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

Carin A. Northuis[a], Thomas A. Murray[b], Pamela L. Lutsey[a], Kenneth R. Butler[c], Steve Nguyen[d], Priya Palta[e] and Kamakshi Lakshminarayan[a]

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/m^2 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/m^2, arm circumference≤34 cm was 29.2 kg/m^2 and arm circumference≤44 cm was 37.4 kg/m^2. 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.

Blood Pressure Monitoring 2022, **27**:50–54

Keywords: Atherosclerosis Risk in Communities, blood pressure cuff sizes, mid-arm circumference, hypertension

[a]Division of Epidemiology and Community Health, School of Public Health, University of Minnesota, [b]Division of Biostatistics, School of Public Health, University of Minnesota, Minneapolis, Minnesota, [c]Department of Medicine, University of Mississippi Medical Center, University of Mississippi, Jackson, Mississippi, [d]Division of Epidemiology, Herbert Wertheim School of Public Health and Human Longevity Science, University of California, San Diego, La Jolla, California and [e]Division of General Medicine, Department of Medicine, Columbia University Irving Medical Center, Columbia University, New York, USA

Correspondence to Kamakshi Lakshminarayan, MBBS, PhD, MS, Division of Epidemiology and Community Health, School of Public Health, University of Minnesota. 1300 S 2nd Street, Suite 300. Minneapolis, MN 55454, USA
Tel: +612 624 1818; fax: +612 624 0315; e-mail: kamakshi@umn.edu

Received 28 May 2021 **Accepted** 10 August 2021

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 an 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,

Supplemental Digital Content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's website, www.bpmonitoring.com.

1359-5237 Copyright © 2021 The Author(s). Published by Wolters Kluwer Health, Inc. DOI: 10.1097/MBP.0000000000000567

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.cscc.unc.edu/aric/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 15 792 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 11 656 participants attended visit 4. Of these, 71 participants were excluded from analysis due to missing a BMI measurement ($n = 38$), missing an arm circumference measurement ($n = 2$) or missing race or were Asian or American Indian race ($n = 31$). Thus, our final analytic sample includes 11 585 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 cutpoint. 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/m^2, 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/m^2, with a specificity of 89.2%, a sensitivity of 91.3% and a c-statistic of 0.96. An arm circumference of ≤34 cm (adult cuff) had a BMI threshold of 29.2 kg/m^2 with 84.4% sensitivity, 84.0% specificity and a c-statistic of 0.93. The arm circumference cut point of ≤42 cm (common arm circumference cut-off for monitors in the market) had a BMI threshold of 37.0 kg/m^2 with a reported specificity of 94.3%, sensitivity of 95.1% and a c-statistic of 0.98. Lastly, the arm circumference cut point of ≤44 cm (large adult cuff) had a BMI threshold of 37.4 kg/m^2 and specificity, sensitivity and c-statistic of 93.9%, 98.7% and 0.99, respectively. Supplementary Figure 1, Supplemental digital content 1, *http://links.lww.com/BPMJ/A148* displays the ROC curves for the four arm circumference cut points. Supplementary Figure 2, Supplement digital content 1, *http://links.lww.com/BPMJ/A148* shows the scatterplot of arm circumference vs. BMI. The BMI thresholds for arm circumference cut points of ≤26 cm, ≤42 cm and ≤44 cm did not differ significantly by age (continuous), sex, race and diabetes status (P for interaction >0.05). The BMI threshold for arm circumference ≤34 cm did not vary statistically significantly by age and race (P for interaction>0.05) but did vary statistically significantly by sex (P for interaction <0.0001). For the arm circumference cut point of <34 cm, males had a BMI threshold of 29.7 kg/m^2 with a sensitivity of 88.3% and a specificity of 78.4%. Females had a BMI threshold of 27.9 kg/m^2 with a sensitivity of 90.8% and a specificity of 85.3%. Supplementary Table 1, Supplemental digital content 1, *http://links.lww.com/BPMJ/A148* displays the BMI threshold for each arm circumference cut point by age group, sex and race.

