

The correlation between body mass index, limb circumferences and blood pressure cuff fit in bariatric surgical patients

ABSTRACT

Introduction: The purpose of this study was to determine the correlation between body mass index (BMI) and upper and lower arm as well as lower leg circumferences and the frequency of correct blood pressure (BP) cuff fit. We explored recommendations for the most likely BP cuff size and location for the three BMI categories.

Materials and Methods: Following IRB approval we retrospectively analyzed a research database of bariatric surgical patients with a BMI of ≥ 40 kg/m². Data included patients' characteristics, upper and lower arm as well as lower leg circumferences. Patients were divided into three groups based on BMI (kg/m², Group I: <45, Group II: 45-55, and Group III: >55). Appropriate cuff fit using a standard or large adult BP cuff (CRITIKON®, GE Healthcare, Waukesha, Wisconsin, USA) on the upper and lower arm, and lower leg was determined. We analyzed the percent proportion of proper cuff fit for cuff sizes and locations between groups using appropriate nonparametric testing.

Results: Limb circumference correlated significantly with BMI ($P = 0.01$), and the upper arm correlated most closely ($r = 0.76$). A standard adult BP cuff on the lower arm fit properly in >90% and >80% and in Groups I and II, respectively. A large cuff on the lower arm was appropriate in 87% of Group III. In two participants, a large cuff fit properly on the lower leg.

Discussion: Limb circumference significantly correlated with BMI. Recommendations for proper cuff fit in different BMI categories can be made.

Key words: Arm circumference; bariatric; blood pressure; cuff fit; obesity

Introduction

Automated noninvasive oscillometric blood pressure (NIBP) devices measure blood pressure (BP) by recording pressure pulses in an inflatable cuff. It is a recommended standard practice to place the cuff on the upper arm for routine BP assessment. Appropriate BP cuff fit according to the manufacturers' specification is important to obtain accurate results. A correct cuff width and length depends on the

patient's age, weight, height and upper arm circumference, and cuff size in relation to limb circumference is of critical importance.^[1-3]

BP cuff fit in obese patients may be a challenge due to adipose tissue distribution affecting arm circumference and shape. Ulijaszek and Henneberg demonstrated that

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the arm circumference, when using a standard adult cuff size is the most important factor determining a significant difference in BP measurement between obese, overweight and normal patients, based on body mass index (BMI).^[4] Prineas showed a systematic bias of NIBP measurements in the obese patients when incorrect cuff width to arm circumference ratio is employed.^[5] Although, special BP cuffs accounting for a cone shape and/or increased arm circumference are available for the obese population, their utilization may not be uniform and consistent in clinical practice. Frequently standard adult and large adult BP cuff sizes applied to the upper arm, forearm or lower leg are used in this population.

The purpose of this study was to determine the correlation between BMI and upper and lower arm, as well as lower leg circumferences, and the frequency of correct BP cuff fit. We hypothesized that limb circumference would increase, and that correct BP cuff fit would decline with increasing BMI class. We explored whether recommendations for the most likely BP cuff size and location could be made for three different categories of the BMI.

Materials and Methods

Following IRB approval we performed a secondary analysis of prospectively collected data from a research database of a separate project. The database contained information from patients presenting for bariatric surgical procedures with a BMI of ≥ 40 kg/m². Data collected included age, gender, height, weight, American Association of Anesthesiologists (ASA) physical status classification, co-morbidities, upper arm, forearm, and lower leg circumferences as well as categorical information on appropriate BP cuff fit according to the manufacturer's specified range.

Limb circumferences were determined by measurements in centimeters at the midpoint of each limb using reproducible anatomical landmarks in this population. These consisted of the acromion and the olecranon for the upper arm, the olecranon and the ulnar head for the forearm, and the midpoint of the patella and the medial malleolus for the calf.

For the purpose of this study, we analyzed patients' data according to their BMI categorized into three groups; Group I: <45 , Group II: 45-55, and Group III: >55 kg/m². Each participant had been sequentially fitted with a large adult BP cuff on the upper arm, a standard adult cuff followed by a large adult cuff on the forearm and finally a large adult cuff on the lower leg (CRITIKON®, GE Healthcare, Waukesha, Wisconsin, USA).

Appropriate BP cuff fit was defined as cuff closure within the manufacturer recommended cuff limits for a given limb circumference.

