Systematic Difference Between Blood Pressure Readings Caused by Cuff Type

Pascal Bovet, Philippe Hungerbuhler, Jessy Quilindo, Marie-Louise Grettve, Bernard Waeber, Bernard Burnand

Abstract In this study we determined whether blood pressure readings using a cuff of fixed size systematically differed from readings made with a triple-bladder cuff (Tricuff) that automatically adjusts bladder width to arm circumference and assessed subsequent clinical and epidemiological effects. Blood pressure was measured with a standard cuff or a Tricuff in 454 patients visiting an outpatient clinic in the Seychelles (Indian Ocean). Overall means of within-individual standard cuff–Tricuff differences in systolic and diastolic blood pressures were examined in relation to arm circumference and sex. The standard cuff–Tricuff difference in systolic and diastolic blood pressures increased monotonically with circumference (from 4.7±0.8/3.2±0.7 mm Hg for arm circumference of 30 to 31 cm to 10.2±1.1/7.0±0.9 mm Hg for arm circumference ≥36 cm) and was larger in women than men. Multivariate linear regression indicated independent effects of arm circumference and sex. Forty percent of subjects with a diastolic blood pressure of ≥95 mm Hg measured with a standard cuff had values less than 95 mm Hg measured with a Tricuff. Extrapolation to the entire population of the Seychelles decreased the prevalence of blood pressure greater than or equal to 160/95 mm Hg by 15% and 24% in men and women, respectively, aged 35 to 64 years. The age-adjusted effect of body mass index on systolic and diastolic blood pressures decreased twofold using blood pressure readings made with a Tricuff instead of a standard cuff. Because of a systematic difference, blood pressure readings made with a cuff of fixed 12-cm width instead of with a Tricuff substantially overestimate the prevalence of high blood pressure and the effect of body mass index on blood pressure. (Hypertension. 1994;24:786-792.)

Key Words • blood pressure measurement • obesity • reproducibility of results • mass screening • hypertension, essential • epidemiology

Indirect measurement of blood pressure (BP) made with a BP cuff and stethoscope is one of the most frequently used diagnostic techniques in today's medical care. Major applications of this maneuver include the clinical and epidemiological detection of hypertension and the follow-up of hypertensive patients. Because hypertension is a frequent condition and often requires treatment over years, incorrect BP measurement and subsequent misdiagnosis of hypertension have major clinical and epidemiological effects.

Recommendations regarding standardized technique and equipment, which should be used to minimize the methodological errors of indirect BP measurement, have been repeatedly formulated and also address the long-standing controversy regarding the appropriate cuff width in relation to arm circumference (AC). Von Recklinghausen,1 who recommended the use of a cuff bladder width of 12 to 14 cm in 1901, was the first to point out that the 5-cm-wide cuff bladder introduced by Riva-Rocci2 in 1896 for indirect BP measurement gave BP readings that were too high and that the error became larger with thicker arms. Indeed, more recent studies have generally found that indirect BP readings with larger cuff sizes give readings closer to direct intra-arterial records in people with large arms.3,4,16 In a review, Geddes and Tievys estimated that the optimal ratio of cuff width to AC ranged from 0.38 to 0.50 for systolic BP and from 0.37 to 0.59 for diastolic BP. The recommendation that the cuff width should be at least 40% of AC was originally made in a report of the American Heart Association in 1951 and survived subsequent revisions of the report.3,4,14,15 The prevailing assumptions, implicit in the authoritative lists of appropriate cuff sizes and in the suggested use of correction factors by others,6,12 are that there is an ideal cuff width specification for each arm size and that many different cuff widths or an adjustment for each reading should be used.

Recently, the use of a triple-bladder cuff (Tricuff) that automatically adjusts bladder width to AC was reported to give readings closer to intra-arterial records compared with readings obtained with a standard cuff.22-24 Therefore, in this study we first examined whether BP readings made with a Tricuff systematically differed from readings made with a standard cuff, with an emphasis on individuals with large arms. Because we found a systematic difference between standard cuff and Tricuff BP readings, we then quantified the misclassification of individuals with high BP depending on which cuff was used. Finally, we evaluated how the relation of body mass index to BP was modified depending on whether BP was measured with a standard cuff or Tricuff.

Methods

The study was carried out in an urban general outpatient clinic of the Seychelles (Indian Ocean) that was the single

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From the Clinical Epidemiology Unit, Institute of Social and Preventive Medicine, University of Lausanne, Switzerland (P.B., B.B.); the Epidemiology and Research Unit, Ministry of Health, Victoria, Seychelles (P.H., J.Q.); the English River Clinic, Ministry of Health, Victoria, Seychelles (M.-L.G.); and the Division of Hypertension, University Hospital, Lausanne, Switzerland (B.W.). Presented in part at the 15th Scientific Meeting of the International Society of Hypertension, Melbourne, Australia, March 19-26, 1994.