Decision rules for adult cuff selection are as follows:

1. BMI ≤23.0 kg/m^2: choose AHA small adult cuff.
2. BMI >23.0 but ≤ 29.2 kg/m^2: choose AHA adult cuff.
3. BMI >29.2 but ≤ 37.4 kg/m^2: 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/m^2 and this will correspond to arm circumference ≤42 cm which is the limit of commercially available cuff sizes.

Table 1 Baseline characteristics of Atherosclerosis Risk in Communities visit 4 study participants (n=11 585; 1996–1998)

	Overall population (n=11 585)	Men (n=5109)	Women (n=6476)
Male, n (%)	5109 (44.1%)	-	-
Age, mean (SD)	62.8 (5.7)	63.2 (5.7)	62.5 (5.6)
Black race, n (%)	2640 (22.8%)	950 (18.6%)	1690 (26.1%)
BMI, mean (SD)	28.8 (5.6)	28.4 (4.5)	29.1 (6.3)
Arm circumference, cm mean (SD)	33.4 (4.3)	34.0 (3.5)	32.8 (4.8)
Diabetes[a], n (%)	1931 (16.7%)	920 (18.0%)	1011 (15.6%)
Hypertension[b], n (%)	5519 (47.8%)	2339 (46.0%)	3180 (49.3%)

[a]Diabetes defined as a fasting glucose ≥126 mg/dL, a nonfasting glucose ≥200 mg/dL, self-reported diabetes or self-reported medication use for diabetes.
[b]Hypertension defined as systolic ≥140 mmHg, diastolic ≥90 or self-reported anti-hypertensive medication use.

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* shows 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

Table 2 BMI threshold for four different arm circumference cut-points, atherosclerosis risk in communities study visit 4 (n=11585; 1996–1998)

Cuff size	Arm circumference cut point	BMI threshold	Specificity	Sensitivity	c-statistic
AHA small adult	≤26 vs. >26 cm	23.0	89.2%	91.3%	0.96
AHA adult	≤34 vs. >34 cm	29.2	84.0%	84.4%	0.93
Commercially available digital and wireless cuff size arm circumference limits	≤42 vs. >42 cm	37.0	94.3%	95.1%	0.98
AHA[a] large adult	≤44 vs. >44 cm	37.4	93.9%	98.7%	0.99

[a]AHA, American Heart Association.

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/m^2 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).

Acknowledgements

The authors thank the staff and participants of the ARIC study for their important contributions.

CAN is supported by the National Heart, Lung and Blood Institute of the National Institutes of Health under award number T32 HL007779. P. Palta is supported by grant K99/R00AG052830 from the National Institute on Aging. In addition, this work is supported by NIH grant R01 HL138332 (PI: KL). The ARIC Study is funded by the National Heart, Lung, and Blood Institute, under contract numbers HHSN268201700001I, HHSN268201700002I, HHSN268201700003I, HHSN268201700004I and HHSN268201700005I.

Conflicts of interest

There are no conflicts of interest.

References

1 Köpcke F, Trinczek B, Majeed RW, Schreiweis B, Wenk J, Leusch T, *et al.* Evaluation of data completeness in the electronic health record for the purpose of patient recruitment into clinical trials: a retrospective analysis of element presence. *BMC Med Inform Decis Mak* 2013; **13**:37.

2 Bruland P, McGilchrist M, Zapletal E, Acosta D, Proeve J, Askin S, *et al.* Common data elements for secondary use of electronic health record data for clinical trial execution and serious adverse event reporting. *BMC Med Res Methodol* 2016; **16**:159.

3 Lakshminarayan K, Murray TA, Westberg SM, Connett J, Overton V, Nyman JA, *et al.* Mobile health intervention to close the guidelines-to-practice gap

in hypertension treatment: protocol for the mGlide randomized controlled trial. *JMIR Res Protoc* 2021; **10**:e25424.

