Rectangular cuffs may overestimate blood pressure in individuals with large conical arms

Paolo Palatini, Elisabetta Benetti, Claudio Fania, Giacomo Malipiero, and Francesca Saladini

OBJECTIVES: Although the upper arm has the shape of a truncated cone, cylindrical cuffs and bladders are currently used for blood pressure (BP) measurement. The aim of this study was to ascertain whether cylindrical and tronco-conical cuffs provide different readings according to arm size and shape.

DESIGN: We studied 220 individuals with arm circumference ranging from 22 to 42.5 cm. Four different cylindrical and four different tronco-conical bladders of appropriate size were used. Sequential same-arm measurements were performed in triplicate by two observers using the two cuffs in a random order. In 100 individuals, the actual pressure transmitted to the arm surface by the two cuffs at the central point was also measured.

RESULTS: Upper arm shape was tronco-conical in all of the individuals. In a multiple regression, conicity was related to arm circumference \( (P < 0.001) \) and length \( (P = 0.001) \). Arm conicity and size were independently related to the between-cuff SBP \( (P = 0.001 \text{ and } 0.002, \text{ respectively}) \) and DBP \( (P = 0.001 \text{ and } <0.001, \text{ respectively}) \) discrepancies. In the group with arm circumference of 37.5–42.5 cm, the cylindrical cuff overestimated BP measured with the tronco-conical cuff by 2.0±0.4/1.8±0.3 mmHg \( (P = 0.001 \text{ and } <0.001) \). In this group, 15% of individuals found hypertensive with the cylindrical cuff were normotensive size (range 22–42.5 cm) and shape.

CONCLUSION: In obese people, the upper arm may have a pronounced tronco-conical shape and cylindrical cuffs may overestimate BP. Tronco-conical cuffs should be used for BP measurement in individuals with large arms.

KEYWORDS: arm size, bladder pressure, conical, cuff, measurement

ABBREVIATIONS: AHA, American Heart Association; BP, blood pressure; ESH, European Society of Hypertension

INRODUCTION

The ability of a doctor to measure blood pressure (BP) accurately may be challenged by the size and shape of the upper arm. When the arm circumference near the shoulder is much greater than the arm circumference near the elbow, a cylindrical (rectangular) cuff will expand irregularly over the lower part of the upper arm, making it difficult to perform a reliable measurement. Cone-shaped arms can be frequently encountered in obese patients, and may be an important source of inaccurate BP measurement [1–3]. Recent anthropometric data document an increased prevalence of obesity among adults [4], resulting in a significant increase in the population mean arm circumference [5]. This problem has always been overlooked in the literature and it is not known what shape and size an optimal cuff should have to fit large-sized arms. In an old study, Maxwell et al. [1] using a conical cuff obtained lower SBP and DBP readings than with the rectangular cuffs independent of arm circumference. The between-cuff discrepancies may be clearly greater if cuffs made of rigid material are used because a hard cylindrical cuff can hardly fit the distal part of a conical arm. Indeed, in 33 individuals, we previously showed that a rigid cylindrical cuff coupled to an automatic oscillometric device markedly overestimated SBP in individuals with large arms [6]. Soft cylindrical cuffs are currently used in clinical practice and might better fit cone-shaped arms than rigid cuffs and could, thus, be as accurate as tronco-conical cuffs in obese individuals. Thus, the aim of the present study was to investigate whether cylindrical and tronco-conical cuffs made of soft material provide different readings in individuals with different arm size (range 22–42.5 cm) and shape.

METHODS

Participants

Participants for this study were individuals that met the following criteria: age of at least 18 years, upper arm circumference between 22 and 42.5 cm, and upper arm length from the axilla to the antecubital fossa of at least 17 cm. Two obese women with upper arm length of 16 cm were excluded. Patients attending general medical outpatient clinics at the Padova University Hospital were
recruited. The study was performed in 220 individuals (110 men). All agreed to participate in the protocol and gave informed consent.

