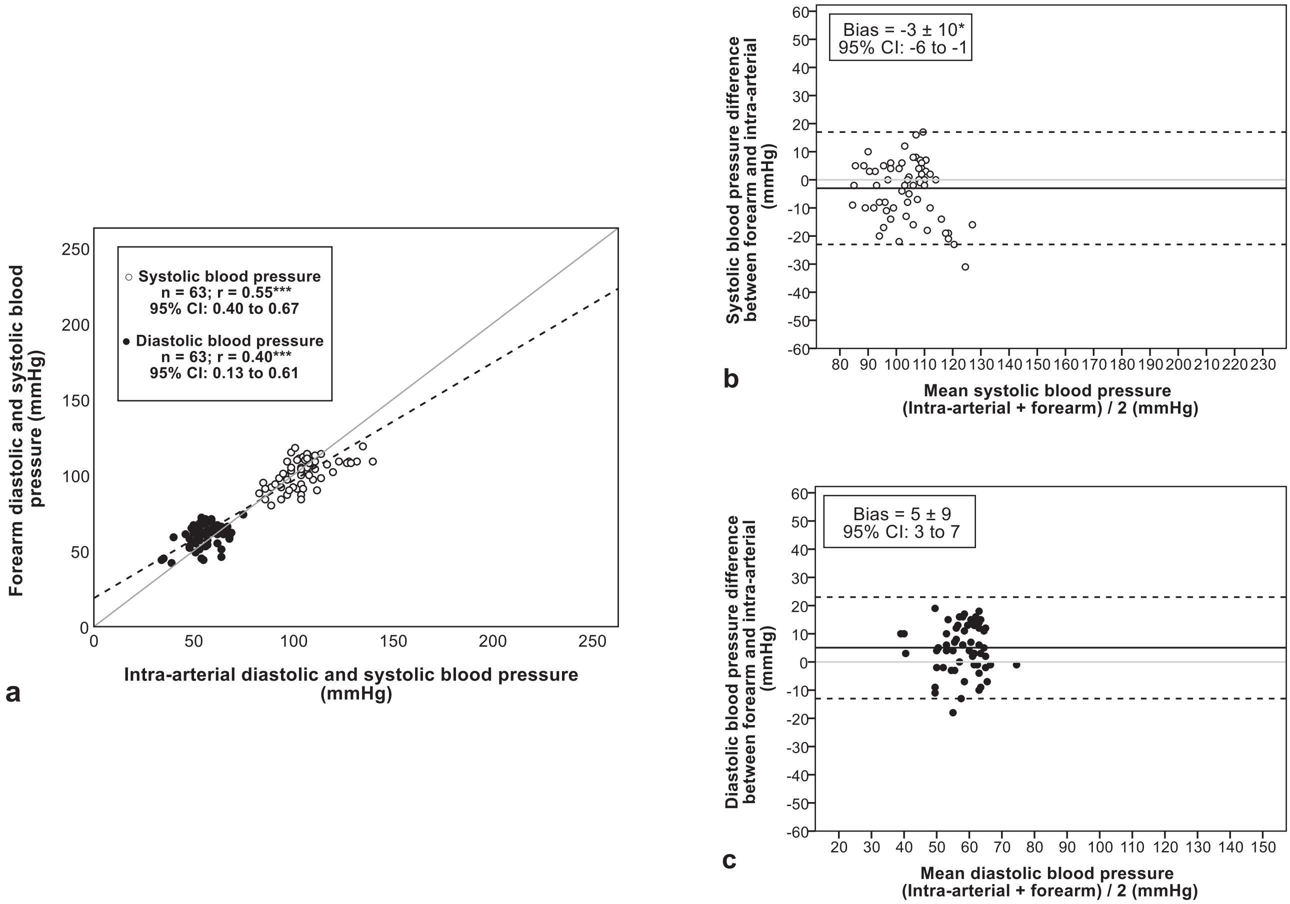

Figure 5. Forearm method and intra-arterial diastolic and systolic measures in the control group semi-fowler, arm supported at heart level (position 2). (**a**) Correlation for systolic and diastolic blood pressure measurements between methods. Solid line represents a theoretical correlation of 1, while dash line represents the estimated correlation. (**b**) Bland–Altman representation for methods for systolic and (**c**) diastolic blood pressure; *r*, Pearson correlation coefficient. *n*, number of data sets. 95% CI, Confidence interval is the range of values within which we are 95% confident that the true population parameter lies. In (b) and (c): solid line represents the measured bias between methods; dash line represents twice the SD around the mean and bias in the box is in mm Hg. **P* < 0.005, ***P* < 0.01, ****P* < 0.001.

Differences between methods: effect of the oscillometric mechanism and systolic brachial/artery amplification

Another reason explaining discrepancies between methods is that noninvasive blood pressure measurements using oscillometric mechanisms (forearm method) have a different pattern of pressure detection vs. an invasive measurement (intra-arterial method). Intra-arterial catheter directly measures the continuous blood flow pressure, whereas oscillometric device indirectly detects blood oscillation with a cuff compressing the arterial wall; systolic/diastolic blood pressures are then empirically derived using mathematical algorithms.[31,32] In a study including 43 patients, 109 sets of blood pressure measured at upper arm with an oscillometric validated device underestimated systolic and overestimated diastolic (−9/9 mm Hg) compared with intra-arterial measures.[33] Another study including 24,225 participants with upper-arm measures using an oscillometric device reported that noninvasive blood pressure measurement was likely to be higher vs. low intra-arterial blood pressure level values and lower vs. high intra-arterial values.