4 Pickering TG, Hall JE, Appel LJ, Falkner BE, Graves J, Hill MN, *et al*.; Subcommittee of Professional and Public Education of the American Heart Association Council on High Blood Pressure Research. Recommendations for blood pressure measurement in humans and experimental animals: part 1: blood pressure measurement in humans: a statement for professionals from the Subcommittee of Professional and Public Education of the American Heart Association Council on High Blood Pressure Research. *Hypertension* 2005; **45**:142–161.

5 Muntner P, Shimbo D, Carey RM, Charleston JB, Gaillard T, Misra S, *et al*. Measurement of blood pressure in humans: a scientific statement from the American Heart Association. *Hypertension* 2019; **73**:e35–e66.

6 Kumar P, Sinha R, Patil N, Kumar V. Relationship between mid-upper arm circumference and BMI for identifying maternal wasting and severe wasting: a cross-sectional assessment. *Public Health Nutr* 2019; **22**:2548–2552.

7 Benítez Brito N, Suárez Llanos JP, Fuentes Ferrer M, Oliva García JG, Delgado Brito I, Pereyra-García Castro F, *et al*. Relationship between mid-upper arm circumference and body mass index in inpatients. *PLoS One* 2016; **11**:e0160480.

8 Barosa R, Roque Ramos L, Santos CA, Pereira M, Fonseca J. Mid upper arm circumference and Powell-Tuck and Hennessy's equation correlate with body mass index and can be used sequentially in gastrostomy fed patients. *Clin Nutr* 2018; **37**:1584–1588.

9 Burden ST, Stoppard E, Shaffer J, Makin A, Todd C. Can we use mid upper arm anthropometry to detect malnutrition in medical inpatients? A validation study. *J Hum Nutr Diet* 2005; **18**:287–294.

10 Talma H, van Dommelen P, Schweizer JJ, Bakker B, Kist-van Holthe JE, Chinapaw JMM, Hirasing RA. Is mid-upper arm circumference in Dutch children useful in identifying obesity? *Arch Dis Child* 2019; **104**:159–165.

11 Nguyen P, Ramakrishnan U, Katz B, Gonzalez-Casanova I, Lowe AE, Nguyen H, *et al*. Mid-upper-arm and calf circumferences are useful predictors of underweight in women of reproductive age in northern Vietnam. *Food Nutr Bull* 2014; **35**:301–311.

12 Das P, Khatun A, Bose K, Chakraborty R. The validity of mid-upper arm circumference as an indicator of low BMI in population screening for undernutrition: a study among adult slum dwellers in eastern India. *Public Health Nutr* 2018; **21**:2575–2583.

13 Nwankwo T, Ostchega Y, Zhang G, Hughes JP. Validating prediction equations for mid-arm circumference measurements in adults: National Health and Nutrition Examination Survey, 2001-2012. *Blood Press Monit* 2015; **20**:157–163.

14 The Atherosclerosis Risk in Communities (ARIC) Study: design and objectives. The ARIC investigators. *Am J Epidemiol* 1989; **129**:687–702.

15 Topouchian J, Agnoletti D, Blacher J, Youssef A, Chahine MN, Ibanez I, *et al*. Validation of four devices: Omron M6 Comfort, Omron HEM-7420, Withings BP-800, and Polygreen KP-7670 for home blood pressure measurement according to the European Society of Hypertension International Protocol. *Vasc Health Risk Manag* 2014; **10**:33–44.

16 Fluss R, Faraggi D, Reiser B. Estimation of the Youden Index and its associated cutoff point. *Biom J* 2005; **47**:458–472.

17 Powell-Tuck J, Hennessy EM. A comparison of mid upper arm circumference, body mass index and weight loss as indices of undernutrition in acutely hospitalized patients. *Clin Nutr* 2003; **22**:307–312.