Body mass index prediction rule for mid-upper arm circumference: the atherosclerosis risk in communities study

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Objectives Electronic health records (EHR) are a convenient data source for clinical trial recruitment and allow for inexpensive participant screening. However, EHR may lack pertinent screening variables. One strategy is to identify surrogate EHR variables which can predict the screening variable of interest. In this article, we use BMI to develop a prediction rule for arm circumference using data from the Atherosclerosis Risk in Communities (ARIC) Study. This work applies to EHR patient screening for clinical trials of hypertension.

Methods We included 11,585 participants aged 52–75 years with BMI and arm circumference measured at ARIC follow-up visit 4 (1996–1998). We selected the following arm circumference cutpoints based on the American Heart Association recommendations for blood pressure (BP) cuffs: small adult (≤26 cm), adult (≤34 cm) and large adult (≤44 cm). We calculated the sensitivity and specificity of BMI values for predicting arm circumference using receiver operating characteristic curves. We report the BMI threshold that maximized Youden’s Index for each arm circumference upper limit of a BP cuff.

Results Participants’ mean BMI and arm circumference were 28.8 ± 5.6 kg/m² and 33.4 ± 4.3 cm, respectively. The BMI-arm circumference Pearson’s correlation coefficient was 0.86. The BMI threshold for arm circumference ≤26 cm was 23.0 kg/m², arm circumference ≤34 cm was 29.2 kg/m² and arm circumference ≤44 cm was 37.4 kg/m². Only the BMI threshold for arm circumference ≤34 cm varied significantly by sex.

Conclusions BMI predicts arm circumference with high sensitivity and specificity and can be an accurate surrogate variable for arm circumference. These findings are useful for participant screening for hypertension trials. Providers can use this information to counsel patients on appropriate cuff size for BP self-monitoring. Blood Press Monit 27: 50–54 Copyright © 2021 The Author(s). Published by Wolters Kluwer Health, Inc.

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Introduction Electronic health records (EHR) present a convenient data source for clinical trial recruitment and allow for inexpensive and efficient patient screening [1,2]. However, EHR may lack one or more pertinent screening variables. One strategy is to identify surrogate EHR variables which can accurately predict the screening variable of interest. The work presented here was motivated by our need to use EHR data for efficient participant screening for a National Institutes of Health-funded trial of blood pressure (BP) self-monitoring [3].

BP monitors have multiple cuff sizes to accommodate the range in patients’ arm circumferences and accurately measure BP [4,5]. There are specific upper limits for arm circumference for each cuff size. Arm circumference is not typically recorded in the EHR for adults. BMI is readily available in most EHR and may be a promising surrogate variable for arm circumference due to the high reported correlation (r = 0.74–0.86) [6–9]. However, few articles report on the relationship between arm circumference and BMI in the general population. A majority of the prior studies were conducted in the context of malnutrition, had BMI as the outcome, or were among youth populations [6–12]. One study used a nationally representative data sample and developed sex-specific predictive equations for arm circumference using age.
height and weight as input variables [13]. The predictive equations, which included interaction terms, achieved agreements ~80% for correct BP cuff selection, though the accuracy was much lower for the small adult cuff (10–54%) than for the larger sized cuffs (74–88%).

Our analysis aimed to develop a simple prediction rule that could be applied in real-time in both clinical and research contexts. We linked a variable readily found in the EHR, BMI, to arm circumference. This prediction rule will give an optimal BMI threshold for a given arm circumference value, facilitating efficient EHR screening and recruitment for trials on hypertension management. In addition, it provides a practical, easily applied rule to enable the selection of the right cuff size for patients during clinic visits without measuring arm circumference or using a complex prediction equation.

**Methods**

Data availability and Atherosclerosis Risk in Communities (ARIC) policies regarding data access can be found on the study website (https://sites.cscu.unc.edu/arie/pubs-policies-and-forms-pg). ARIC data is also available upon request from the National Heart Lung and Blood Institute BioLINCC repository (https://biolincc.nhlbi.nih.gov/studies/aric/).

**Study population and design**

The ARIC is a population-based cohort of predominantly Black and White adults recruited from four US communities: Washington County, Maryland; Forsyth County, North Carolina; selected suburbs of Minneapolis, Minnesota and Jackson, Mississippi. A total of 15792 men and women aged 45–64 years were recruited and had a baseline examination in 1987–1989 [14]. Subsequent follow-up clinic visits have been completed. We used the visit 4 (years 1996–1998) cohort examination data for our cross-sectional analyses. The study design and data collection protocols of ARIC are published [14]. All ARIC participants provided written informed consent and the institutional review boards at each participating institution approved the study protocol.

A total of 11656 participants attended visit 4. Of these, 71 participants were excluded from analysis due to missing BMI measurement ($n=38$), missing arm circumference measurement ($n=2$) or missing race or were Asian or American Indian race ($n=31$). Thus, our final analytic sample includes 11585 participants.