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provider of ambulatory medical care to all individuals in the district. Approximately 80% of the population of the Seychelles is of black African descent; however, the individual ethnic origin of participants in the study was not recorded. To be able to precisely assess the standard Tricuff difference in BP readings in individuals with large arms, we chose the study population to oversample subjects with large AC. Therefore, we examined 351 consecutive patients with an AC greater than or equal to 30 cm (mean±SD age, 43.5±14.7 years) and 103 patients with an AC less than 30 cm (36.1±16.7 years). The study was approved by the Ministry of Health of the Seychelles, and all participants in the study gave informed consent.

BP was measured with a mercury sphygmomanometer connected either to a standard nylon cuff containing a 12×35-cm rubber bag (Boso, Bosch) or to a cuff that automatically adjusts bladder width to AC (Tricuff, Pressure Group AB). These two cuffs are referred to in this article as the “standard cuff” and “Tricuff,” respectively.

The Tricuff has been described elsewhere. Briefly, it consists of a cuff cover enclosing a combination of three bladders (9×26, 12×37, and 15×46 cm) that are located on top of each other and connected by tubes. When the cuff is wrapped around the patient’s arm and secured with Velcro, a lock blocks the tubing at the point where the cuff overlaps (Figure). Whether this point is A, B, or C (as shown on the Figure) depends on the patient’s AC and needs no decision on the part of the person measuring the BP. The tubing is designed to meet the “40% rule.” This mechanism ensures that the 9-cm-wide bag is connected on arms with a 15- to 21-cm circumference, the 12-cm bag is connected on arms between 22 and 31 cm, and the 15-cm bag is connected on arms between 32 and 44 cm. When the arm is large enough to require a “thigh cuff” (AC≥44 cm), the lock does not reach the tube, which is open at the end, and the cuff cannot be inflated. This is also true for very narrow arms (AC<15 cm).

All BP readings were taken by either one of two experienced investigators (P.H., J.Q.) right after the subject had completed his or her usual consultation with his or her usual physician. All subjects therefore had been staying in a quiet environment for more than 15 minutes before the first BP reading was measured for this study. Two sets of BP readings were obtained for each cuff type before and after a 10-minute interval devoted to an interview and measurement of the subject’s AC, height, and body weight. BP readings with each cuff type were taken at 1-minute intervals. All subjects were randomly allocated to have the first BP reading made with either one of the two cuff types, subsequent BP readings alternating with the previous one. Duplicate BP measurements were carried out to follow the recommended procedures for BP measurement. All measurements were taken on the left arm, to the nearest 2 mm Hg, with the patient sitting down. The onset of Korotkoff sounds (phase I) was used for systolic BP, and the disappearance of sounds (phase V) was used for diastolic BP. The AC of each participant was measured at the midpoint between the olecranon process and the acromion with a tape ruler. Body mass index was calculated as weight (kilograms) divided by height (meters) squared.

### Analysis and Statistics

We summarized agreement between duplicate casual BP measurements with each cuff type by examining the bias, which is estimated by the mean difference, and by calculating the “limits of agreement,” which are expressed as the range between 2 SD below and 2 SD above the mean of the differences (indicating that 95% of the differences between the

<table>
<thead>
<tr>
<th>TABLE 1. Patient Characteristics</th>
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</thead>
<tbody>
<tr>
<td><strong>Men</strong></td>
</tr>
<tr>
<td>n</td>
</tr>
<tr>
<td>Age, y</td>
</tr>
<tr>
<td>Arm circumference, cm</td>
</tr>
<tr>
<td>Body mass index, kg/m²</td>
</tr>
<tr>
<td>Systolic BP with standard cuff, mm Hg</td>
</tr>
<tr>
<td>Systolic BP with Tricuff, mm Hg</td>
</tr>
<tr>
<td>Diastolic BP with standard cuff, mm Hg</td>
</tr>
<tr>
<td>Diastolic BP with Tricuff, mm Hg</td>
</tr>
</tbody>
</table>