**Measurements**

Upper arm length was measured from the axilla to the antecubital fossa; arm proximal circumference was measured just below the axilla and distal circumference just above the antecubital fossa to the nearest 0.5 cm with a measuring tape. Upper arm middle circumference was measured at the midpoint from the acromion to the olecranon. For measurement of arm dimensions, participants were placed in the supine position with arms resting comfortably at the sides with forearms in the pronated position. In this calculation, the limb is visualized to be in the shape of a truncated cone (Fig. 1). The circumference of the extremity at the proximal and distal limits of the segment, together with the length between them, was used to calculate the slant angle (in degrees) using the formula: slant angle = \arccos\left(\frac{C_1 - C_2}{2 \cdot \pi \cdot L}\right) \times \frac{360}{2 \cdot \pi} \text{ in which '} C_1 \text{' is the arm proximal circumference, '} C_2 \text{' is the arm distal circumference, and '} L \text{' is the arm length. Skinfold thickness was measured in triplicate at the triceps and biceps, with a manual caliper, and the average of the six measurements was defined as skinfold thickness. BP was measured with a mercury sphygmomanometer in the sitting position. BMI was calculated as body weight divided by height squared.

**Cuffs**

Four different tronco-conical and four different cylindrical cuffs and bladders of appropriate size were constructed (EMed. Garda S.r.l., Costermano, Italy), following the recommendations of the American Heart Association (AHA) [7], for arm circumferences ranging from 22.0 to 27.0 cm (group 1); from 27.5 to 32.0 cm (group 2); from 32.5 to 37.0 cm (group 3); and from 37.5 to 42.5 cm (group 4). For each arm size group, both tronco-conical and cylindrical bladders had a length that was at least 80% and a width that was at least 40% of arm circumference at the midpoint. Each couple of bladders had exactly the same width and the same length at the midpoint (±1 mm). Tronco-conical bladder slant angles for each arm size group were derived from the anthropometric measures previously obtained in 410 participants (Table 1). The cuffs were formed of two layers of soft, pliable, polymer that was strong enough for repeated inflations. Measures of proximal and distal circumferences of the conical cuffs are reported in Table 1.

**Procedures**

The procedures followed were in accordance with institutional guidelines. A method comparison design was used to compare two different upper arm cuff bladders (cylindrical shape or conical shape) for noninvasive BP measurement in four groups of participants with different arm size. Each

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**TABLE 1. Dimensions of the four conical cuffs used in the participants**

<table>
<thead>
<tr>
<th>Arm size (cm)</th>
<th>Group 1 (22–27)</th>
<th>Group 2 (27.5–32)</th>
<th>Group 3 (32.5–37)</th>
<th>Group 4 (37.5–42.5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximal length (cm)</td>
<td>23.3</td>
<td>28</td>
<td>33</td>
<td>38.2</td>
</tr>
<tr>
<td>Middle length (cm)</td>
<td>22</td>
<td>26</td>
<td>30</td>
<td>34</td>
</tr>
<tr>
<td>Distal length (cm)</td>
<td>20.7</td>
<td>24</td>
<td>27</td>
<td>29.8</td>
</tr>
<tr>
<td>Width (cm)</td>
<td>11</td>
<td>13</td>
<td>15</td>
<td>17</td>
</tr>
<tr>
<td>Frustum of cone slant angle (°)</td>
<td>87.9</td>
<td>87.2</td>
<td>86.4</td>
<td>85.5</td>
</tr>
</tbody>
</table>
participant served as their own control with BP measured with both cuffs. The primary dependent variables were the difference in SBP and DBP measurements between the two cuffs. BP measurements were performed by two persons experienced in device validation using similar procedures to those recommended by the 2002 European Society of Hypertension (ESH) guidelines for validation of BP measuring devices [8]. The two observers used for the present validation study (E.B. and F.S.) participated in previous published validation studies [6,9]. They were tested according to the suggestions of the ESH protocol and the agreement between these two observers was \(-1.0 \pm 2.0\) mmHg for SBP and \(-0.7 \pm 2.3\) mmHg for DBP. The two observers were blinded to the measurement values of each other and took BP measurement with a mercury sphygmomanometer. For analysis, the results of the two observers were combined. Two series of four graduated size cylindrical and four conical cuffs were used, each being adapted to be used by encompassing a limb of a size related to such cuff [7]. The deflated cuffs were snugly applied to the upper arm with the centre of the bladder over the medial surface of the arm. Sequential same arm measurements were performed. Each participant was randomly allocated to have their first BP reading with either of the two cuffs, subsequent readings then alternating with the other. All readings were taken after sitting for at least 5 min, using diastolic phase V. Three readings were taken with each of the two cuffs. In the last 25 participants of each arm size group, the pressure present in the inflated cuffs was measured at four different pressure levels (60, 90, 120, and 150 mmHg) on the arm surface under the cuff. The pressure on the arm surface was measured using paper-thin pressure sensors attached to the central point of the cuffs and connected to a pressure transducer (Microlab, Padua, Italy). At each pressure level, three readings were collected and averaged with both the cylindrical and the tronco-conical cuffs using the same sequence employed for BP measurements. Thus, in each arm size group, 300 readings obtained with the conical and the cylindrical cuffs were compared.