**Predictor and outcome variable measurements**

All participants wore scrubs and no shoes for anthropometric measurements carried out by trained study staff. We calculated BMI (kg/m$^2$) from measured weight (kg) and height (m). Participants’ arm circumference (cm) was measured on their right arm bent 90 degrees at the elbow using the midway point between the acromion and the elbow.

**Covariate measurements**

Relevant covariates include age, sex, race and diabetes status recorded at visit 4. Age is modeled both as a continuous variable and dichotomously at <60 years and ≥60 years. Participants of the Black and White race are included for analysis. Diabetes mellitus is defined as a fasting glucose ≥126 mg/dL, a nonfasting glucose ≥200 mg/dL, a self-report that a physician has provided a diabetes diagnosis in the past or when participants are reported medication use for diabetes. Participants missing the diabetes status are coded as unknown diabetes status.

**Statistical analysis**

Overall study sample, as well as sex-specific baseline characteristics are described using frequencies and percentages for categorical variables and means and SD for continuous variables. The correlation between arm circumference and BMI is calculated as Pearson’s correlation coefficient.

We used receiver operating characteristic (ROC) curves to assess the sensitivity and specificity of the predictor (BMI< $x$) for outcome (arm circumference) prediction. This provided the BMI threshold ($x$) with the best sensitivity and specificity profile for the higher end of the arm circumference range (e.g. arm circumference of 44 cm for a large adult cuff). An American Heart Association (AHA) Scientific Statement recommends the following arm circumference ranges for cuff sizes: 22–26 cm for a small adult cuff; 27–34 cm for an adult cuff; 35–44 cm for a large adult cuff [4,5]. We selected three-arm circumference cutpoints in agreement with these recommendations: (1) ≤26 cm vs. >26 cm, (2) ≤34 cm vs. >34 cm and (3) ≤44 cm vs. >44 cm. We included an additional arm circumference cutpoint of ≤42 cm vs. >42 cm because this is the upper limit for commonly available, over-the-counter BP monitors [15]. We report the BMI threshold for each arm circumference value that maximized Youden’s index. Youden’s index identifies the optimal decision threshold of the predictor variable that balances sensitivity and specificity [16]. Therefore, the predicted BMI thresholds represent the equivalent of the higher end of an arm circumference range for a given cuff size when the sum of sensitivity and specificity are maximized [16]. We also calculated the c-statistic, a measure of concordance or goodness-of-fit for the prediction of arm circumference by BMI. We performed internal validation using a bootstrap resampling approach with 1000 samples to estimate the mean optimal BMI threshold based on Youden’s index for each arm circumference cutpoint.

We used logistic regression to evaluate if the calculated BMI thresholds differed by age, sex, race and diabetes status by including a multiplicative interaction term. The outcome variable was an indicator of whether the participant’s arm circumference was above or below the...
specified cutoff. The secondary analysis explored BMI thresholds for each arm circumference cut point by age group (<60 years and ≥60 years), sex and race.

Results

Table 1 displays the baseline characteristics in the overall sample and is stratified by sex. Participants had a mean age of 62.8 ± 5.7 years, 44.1% were male, and 22.8% were Black. The mean BMI was 28.8 ± 5.6 kg/m², and the mean arm circumference was 33.4 ± 4.3 cm (Table 1). In the overall sample, Pearson's correlation coefficient between BMI and arm circumference was 0.863 (95% confidence interval (CI), 0.858–0.868; P < 0.001).

Table 2 presents the BMI thresholds by arm circumference cutpoint. The area under the curve was high for each arm circumference cut point. The BMI threshold for a small adult cuff (arm circumference ≤26 cm) was 23.0 kg/m², with a specificity of 89.2%, a sensitivity of 78.4% and a c-statistic of 0.93. The BMI threshold for a large adult cuff (common arm circumference cut-off for monitors in the market) had a BMI threshold of 37.0 kg/m² with a sensitivity of 94.3%, specificity of 95.1% and a c-statistic of 0.98. Lastly, the BMI threshold for each arm circumference cut point varied significantly by sex and race.

In this cross-sectional analysis, we observed a strong correlation between arm circumference and BMI in middle-aged and older adults. We report BMI thresholds not be obtainable or readily available within EHRs. This analysis showed that BMI can accurately predict arm circumference among a middle-aged and older Black and White adult population. The simple decision rules can be used in clinical practice to enable appropriate cuff-size selection. Care providers can similarly counsel patients.

| Decision rules for adult cuff selection are as follows: |
|----------------------------------------------------------|
| 1. BMI ≤23.0 kg/m²: choose AHA small adult cuff. |
| 2. BMI >23.0 but ≤ 29.2 kg/m²: choose AHA adult cuff. |
| 3. BMI >29.2 but ≤ 37.4 kg/m²: choose AHA large adult cuff. |

| Decision rule for using EHR to screen patients for clinical trials as follows: |
|---------------------------------------------------------------------------|
| 1. Include patients with BMI ≤37.0 kg/m² and this will correspond to arm circumference ≤42 cm which is the limit of commercially available cuff sizes. |