In clinical practice, a functioning cuff (i.e., a BP reading was obtained) independent of considerations for appropriate cuff sizing is often accepted, and we separately tracked the frequency of BP cuff failure. The latter was defined as:

1. Failure of cuff closure,
2. Failure to obtain a BP reading (independent of BP cuff fit considerations, usually due to limb shape), and
3. Spontaneous BP cuff detachment from the limb during a measurement cycle.

The two-tailed Pearson correlation was used to determine the relationship between BMI and limb circumferences and BMI and proper cuff fit. Given a predominantly nonnormal distribution of values, we determined the limb circumferences between groups and the frequencies of correct cuff fit between BMI categories conservatively using the Kruskal–Wallis test, and employed the Mann–Whitney U-test for individual intergroup comparisons. A $P < 0.05$ was considered significant. For statistical analysis, we used IBM SPSS Statistics Version 21 (IBM, Armonk, NY, USA). Data are reported in means \pm standard deviation for continuous variables and proportion of frequencies in percent for categorical variables.

Results

Data of 108 patients were available for analysis. The patients' characteristics are summarized in Table 1. Patients in Group III were significantly younger compared to Groups I and II. No statistically significant difference between groups was found for gender, ASA status, and procedure type.

The differences in arm and leg circumferences were statistically significantly different between BMI groups [Table 2]. Pearson correlation plots comparing, BMI and limb circumferences as continuous variables are shown in Figure 1. The best correlation between BMI and circumferences was found for the upper arm ($r = 0.76$) followed by the lower leg ($r = 0.69$) and the lower arm ($r = 0.57$). All correlations were significant ($P = 0.01$).

A regular BP cuff on the lower arm fit properly in $>90\%$ and $>80\%$ and in Groups I and II respectively, and this was statistically significantly different to Group III ($P = 0.001$). A large cuff on the lower arm was appropriate in 87% of the time in Group III, and this was significantly different to Groups I and II [$P = 0.009$, Table 2 and Figure 2]. Only two

Table 1: Patients characteristics

Characteristics, Procedure type and Co-morbidities	BMI categories			Total	P
	<45	45-55	>55		
n	44	48	16	108	—
Age (years)	47.3±12.6 (21-70)	48.0±13.6 (22-72)	38.8±8.9* (21-50)	46.4±12.9 (28/80)	0.03
Gender ♂/♀, % (n)	20.4/79.6 (9/35)	27.1/72.9 (13/35)	37.5/62.5 (6/10)	25.9/74.1 (28/80)	0.4
BMI (kg/m ²)*	42.2±1.6 (40.0-44.9)	49.6±2.5 (45.1-54.7)	62.9±5.4 (56.4-73.8)	48.6±7.4 (40.0-73.8)	<0.001
Type of procedure %, (n)					
LGBP	66, (29)	52.1, (25)	37.5, (6)	55.6, (60)	0.14
LSG	34, (15)	43.7, (21)	62.5, (10)	42.6, (46)	
LGB	0	4.2, (2)	0	1.8, (2)	
ASA %, (n)					
II	20.6, (9)	22.9, (11)	18.7, (3)	21.3, (23)	0.67
III	79.4, (35)	77.1, (37)	81.3, (13)	78.7, (85)	
Co-morbidities %, (n)					
Hypertension	45.4, (20)	58.3, (28)	62.5, (10)	53.7, (58)	—
Diabetes	40.9, (18)	39.6, (19)	43.8, (7)	40.7, (44)	
OSA	38.6, (17)	43.8, (21)	62.5, (10)	44.4, (48)	
GERD	38.6, (17)	33.3, (16)	37.5, (6)	36.1, (39)	
Asthma	22.7, (10)	20.8, (10)	31.2, (5)	23.1, (25)	

Data in means ± SD (range); *Statistically significant difference for between groups comparison; BMI: Body mass index; ASA: American Society of Anesthesiologists physical status classification; OSA: Obstructive sleep apnea; GERD: Gastroesophageal reflux disease; LGBP: Laparoscopic gastric bypass; LSG: Laparoscopic sleeve gastrectomy; LGB: Laparoscopic gastric banding; SD: Standard deviation

of the 108 participants had a proper fit of the large adult cuff on the lower leg.

Table 3 summarizes the outcome of BP cuff failure. No cuff failure was observed on the lower arm.

Discussion

As can be expected, the results of our study in this bariatric surgical population confirm that the circumferences of the upper and lower arm, as well as the lower leg, significantly increase with BMI. However, our data suggest that with increasing BMI adipose tissue accumulation to the limbs is centripetal, and the upper arm is more affected than the lower leg and the lower arm in that order respectively.