Statistical analysis
Data are presented as mean ± SD unless specified. For comparisons between arm size groups, an analysis of variance (ANOVA) test was used adjusting for age and sex. Potential arm size × arm length interactions on between-cuff discrepancies in SBPs and DBPs were evaluated in a two-way analysis of covariance after adjustment for age and sex. The significance of differences in categorical variables was assessed with the χ²-test or the McNemar test where appropriate. Relations between continuous variables were assessed using Pearson’s correlation with Bonferroni adjustment for multiple comparisons. Predictors of conicity and of between-cuff pressure discrepancies were included in linear multivariable regression analyses. A P value of 0.05 or less was considered as statistically significant.

RESULTS
Participants’ mean ± SD age was 54 ± 18 years, SBP was 134 ± 20 mmHg, DBP was 80 ± 13 mmHg, and BMI was 30 ± 9 kg/m². Mean upper arm proximal, middle, and distal circumferences were 35.9 ± 5.7, 32.3 ± 4.9, and 28.3 ± 3.7, respectively. Arm length was 20.9 ± 1.4 cm. Upper arm shape was tronco-conical in all of the participants with slant angles ranging from 89.2–82.4° (mean 86.7 ± 1.2°). Thus, the circumference near the shoulder was always greater than the circumference near the elbow with differences ranging from 2 to 15 cm and a mean value of 7.7 ± 2.8 cm. In the whole population, the upper arm slant angle was similar in men (86.8 ± 1.2°) and women (86.6 ± 1.3°; P = 0.15). However, in group 4 it tended to be smaller among the women than the men (85.3 ± 1.3° versus 85.9 ± 1.2°; P = 0.086). The slant angle was inversely correlated to mid-arm circumference (P < 0.001), average skinfold thickness (P < 0.001), and BMI (P < 0.001) and was correlated to arm length (P = 0.043). In a multiple linear regression that included age, sex, upper arm length, circumference, and skinfold thickness, only arm circumference (P < 0.001) and length (P = 0.001) independently predicted the conical shape of the arm. Sex-specific analyses provided similar results.

The upper arm slant angle progressively decreased with increasing arm size due to a progressive increase in the difference between the distal and proximal circumference (Table 2). In contrast, arm length was totally unrelated to arm size. BMI and skinfold thickness progressively increased on going from group 1 to group 4. Age, sex distribution, SBP and DBP did not differ significantly between the four groups (data not shown).

Cylindrical versus conical cuff
SBP and DBP differences between the two cuffs according to arm size are presented in Fig. 2. BP differences were negligible in group 1. In group 2, a slightly lower BP was

| TABLE 2. Participants’ anthropometric characteristics by arm size |
|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|
| Arm size (cm)        | Group 1 | Group 2 | Group 3 | Group 4 | P for ANOVA |
| Body mass index (kg/m²) | 22.2 ± 0.7 | 26.7 ± 0.7 | 31.4 ± 0.7 | 41.4 ± 0.7 | <0.001 |
| Upper arm proximal circumference (cm) | 28.2 ± 0.3 | 33.3 ± 0.3 | 37.6 ± 0.3 | 43.0 ± 0.3 | <0.001 |
| Upper arm middle circumference (cm) | 25.0 ± 0.2 | 29.9 ± 0.2 | 33.8 ± 0.2 | 38.8 ± 0.2 | n.a. |
| Upper arm distal circumference (cm) | 22.7 ± 0.3 | 26.5 ± 0.3 | 29.3 ± 0.3 | 32.7 ± 0.3 | <0.001 |
| Upper arm length (cm) | 21.1 ± 0.2 | 20.8 ± 0.2 | 21.4 ± 0.2 | 20.9 ± 0.2 | NS (0.19) |
| Proximal – distal circumference (cm) | 5.4 ± 0.3 | 6.7 ± 0.3 | 8.3 ± 0.3 | 10.3 ± 0.3 | <0.001 |
| Upper arm slant angle (°) | 87.7 ± 0.1 | 87.1 ± 0.1 | 86.5 ± 0.1 | 85.5 ± 0.1 | <0.001 |
| Skinfold thickness (cm) | 1.1 ± 0.1 | 1.7 ± 0.1 | 1.9 ± 0.1 | 2.9 ± 0.1 | <0.001 |