[34] In our study, blood pressure was different between groups with higher level observed in the severely obese group. The lower systolic blood pressure measured with the oscillometric method in the semi-fowler position tended to get closer to intra-arterial systolic blood pressure when forearm moved from supported at heart level to unsupported. This attenuated difference in systolic blood pressure between the 2 methods observed with the forearm unsupported could be the result of increased hydrostatic pressure with the change in forearm position. Better agreement between methods in this position for the severely obese patients could also be explained by a compensation for the higher systolic blood pressure amplification along the brachial–radial artery in this group.[35]

Differences between methods: forearm values closer to gold standard

In the severely obese patients, as expected, we observed clinically unacceptable differences between upper arm and intra-arterial methods regarding systolic blood pressure in all positions (all differences ≥14 mm Hg). To our knowledge, this is the first study quantifying the bias in blood pressure measurement induced by uncorrected adjustment with the routinely used inadequate cuff size in a large group of severely obese patients. Differences between upper arm and intra-arterial diastolic blood pressure were clinically acceptable. Few studies used intra-arterial blood pressure as the gold standard reference to validate forearm approach in severely obese patients,[11,36–38] in the supine or sitting positions. The oldest study including 6 severely obese patients with arterial line positioned in the brachial or radial artery showed better agreement for systolic and diastolic blood pressure with forearm method using a mercury device (−3/12 mm Hg) vs. upper arm (55/36 mm Hg).[36] Forsberg et al.[38] reported that the forearm method better agreed with brachial intra-arterial blood pressure compared with upper arm in 5 severely obese patients using an auscultatory device, even though both methods overestimated systolic and diastolic blood pressure (10/8 vs. 36/30 mm Hg). Anast et al.[37] compared (i) forearm, (ii) conical upper arm, and (iii) cylindrical upper arm to radial intra-arterial method in 30 severely obese patients (mean BMI: 40 kg/m2). No significant differences between all pairs of methods were found with better agreement between forearm and intra-arterial measurement (2/0 mm Hg).[37]