BP Indicates blood pressure. Values are mean±SD.
*P<.05, †P<.01, for difference between men and women.
two readings will lie between these limits if the differences are normally distributed). To examine whether BP readings made with the standard cuff systematically differed from readings made with the Tricuff, we calculated overall means and confidence intervals of within-individual standard cuff–Tricuff differences in BP for various AC levels and for each gender. We calculated the within-individual standard cuff–Tricuff difference in BP by subtracting the average of the duplicate readings made with the Tricuff from the average of the duplicate readings made with the standard cuff. We obtained confidence intervals for the standard cuff–Tricuff differences in BP using the procedure described by Bland and Altman to correct for the measurement error removed by considering duplicate rather than single measurements with each cuff type. We used multivariate linear regression to model the relation between the standard cuff–Tricuff difference in BP and age, sex, AC, and actual BP level. We estimated the actual BP level by taking the average of BP readings made with the standard cuff and with the Tricuff. We quantified the misclassification of individuals with high BP made with the standard cuff for various diastolic BP cutoff values, assuming Tricuff readings to be the gold standard. We estimated the misclassification of high BP prevalence in the entire population aged 35 to 64 years using a standard cuff instead of a Tricuff by extrapolating parameters obtained in this study to population data obtained in 1989 from a sex- and age-stratified random sample of the entire adult population of the Seychelles (BP with standard cuff and AC were measured). Finally, we estimated the bias in the effect of body mass index on blood pressure, caused by differential misclassification of BP readings made with the standard cuff instead of the Tricuff, by comparing the age-adjusted regression coefficients of body mass index on BP, based on BP readings with either cuff type.

### Results

#### Characteristics of the Study Sample

Table 1 shows that participants in the study had fairly high BP values and that women had a higher mean body mass index than men, which corresponds to findings in the general population of the Seychelles.

#### Order Effect and Agreement of Duplicate BP Readings

The second BP readings were on average significantly lower than the first readings for both systolic and diastolic BP, indicating a systematic order effect (Table 2). This bias was not significantly different between the standard cuff and Tricuff for both systolic and diastolic BP \((P > .05)\). Pearson correlation coefficients between the first and second BP measurements were similarly high for both cuff types for systolic BP (standard cuff, \(r = .94\); Tricuff, \(r = .94\)) and diastolic BP (standard cuff, \(r = .94\)).

### Table 2. Mean Difference and Limits of Agreement Between First and Second Blood Pressure Measurements Using a Standard Cuff or Tricuff

<table>
<thead>
<tr>
<th>Arm Circumference</th>
<th>Sex</th>
<th>n</th>
<th>Mean</th>
<th>95% CI</th>
<th>Mean</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Systolic</td>
<td></td>
<td>Systolic</td>
<td></td>
</tr>
<tr>
<td>&lt;30 cm</td>
<td>Total</td>
<td>103</td>
<td>1.11</td>
<td>-0.35, 2.31</td>
<td>-0.08</td>
<td>-1.28, 1.13</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>45</td>
<td>2.13</td>
<td>-0.43, 4.69</td>
<td>0.04</td>
<td>-2.08, 2.16</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>58</td>
<td>0.32</td>
<td>-1.38, 2.02</td>
<td>-0.19</td>
<td>-1.63, 1.25</td>
</tr>
<tr>
<td>30-31 cm</td>
<td>Total</td>
<td>74</td>
<td>4.68</td>
<td>2.98, 6.38</td>
<td>3.15</td>
<td>1.65, 4.62</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>34</td>
<td>3.26</td>
<td>0.75, 5.77</td>
<td>2.55</td>
<td>0.17, 4.92</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>40</td>
<td>5.06</td>
<td>3.44, 6.62</td>
<td>3.66</td>
<td>1.70, 5.61</td>
</tr>
<tr>
<td>32-33 cm</td>
<td>Total</td>
<td>105</td>
<td>6.29</td>
<td>4.42, 8.15</td>
<td>4.55</td>
<td>3.00, 6.09</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>46</td>
<td>3.86</td>
<td>1.99, 5.73</td>
<td>2.40</td>
<td>0.37, 4.39</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>59</td>
<td>8.18</td>
<td>5.48, 10.9</td>
<td>6.25</td>
<td>4.05, 8.45</td>
</tr>
<tr>
<td>34-35 cm</td>
<td>Total</td>
<td>86</td>
<td>8.24</td>
<td>5.99, 10.5</td>
<td>6.92</td>
<td>5.36, 8.47</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>39</td>
<td>6.22</td>
<td>3.59, 8.84</td>
<td>5.43</td>
<td>3.36, 7.49</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>47</td>
<td>9.92</td>
<td>7.16, 12.7</td>
<td>8.14</td>
<td>5.86, 10.4</td>
</tr>
<tr>
<td>≥36 cm</td>
<td>Total</td>
<td>86</td>
<td>10.04</td>
<td>7.77, 12.3</td>
<td>8.01</td>
<td>6.15, 9.86</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>29</td>
<td>8.03</td>
<td>4.23, 11.8</td>
<td>5.79</td>
<td>2.83, 8.71</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>57</td>
<td>11.07</td>
<td>8.21, 13.9</td>
<td>9.14</td>
<td>7.20, 11.0</td>
</tr>
</tbody>
</table>

BP indicates blood pressure; CI, confidence interval of the mean.