Data are mean ± SD. P values are adjusted for age and sex. ANOVA, analysis of variance; n.a., not applicable.
*Mean of biceps and triceps.
obtained with the conical cuff. BP differences increased in groups 3 and 4 in which the cylindrical cuff overestimated BP by 1.7 ± 0.4/0.8 ± 0.3 and 2.0 ± 0.4/1.8 ± 0.3 mmHg, respectively, compared with the conical cuff. Compared with group 1, these differences adjusted for age and sex were significant for SBP in group 3 (P = 0.002) and for both SBP and DBP in group 4 (P = 0.001 and < 0.001, respectively). In group 4, the between-cuff SBP differences were greater among the women (unadjusted P = 0.015), but the sex-related difference disappeared after adjustment for arm length (P = 0.61). Bivariate correlations between BP differences and clinical variables are reported in Table 3. SBP differences were correlated with SBP, BMI, and upper arm circumference, length, skinfold thickness, and slant angle. DBP differences were correlated with BMI and upper arm circumference, length, and slant angle. In multivariable linear regressions, independent predictors of the between-cuff SBP difference were arm circumference (P = 0.002), arm length (inverse relationship, P = 0.005), and SBP level (P < 0.001). Predictors of the DBP difference were arm circumference (P < 0.001) and length (inverse relationship, P = 0.002). The upper arm slant angle was also a significant predictor of the BP differences when included in the multivariable regressions in place of arm dimensions (P = 0.001 for both). In the seven participants of group 4 with upper arm slant angle less than 84°, the between-cuff BP mean differences were 4.2/4.1 mmHg and in the two women with slant angle 83° or less, they were 9.7/7.8 mmHg. In a two-way ANOVA in which the participants were divided into two subgroups of arm circumference of 34 cm or less or more than 34 cm according to the cutoff suggested by AHA [7] and into tertiles of arm length, a significant effect of arm length was found on the SBP difference only among the participants with larger arm with a significant interaction between arm size and length (Fig. 5). Similar results were found when the 32 cm cutoff was used. Among the participants of group 4, the prevalence of hypertension differed according to whether the diagnosis was based on BP measured with the cylindrical or the conical cuff (54.6 versus 40.0%, P < 0.001). Thus, in this group, 15% of the participants found hypertensive with the cylindrical cuff turned out to be normotensive when assessed with the conical cuff.

**Differences between the pressures recorded in the cuffs at different pressure levels**

At each sensor pressure level, negligible differences between the cylindrical and the tronco-conical cuffs were observed in the two groups with arm circumferences 32 cm or less (Fig. 4). In contrast among the participants with circumference more than 32 cm, a higher pressure was recorded in the cylindrical cuff compared with the conical cuff at all pressure levels, with mean differences of 1.7 ± 0.4 and 1.9 ± 0.4 mmHg, respectively, in groups 3 and 4 (P for ANOVA < 0.001). A close correlation was found between the pressure differences obtained at the four pressure levels with correlation coefficient ranging from