This observation may in part explain our finding that the forearm was the best site for a correct match of limb circumference with a standard BP cuff in Groups I and II and with a large cuff in Group III. We determined that a standard adult BP cuff for a BMI between 40 and 55 kg/m² and a large adult BP cuff for a BMI >55 kg/m² on the forearm respectively provide the best chances to meet proper BP cuff fit criteria. In patients with a BMI of <45 kg/m², the upper arm remained an option for a correct large adult BP cuff fit in more than 60%. The lower leg fitted with a standard large adult BP cuff does not appear to represent a good alternative site and cuff size for BP assessment based on cuff fit criteria.

Table 2: Limb circumferences and proper BP cuff fit by BMI group

Limb circumferences and cuff fit	BMI categories			Total	P
	<45	45-55	>55		
n	44	48	16	108	
Upper arm circumference (cm)	39.9±3.6	44.8±4.1	50.9±4.3	43.7±5.4	≤0.001*
Lower arm circumference (cm)	29.6±2.6	31.0±2.9	34.7±2.4	31.0±3.2	≤0.001*
Lower leg circumference (cm)	45.6±3.1	50.1±6.1	57.7±5.4	49.4±6.4	≤0.001*
Proper NIBP cuff fit %, (n)					
Upper arm (large cuff)	61.4, (27) [#]	10.4, (5)	0, (0)	29.6, (32)	≤0.001
Lower arm (regular cuff)	90.9, (40)	81.2, (39)	37.5, (6) [#]	78.7, (85)	0.001
Lower arm (large cuff)	32.0, (14)	50.0, (24)	87.5, (14) [#]	48.1, (52)	0.009
Lower leg (large cuff)	4.5, (2)	0, (48)	0, (16)	1.8, (2)	0.39

There was a statistically significant difference between circumferences of each limb in each category; A nonproper cuff fit was due to a cuff being too small for the circumference except for a large cuff on the lower arm which was too large for the circumference.

*Statistically significant difference for group comparison and also between individual groups;

[#]Significant difference compared to each of the other group's cuff fit values. BMI: Body mass index (kg/m²); BP: Blood pressure; NIBP: Noninvasive blood pressure

For the standard location of BP assessment on the upper arm, the American Heart Association (AHA) published recommendations for appropriate BP cuff sizes in relation to upper arm circumferences which have been widely recognized.^[6] The standard location of reference for NIBP measurements is the brachial artery at the upper arm, which may not always be an option in severely obese patients

Table 3: BP cuff failures

BP cuff fit failure	BMI categories			Total
	<45	45-55	>55	
<i>n</i>	44 (9 male/35 female)	48 (13 male/35 female)	16 (6 male/10 female)	108 (28 male/80 female)
Upper arm, <i>n</i> (%)				
Failure of cuff closure	0	3 (6.25)	7 (43.75)	10 (9.26)
Failure to obtain a BP reading	2 (4.5)	1 (2.1)	0	3 (2.78)
Spontaneous BP cuff detachment from the limb during a measurement cycle	0	5 (10.4)	3 (18.75)	8 (7.41)
Lower leg (%)				
Failure of cuff closure	4 (9.1)	12 (25.0)	14 (87.5)	30 (27.78)
Failure to obtain a BP reading	1 (2.3)	0	0	1 (0.92)
Spontaneous BP cuff detachment from the limb during a measurement cycle	2 (4.5)	7 (14.6)	1 (6.25)	10 (9.26)

Descriptive statistics of cuff failures at different sites for each BMI category; There was no cuff failure on the lower arm; BP: Blood pressure; BMI: Body mass index (kg/m²)