Table 2 presents the BMI thresholds by arm circumference cutpoint. The area under the curve was high for each arm circumference cut point. The BMI threshold for a small adult cuff (arm circumference ≤26 cm) was 23.0 kg/m², with a specificity of 89.2%, a sensitivity of 78.4% and a c-statistic of 0.93. The BMI threshold for a large adult cuff (common arm circumference cut-off for monitors in the market) had a BMI threshold of 37.0 kg/m² with a sensitivity of 94.3%, specificity of 95.1% and a c-statistic of 0.98. Lastly, the BMI threshold for each arm circumference cut point varied significantly by sex and race.

The BMI thresholds estimated by bootstrap validation were very similar to the estimates presented above. Supplementary Table 2, Supplement digital content 1, http://links.lww.com/BPMJ/A148 displays the BMI thresholds by arm circumference cut point as estimated by bootstrap validation. Supplementary Table 3, Supplemental digital content 1, http://links.lww.com/BPMJ/A148 shows bootstrap validation estimates for BMI thresholds by subgroups.

Discussion

In this cross-sectional analysis, we observed a strong correlation between arm circumference and BMI in middle-aged and older adults. We report BMI thresholds with high sensitivity and specificity for each evaluated arm circumference cut point. Only a BMI threshold for an arm circumference of ≤34 cm varied significantly by sex. No BMI thresholds differed significantly by age, race or diabetes status.

Arm circumference is used to select cuff sizes for BP measurement [4,5]. An accurate BP measurement is essential for diagnosing and managing hypertension [4,5]; however, arm circumference measurements may not be obtainable or readily available within EHRs. This analysis showed that BMI can accurately predict arm circumference among a middle-aged and older Black and White adult population. The simple decision rules can be used in clinical practice to enable appropriate cuff-size selection. Care providers can similarly counsel patients.
on an appropriate cuff size for home BP self-monitoring. This has become more salient due to the increase in virtual care delivery following the COVID-19 pandemic.

Our work was initiated due to a need for EHR-based screening of participants for a clinical trial on hypertension. The decision rule we developed (see text box) provides a BMI cutoff of 37.0 kg/m² to screen patients successfully for a self-monitoring intervention using commercially available cuffs [3]. Previous studies have used arm circumferences to predict BMI (e.g. the converse of our analysis) [6-9,11,12]. A majority of these studies were conducted in the context of predicting malnutrition [6-9,12,17] or the occurrence of underweight patients [11] in predominantly lower and middle-income countries. These studies reported similar high correlations between arm circumference and BMI. A previous study that included a wide range of BMIs found a similar relationship with arm circumference as our cross-sectional study; however, BMI was the outcome of interest, and the arm circumference was the predictor, the opposite of our analysis [17]. One previous study, conducted with National Health and Nutritional Examination Survey data, used multivariable linear regression to account for the linear and nonlinear combinations of age, height and weight, stratified by sex [13]. The predictive equations, which included interaction terms, achieved agreements ~80% for correct BP cuff selection, though the accuracy was much lower for the small adult cuff (10–54%) than for the larger sized cuffs (74–88%). When we applied the equation to the ARIC study population at visit 4, we found a 76% agreement between predicted and measured mid-arm circumference. Our proposed analysis is more direct; simple with high sensitivity and specificity, uses only one measured variable, proposes dichotomous cut points, and can be applied in real-time without complex calculations during clinic visits.

Strengths of this study include the large sample size and representation of middle-aged to older Black and White men and women. However, we acknowledge the following limitations. We did not assess other variables or exclude participants with preexisting conditions to create the BMI thresholds. Additionally, potential differences based on underlying medical conditions, behavioral factors or socioeconomic factors were not assessed. The goal of our study was to create a prediction rule based on information readily found within the EHR. Certain factors, like physical activity, are not typically recorded in the EHR and, therefore, would not be useful in developing prediction models for screening participants using EHR data. Finally, we acknowledge that our BMI limits are not generalizable to non-White and non-Black populations.

**Conclusion**

The use of BMI thresholds to predict arm circumference ranges can facilitate EHR screening and recruitment for clinical trials on hypertension management. BMI can be a practical alternative to identify the appropriate BP monitor cuff size when the arm circumference is not measured or recorded. As shown in the text box, our decision rules are also applicable in a clinical setting without complex calculations. Care providers can use the decision rules to counsel patients on selecting home BP monitors to facilitate self-monitoring and virtual care. The prediction rule described here was created for, and is currently implemented in, an ongoing clinical trial involving BP self-monitoring (ClinicalTrials.gov, NCT03612271).

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**Conflicts of interest**

There are no conflicts of interest.

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