**TABLE 3. Bonferroni corrected simple correlations of participants’ characteristics with the SBP and DBP between-cuff differences**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Systolic difference</th>
<th>Diastolic difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>0.08</td>
<td>0.02</td>
</tr>
<tr>
<td>SBP (mmHg)</td>
<td>0.16</td>
<td>n.a.</td>
</tr>
<tr>
<td>DBP (mmHg)</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>Upper arm middle circumference (cm)</td>
<td>-0.18</td>
<td>-0.15</td>
</tr>
<tr>
<td>Upper arm length (cm)</td>
<td>0.13</td>
<td>0.13</td>
</tr>
<tr>
<td>Upper arm slant angle (°)</td>
<td>0.18</td>
<td>0.16</td>
</tr>
<tr>
<td>Upper arm skinfold thickness (cm²)</td>
<td>-0.14</td>
<td>-0.09</td>
</tr>
<tr>
<td>Body mass index (Kg/m²)</td>
<td>-0.21</td>
<td>-0.19</td>
</tr>
</tbody>
</table>

N = 660. n.a., not applicable.
*Calculated as conical cuff – cylindrical cuff.
*Mean of biceps and triceps.

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FIGURE 3 SBP discrepancies between the tronco-conical and the cylindrical cuffs in the participants stratified by arm circumference and tertile of arm length. A negative value indicates that the cylindrical cuff measurement is greater than the tronco-conical cuff measurement. Data are mean ± SEM and are adjusted for age and sex. Results of two-way analysis of covariance: arm circumference, F = 5.8, P = 0.003; arm length, F = 8.7, P = 0.003; arm circumference × length, F = 4.1, P = 0.017. 0.48 to 0.89 (all Bonferroni corrected P < 0.001). The between-cuff pressure differences recorded in the cuffs significantly correlated with the between-cuff SBP (P = 0.019) and DBP (P < 0.001) discrepancies found by the observers during BP measurement in the same 100 participants.

DISCUSSION

This study found that in individuals with arm circumference more than 32 cm, the use of a cylindrical (rectangular) cuff on the upper arm significantly overestimated BP measurements obtained with a tronco-conical cuff. The differences observed were larger in the individuals with arm circumference from 37.5 to 42.5 cm (group 4) and were proportional to the conical shape of the arm, with discrepancies as large as 9.7 mmHg in upper arms with slant angle 83° or less.

In agreement with our previous results, the shape of the upper arm was tronco-conical in all of the 220 participants [6]. The difference between the circumference near the shoulder and the circumference near the elbow ranged from 5 to 15 cm in the participants of group 4 with an average value of 10.3 cm. The conical shape of the arm was closely correlated to arm circumference and adiposity and to arm length in an inverse fashion. However, in a multiple linear regression analysis only circumference and length remained independent predictors of arm conicity in both sexes.

This is the first upper arm cylindrical versus conical cuff study performed in different groups of arm size. The present results are consistent with previous findings obtained long ago by Maxwell et al. [1] in a general population. Using a single 16 cm-wide conical cuff with a slant angle of 86°, previously worked out by Huige [2], these authors obtained 4 mmHg lower SBP and DBP readings compared with those obtained with cylindrical cuffs, a difference that was unrelated to arm circumference. A limitation of Maxwell et al. study was that the same large-sized conical cuff was used across a wide range of arm circumferences (<30 cm in 51.1%), whereas for the cylindrical cuff a standard cuff (12 × 23 cm) and a larger cuff (15 × 32 cm) were used according to arm size. As the authors themselves admitted the lower readings obtained with the conical cuff in small and average-sized arms were likely to be due to the so-called ‘wide cuff effect’ [7] caused by an inappropriately large conical cuff. In addition, in the article by Maxwell et al., no information was available as to the material used for cuffs. The magnitude of the BP discrepancies may depend on the characteristics of the sleeve and are likely to be greater with cuffs made of rigid or semi-rigid material as suggested by our previous results obtained with an oscillometric device [6]. To obtain accurate BP measurements, the cuff is assumed to perfectly adhere to the arm and to apply uniform pressure on the arm surface [10,11]. A cylindrical cuff cannot exert a uniform pressure on a conical arm because the distal part will remain loose (Fig. 1) and expand irregularly, thereby transmitting a lower pressure to the subcutaneous tissue overlying the artery. The effect of cuff looseness on BP measurement was recently shown by Taleyarkhan et al. in 24 individuals [12]. These authors showed that cuff looseness caused an overestimation of BP readings taken with the cuff at an appropriately snug fit.