**TABLE 3.** Difference in Blood Pressure Measurements Made With a Standard Cuff Compared With Tricuff

<table>
<thead>
<tr>
<th>Arm Circumference</th>
<th>Sex</th>
<th>n</th>
<th>Systolic</th>
<th>95% Cl</th>
<th>Diastolic</th>
<th>95% Cl</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;30 cm</td>
<td>Total</td>
<td>103</td>
<td>2.55</td>
<td>1.10</td>
<td>3.19</td>
<td>1.63</td>
</tr>
<tr>
<td></td>
<td>95% CI of the mean</td>
<td>1.75, 3.35</td>
<td>0.49, 1.68</td>
<td>2.43, 3.95</td>
<td>1.05, 2.21</td>
<td></td>
</tr>
<tr>
<td>Limits of agreement*</td>
<td>-14.4, 19.5</td>
<td>-11.6, 13.8</td>
<td>-13.0, 19.4</td>
<td>-10.9, 14.1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Cl indicates confidence interval. Values are expressed in millimeters of mercury. *95% confidence intervals of limits are less than 1.4 mm Hg above or below the estimates.
We performed stratified analysis to explore the effect of body mass index on the higher standard cuff–Tricuff difference in BP in women than men. Table 5 shows that body mass index increased monotonically across AC categories for both genders. However, the increase in body mass index was significantly higher in women than men in all AC categories in which a significant standard cuff–Tricuff difference in BP was found (ie, AC ≥30 cm), suggesting an effect of body mass index on BP readings.

### Standard Cuff–Tricuff Difference in BP Readings and Misclassification of Hypertension in Clinical and Epidemiological Settings

Table 6 shows that approximately one tenth of all subjects were mislabeled as hypertensive when diastolic BP was measured with a standard cuff instead of a Tricuff, based on various diastolic BP cutoff values. Alternatively, approximately one third of the subjects labeled as hypertensive based on BP measurements with a standard cuff were normotensive when BP was measured with a Tricuff, for elevated diastolic BP cutoff values.

To appreciate the extent of misclassification of high BP in the total population of the Seychelles related to BP measurement with either cuff type, we extrapolated parameters estimated in this study to the entire adult population using data of a population-based survey of cardiovascular risk factors carried out in the Seychelles in 1989. Analytic adjustment using parameters shown in Table 4 (eg, Estimated Tricuff Systolic BP = Measured Standard Systolic BP - [-22.60 + 0.70 · AC - 2.35 · Sex]) was applied only to individuals with AC greater than or equal to 30 cm because there was no systematic standard cuff–Tricuff difference in systolic/diastolic BP for individuals with AC less than 30 cm (Table 2). Table 7 shows that higher proportions of women than men had...
vated body mass index and large AC in the entire population aged 35 to 64 years. This explains why a proportionally larger decrease in the prevalence of high BP was found in women (−24.0%) than in men (−11.5%) after estimates were corrected for the standard cuff–Tricuff difference in BP. Hence, with the use of this model, screening for high BP with a standard cuff instead of a Tricuff could have resulted in overdiagnosing hypertension in 3.5% and 6.0% of the total male and female populations, respectively, aged 35 to 64 years.

Biased Relation Between Body Mass Index and Blood Pressure Caused by Differential Misclassification of BP

Body mass index was associated with AC (r=.85), whereas AC was associated with the standard cuff–Tricuff difference in systolic and diastolic BP (r=.47 and r=.45, respectively). Therefore, body mass index was associated with the standard cuff–Tricuff difference in BP. As a consequence, the effect of body mass index on BP, as measured by the regression coefficient of body mass index on BP and adjusted for age to control for the confounding effect of age, was halved when BP readings were obtained with a Tricuff instead of a standard cuff (Table 8). Analysis in the aforementioned population survey using calculated Tricuff BP values provided similar results.