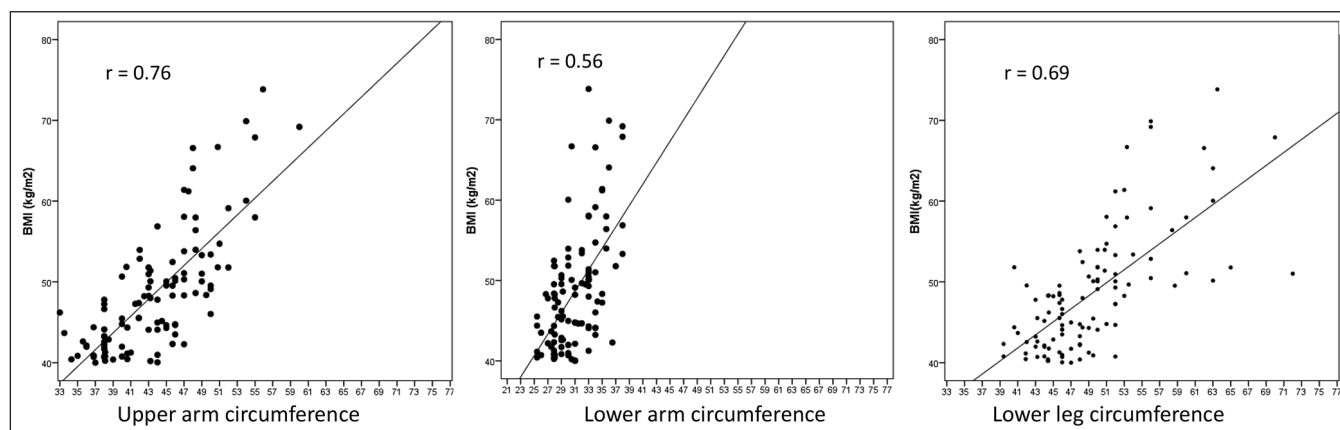


Figure 1: Correlation between body mass index and limb circumferences. There was a significant correlation between body mass index and limb circumferences (cm, Pearson correlation, *P* = 0.01)

due to limb shape, size or both. In one outpatient study, undercuffing large arms accounted for 84% of miscuffings, a result that may still be relevant considering the increasing prevalence of obesity and subsequently more frequent encounters with large arm circumferences.^[7] Regarding the obese population, the AHA recommends the availability of different BP cuff sizes and concedes that even then proper BP assessment might be challenging and the lower arm can be considered as a site when fitted with an appropriately sized BP cuff.^[6] However, the accuracy of the latter has not been validated.

When choosing an alternative location for BP assessment practitioners need to be mindful of the possibility of significant differences in BP in different sections of the arterial tree, with SBP increasing, and DBP decreasing in distal arteries.^[2] Moore *et al.* investigated noninvasive measurements at the arm, calf and ankle in healthy volunteers using properly fitted standard BP cuffs at these sites and determined that the mean BP could be as much as 28 mmHg and 33 mmHg higher at the calf and ankle, respectively.^[8] These results indicate that in addition to

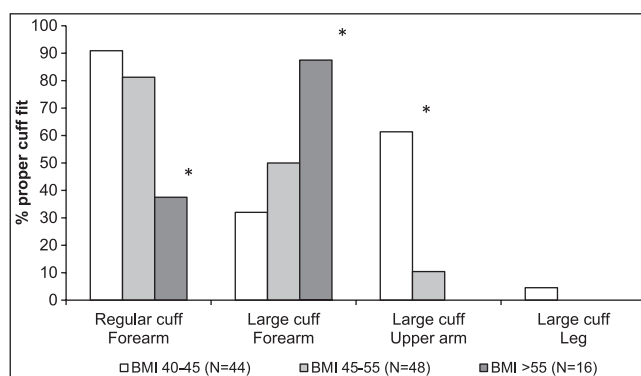


Figure 2: Blood pressure cuff fit per group and location. BMI: Body mass index; *: Statistically significant difference of cuff fit compared to other groups

miscuffing, the site of measurement may add additional complexity to the accuracy of BP determinations, especially in patients with obesity.

It has long been established that an undersized cuff may overestimate true BP, while an oversized one can underestimate true BP by 10 to 30 mmHg.^[7] Such differences

may be of critical importance perioperatively, and may influence intra- and post-operative management decisions. A cuff too small in relation to circumference constitutes the most common mistake and frequently results in an overestimation of the true BP.^[2,9,10]

There are several limitations to our investigation in addition to the retrospective study design. We exclusively studied a regular adult and a large adult BP cuff, as these are the most frequently available cuffs in many perioperative environments. Having additional cuff sizes available as well as special cuffs designed for a conical limb shape frequently encountered in obese individuals may greatly increase the possibility of a proper cuff fit. Our study also did not address the accuracy of NIBP measurements of appropriately sized BP cuffs at alternative measurement sites, and this should be systematically investigated. Finally, the sample size of patients with a BMI above 55 kg/m² was relatively small.

Conclusion

We found that limb circumference increases in correlation with BMI, and the upper arm was the most affected. In the BMI category between 40 and 55 kg/m², given the choice between a large and a standard adult BP cuff, the latter offers the best chances of a proper fit at the lower arm location. In patients with a BMI beyond 55 kg/m², the large adult cuff on the lower arm provides the best chances of a proper fit.

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Conflicts of interest

There are no conflicts of interest.

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