In accordance with our previous study using a similar design,[11] forearm blood pressure measurement seems to agree to the gold standard and therefore be considered clinically interchangeable according to the Bland–Altman methodology. Even though, the Association for the Advancement of Medical Instrumentation (AAMI) criteria were respected regarding mean differences between methods in dorsal decubitus (≤5 mm Hg), the dispersion of differences between methods exceeded the recommended SD (>8 mm Hg). Amplitude of differences between forearm and intra-arterial was also closely related to differences in this study for systolic but not for diastolic blood pressure (5/5 mm Hg), whereas differences between upper arm and intra-arterial were out of the acceptable range (−8/9 mm Hg).[11]

The forearm approach features

To our knowledge, no study has validated a forearm method using an ambulatory blood pressure measurement type of device. Only 1 case report involved a severely obese women (BMI: 49 kg/m^2, arm circumference: 53 cm) who wore the cuff at the forearm level for 24 hours.[39] Authors concluded that the forearm method use for the ambulatory blood pressure measurement is an option in patients with large upper arms and recommended the patient to support the forearm at heart level during measures.[39] However, our data suggest the opposite, i.e., keep the forearm unsupported (under heart level) during measures because the semi-fowler position with forearm unsupported (position 3) showed the closest representation of a potential ambulatory blood pressure measurement. No consensus regarding arm position during ambulatory measurements is provided in guidelines[4–6,40,41] or using the forearm method which is incompletely described in the literature. European[6] guidelines suggested to support the arm at heart level during measures, whereas American[5,40] and Canadian[4] guidelines are silent in this matter. To address the lack of standardization, a recent review suggested to advise patients to keep the arm straight down the side of the body during blood pressure measurement; this advice is easily understood for most patient and avoid confusion during blood pressure readings at the upper-arm level.[41] This mention could be probably applied to the forearm method as our results show better agreement when the forearm is downward but remains to be validated in ambulatory patients. Undoubtedly, upper-arm systolic blood pressure measurements in severely obese patients provided biased readings, while diastolic readings were more related to intra-arterial measures in almost all positions. We found better agreement in the supine position in severely obese patients. However, if the supine position is clinically challenging, the patient could remain seated in semi-fowler with the forearm unsupported (straight down the side of the body), which is technically more reproducible and easier to adopt.

Limitations

There are some limitations in our study. First, the oscillometric ambulatory British Hypertension Society (BHS) device used in this project met the validation criteria of the BHS protocol,[42] implying a precommercialization validation with a mercury manometer in nonobese population only. Secondly, even though technically unavoidable in this study due to the research design, using 2 different devices (Philips for intra-arterial and upper-arm readings and Mobil-O-Graph for forearm BP readings) may have introduced an unmeasured informative bias leading to over or underestimations of differences. Thirdly, our study was performed in a clinical setting different from the real-life context. This may have introduced a selection bias as patients in our study were postsurgery patients (bariatric and cardiac) and differ from an outpatient population. Intrinsic pitfalls related to the intra-arterial and oscillometric methods could be implicated in differences between methods: all patients received intravenous medications and interactions with vascular endothelium could generate disharmony between oscillations detected by cuff and intra-arterial readings. Fourthly, we had a limited number of measures by position, which could affect precision of the estimated bias between methods. However, this study, to our knowledge, is the first to validate forearm blood pressure in severely obese patients in different body and arm positions. In this experimentation, the same investigator performed all measurements, then reducing the risk of inter-observer variability. Also, the same oscillometric device was used through the study for all blood pressure measured at the forearm, favoring reproducibility. Further research is needed to compare paired methods (intra-arterial and oscillometric forearm) in unrestricted positions and ambulatory severely obese patients for a longer monitoring period (i.e., 12-hour monitoring).

PERSPECTIVES

In this study, forearm systolic blood pressure consistently agreed with the gold standard in the supine position in the severely obese and control groups. The forearm approach should be considered valid in this position and can be used in clinical settings to measure blood pressure when upper-arm measurement is challenging in severe obesity.

SUPPLEMENTARY DATA

Supplementary data are available at *American Journal of Hypertension* online.

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DISCLOSURE

The authors declared no conflict of interest.

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