Discussion

This study showed that BP readings with a triple-bladder cuff (Tricuff) that automatically adjusts bladder width to AC were systematically lower than BP readings obtained with a standard 12-cm-wide cuff for AC greater than or equal to 30 cm. The standard cuff–Tricuff difference in BP readings was higher in women than men. Because body mass index was higher in women than men within AC categories and because body mass index is known to correlate strongly with an individual’s fat content, the higher standard cuff–Tricuff difference noticed in women could possibly relate to a higher fat content (or alternatively a lower muscle content) in women compared with men. An effect of the composition of the tissue underlying the cuff on BP readings has been repeatedly hypothesized. In a study aimed at separating the effects of AC and triceps skinfold thickness, Karvonen et al notably found that skinfold thickness, as an indicator of arm fat content but not AC, was predictive of intra-arterial/indirect BP differences. However, a major problem in such analyses is related to the high collinearity between two independent variables (AC and body mass index/skinfold thickness), and the question of whether increased fat content in the upper arm produces spurious higher BP readings is therefore not settled.

A systematic overdiagnosis by a few millimeters of mercury, as, for example, follows the use of a standard cuff instead of a Tricuff, results in mislabeling normotensive individuals as hypertensive, with subsequent unwarranted hypertension diagnosis and treatment. The potential clinical effect is substantial because hypertension affects more than 20% of adults in many populations in the world (most of whom, perhaps as many as 60%, have “mild” hypertension) and because medication for the treatment of hypertension is usually prescribed over many years. Our finding that BP measurement made with a standard cuff instead of a Tricuff results in misdiagnosing one third of patients in a clinical setting as hypertensive is consistent with the results of studies examining subjects allocated to either 12-cm-wide standard or 15-cm-wide cuffs. When the systematic standard cuff–Tricuff BP difference is extrapolated to the entire population, the proportion of normotensive subjects mislabeled as hypertensive because of BP measurement made with a standard cuff instead of...
a Tricuff may be as high as 1 in 10 in a rather slender population (such as men in the Seychelles) to 1 in 4 in a population with a high proportion of obese individuals (such as women in the Seychelles). In addition to the clinical and epidemiological implications of erroneous diagnosis, systematic mislabeling of normotensive individuals as hypertensive has a large economic effect. For example, it has been calculated that lowering the diastolic BP cutoff point for treatment from 100 mm Hg results in 50% higher treatment costs.39 Differential misclassification of BP readings caused by systematic standard cuff–Tricuff difference in BP results in biased epidemiological estimates. Indeed, our data suggest that the age-adjusted effect of body mass index on BP decreases by approximately one half when Tricuff instead of standard cuff BP readings are used. Likewise, hypertension prevalence based on standard cuff BP readings is likely to be overestimated in the female population of the Seychelles than in populations of Western countries because more women are obese in the Seychelles than in Western countries (36% of women with AC >33 cm versus 20% of women with AC >33 cm). As standard cuffs have been used almost exclusively in past epidemiological and clinical studies,10 there is a fundamental problem of noncorrespondence between measurements adjusted for AC, in keeping with recommendations, and measurements not so adjusted, which constitute most of the reference data. Although unresolved, this problem points to the need for careful consideration of the prevalence of obesity (and subsequently the proportion of individuals with large AC) in the original study populations when the significance of effect measures and prevalence estimates related to BP is examined.

As an alternative to Tricuff use, the overestimation of the indirectly measured BP that occurs when a standard cuff is used in individuals with large AC may be minimized by choosing appropriate cuffs in subjects with large arms. However, routine use of various cuff sizes for definitive AC is not easily implemented by clinicians. For example, the finding that as many as one third of BP measurements were performed with an inappropriate cuff by trained observers, who were to select one of four different cuffs in a survey of BP measurement technique,40 supports the routine use of a Tricuff, which avoids miscuffing and requires no decision on the part of the person measuring the BP. In clinical practice, however, it should be recognized that the precision of casual BP readings with a standard cuff or with a Tricuff is similarly poor, as indicated by comparably large agreement limits between duplicate readings made with a standard cuff or a Tricuff. This emphasizes the basic principle that much reduction in the variability of casual BP measurements, thereby increased precision and validity, can be obtained by performing multiple BP readings in addition to selecting an appropriate cuff width and using other standardized techniques to control for the many methodological factors that affect BP measurement.4,6,23

### Acknowledgments

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### References


### Table 8: Relation of Body Mass Index to Blood Pressure Using Blood Pressure Measurements Made With a Standard Cuff or Tricuff

<table>
<thead>
<tr>
<th>Cuff</th>
<th>Systolic BP</th>
<th>Diastolic BP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>1.08</td>
<td>0.27,0.79</td>
</tr>
<tr>
<td>Tricuff</td>
<td>0.49</td>
<td>0.95</td>
</tr>
</tbody>
</table>

BP indicates blood pressure. Shown are age-adjusted linear regression coefficients for body mass index; 95% confidence intervals (CI) of regression coefficient.


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