A tronco-conical cuff can fit better on upper arms than the cylindrical cuff ensuring proper and consistent cuff placement. It has been shown that the artery experiences extravascular pressure close to cuff pressure under the centre of the cuff, whereas the pressure transmission ratio (pressure in the tissue divided by pressure on the surface) drops gradually down to 30% at the edge of the cuff [10]. This drop in pressure will be clearly greater and unpredictable under the distal part of a cylindrical cuff applied on a conical arm because of the air gap between the elbow end of the cuff and the distal upper arm circumference and can be an important source of error measurement. Indeed, to obtain the same pressure on the surface of the upper arm under the cuff, a higher pressure must be pumped into the cylindrical bladder compared with the conical bladder, a
difference that in our study roughly corresponded to the SBP and DBP discrepancies obtained with the two cuffs. These differences could be even greater if BP is measured with the oscillometric method in which measured cuff pressure oscillations are a reflection of the entire artery volume change under the cuff rather than that of the central section [10]. Thus, the present results apply only to the traditional auscultatory technique and not to BP measurement performed with oscillometric devices.

The average 2 mmHg BP differences obtained with the two cuffs in the present study in people with large arms may appear negligible. However, we found a strong effect of the conical shape of the arm on BP measurements within this range of arm circumference. The between-cuff SBP discrepancy was inversely proportional to arm length and in seven participants of group 4 with upper arm slant angle less than 84°, the between-cuff BP differences were 4.2/4.1 mmHg. In two women with slant angle 83° or less, they were 9.7/7.8 mmHg. Indeed, 15% of group 4 participants found to be hypertensive with the use of the cylindrical cuff turned out to be normotensive when assessed with the tronco-conical cuff. There is, thus, the potential for inaccurate BP readings and an overestimation of patients in need of therapy for hypertension, particularly among obese persons with short humerus length.

Limitations
From our results, we assumed that in large-size arms, the use of a cylindrical cuff caused an overestimation of the true BP. However, we had no gold standard measurement to refer to and cannot prove that it was the conical cuff that provided more accurate measurements. However, several considerations support the likelihood that the cylindrical cuff provided falsely elevated BP readings. Previous results obtained with intra-arterial measurement showed that cylindrical cuffs overestimated intra-arterial BP in large conical arms, whereas BP readings obtained with a tronco-conical cuff were more accurate [2]. In addition, the results of the present study performed with the pressure sensor under the cuffs showed that there was a loss of pressure under the central part of the cylindrical cuff in larger arms which may account for the higher BP observed with the cylindrical cuff. Another limitation is that it was impossible to obtain ‘blinded’ readings, because the observers knew the type of cuff that was being used. On the contrary, for the reasons delineated above, data obtained with an automatic device cannot be extrapolated to the traditional auscultatory measurement. Finally, BP measurement with a cuff of the appropriate size is difficult or even impossible in obese individuals with short humerus length [13]. In the present study, we excluded two obese individuals with upper arm length less than 17 cm, because in short arms the use of the extra-large cuff would overlap the antecubital fossa. However, this problem affected less than 1% of our potential participants for whom alternative approaches should be used [13,14].

In conclusion, the choice of the appropriate cuff is a key element for obtaining an accurate BP measurement. In obese people, the upper arm always has a tronco-conical shape, especially among women, and cylindrical cuffs may overestimate BP. However, the arm shape is not taken into account by current international guidelines. Data from National Health and Nutrition Examination Survey 1999–2002 show that some 15 million men aged 40–59 years and 10 million women aged 40–59 years currently require the use of large-sized rather than standard adult-sized cuffs [15]. This study’s findings show that in patients with large arm circumference, the use of a cylindrical cuff even of appropriate size may lead to inaccurate BP measurement. BP overestimation may be pronounced especially in obese women with short humerus length and be as great as 9.7 mmHg in individuals with so-called ‘funnel arm’. This may lead clinicians to incorrectly identify hypertension with inappropriate patient’s management. Tronco-conical cuffs better fit on large arms and are likely to provide more accurate readings than cylindrical cuffs in obese individuals. Given the large number of individuals with these characteristics, manufacturers of BP devices need to develop appropriately shaped cuffs for this population. Tronco-conical cuffs with slant angles between 85 and 86° are likely to be appropriate for the majority of obese individuals.

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Conflicts of interest
No conflict of interest to declare.
No author has a conflict of interest with the present results.

REFERENCES


