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ARTICLE

The utility of resting pulse rate in defining high blood pressure among adolescents in Mbarara municipality, Uganda

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Abstract

High resting pulse rate (RPR) is associated with adverse cardiovascular events and could be used as a marker of cardiovascular health. We determined the correlation between RPR and blood pressure (BP); and its accuracy in defining high blood pressure among adolescents attending secondary schools in Mbarara municipality, south-western Uganda. We conducted a cross-sectional study among secondary school adolescents aged 12–19 years in Mbarara municipality, Uganda. We captured demographic characteristics using a structured questionnaire; and measured anthropometric indices and BP. We performed a linear regression analysis to determine the relationship between RPR and blood pressure and plotted receiver operating characteristics curves (ROC) to assess the accuracy of RPR in defining high BP. We enrolled 616 adolescents with a mean age of 15.6 ± 2.0 years and 65.6% (404/616) were female. The RPR was significantly correlated with diastolic blood pressure (DBP) in both boys (Beta = 0.22 [95% CI: 0.10; 0.36]), $p < 0.001$ and girls (Beta = 0.51 [95% CI: 0.43; 0.60]), $p < 0.001$. RPR was significantly correlated with systolic blood pressure (SBP) only in the girls (Beta = 0.23 [95% CI: 0.15; 0.30]), $p < 0.001$. The optimal threshold for RPR in defining prehypertension was RPR ≥ 76 bpm with an area under the curve (AUC) of 0.653 [95% CI: 0.583–0.722], the sensitivity of 0.737 and specificity of 0.577. In defining hypertension, the optimal threshold was RPR ≥ 79 bpm at a sensitivity of 0.737 and specificity of 0.719, with an AUC of 0.728 [95% CI: 0.624–0.831]. Resting pulse rate was positively correlated with BP and was more accurate in defining hypertension compared to prehypertension in the study.

Introduction

Hypertension (HTN) was previously considered a rare condition among adolescents [1]. In contrast, it has become more common and is increasing unexpectedly in this age group [2]. The prevalence of HTN among adolescents has been reported in several countries and varies from 3.6 to 30% [2]. High blood pressure (BP) in young subjects is associated with accelerated vascular ageing and increased risk for adult HTN and cardiovascular disease [3]. The diagnostic algorithm for HTN in children and adolescents does not rely on single BP cut-offs as is the case for adults. This is believed to be the cause of its under-diagnosis in young populations, because the normal and abnormal BP values vary with sex, height, and age, making it difficult for clinicians to remember [4]. Furthermore, the algorithm involves repeated BP measurements and follow-up visits [5, 6]. This is laborious and may not be suitable for resource-limited settings, with a low clinician to patient ratio. Thus, easier to use diagnostic approaches are needed in resource-limited settings, to facilitate the identification of adolescents with high BP and those who need interventions to prevent or control HTN to improve long-term outcomes. In addition, determining prehypertension (PreHTN) is a vital warning sign the someone might develop HTN in the future if no changes to lifestyle are made.

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Resting pulse rate (RPR) has recently attracted attention as an important predictor of high BP [7] and a risk factor for cardiovascular morbidity and mortality in general populations [8]. Additionally, various studies among children and adolescents, have reported a significant correlation of elevated RPR with both systolic (SBP) and diastolic BP (DBP) [9], highlighting its possible role in screening for high BP. HTN results from alterations in the overall hemodynamic load on the cardiovascular system [10], which is an interplay between the cardiac output (CO) and total peripheral vascular resistance [11]. The CO is affected by changes in the pulse rate, which in turn depends on the autonomic tone of the cardiovascular system [12]. Thus, any changes in RPR ultimately affect an individual's arterial BP. Moreover, the role of RPR as a surrogate for cardiovascular autonomic dysfunction, and its possible utilization in identifying individuals at risk of high BP has previously been suggested [13]. The relationship between RPR and BP, among adolescents, has not been well studied in sub-Saharan Africa. RPR is considered a simple and cheap measurement, which does not necessitate the use of special instruments and patients can conveniently measure it by themselves. Therefore, RPR would be a useful screening tool for HTN among adolescents.

In this cross-sectional study, we aimed to assess the utility of RPR in defining high BP (SBP and DBP) among adolescents from selected secondary schools in Mbarara municipality. South-western Uganda. We hypothesized that there was an association between RPR and BP (SBP and DBP) among the adolescents and tested this hypothesis in a cross-sectional study.

Methods

Study sample

The participants were part of a cross-sectional study, which involved three secondary schools in Mbarara municipality, southwestern Uganda between May and November 2018. The sample size was estimated using the Kish Leslie method of 1965 [14] assuming a prevalence of HTN of 10.7% among secondary school adolescents [15], and a 95% confidence interval (CI) within a 3% error margin. The final sample size was adjusted for an anticipated participant nonresponse rate of 10%; thus 449 participants were required. In this analysis, a total sample of 616 adolescents aged 12–19 years was used. Consecutive sampling was used to recruit participants.

Socio-demographic information

The age of the participant was self-reported and was the number of complete years since birth while the sex of the participant was a binary variable (male or female) and based on the sexual characteristics as was observed by the researcher.

Determination of anthropometric indices

The methods used to determine the height, weight, neck circumference (NC), waist circumference (WC), and their respective ratios, have been described in detail elsewhere [16]. Briefly, height was measured using a wall mount height board in centimeters with the participant having no shoes [17]. A standard Seca scale was used to determine the weight to the nearest 0.5 kg [18]. Body mass index (BMI) was calculated as the ratio of weight in kilograms to height in square meters. WC was measured at the midpoint between the lowest border of the rib cage and the top of the lateral border of the iliac crest while hip circumference was measured at the greatest horizontal circumference below the iliac crest at the level of the greater trochanter using a nonelastic measuring tape (Seca 203 Ergonomic circumference measuring tape, Hamburg, Germany). Waist to hip ratio (WHR) was the ratio of WC to HC, while the waist to height ratio (WHtR) was the ratio of WC divided by height. The NC assessed as a surrogate measure for upper body adipose tissue distribution. It was measured at the level of the laryngeal prominence using an inelastic flexible measuring tape (Seca 203 Ergonomic circumference measuring tape, Hamburg, Germany), with the subjects in the standing position and the head held erect and eyes facing forward to the nearest 0.1 cm [19].

Measurement of BP and RPR

BP and RPR were measured using a digital BP machine (Scian SP-582 Digital Blood Pressure Monitor) as previously described by Katamba et al. [16]. Each participant was allowed to seat on a chair with back supported, feet on the floor, arm supported, and cubital fossa at heart level after 5 min of sitting rest without talking [20, 21]. The cuff of appropriate size (ranged from 12 × 22 to 16 × 30 cm) was placed at the bare upper arm, one inch above the bend of the participant's elbow. It was ensured that the tubing fell over the front center of the arm so that the sensor was correctly placed. The end of the cuff was pulled so that it was evenly tight around the arm. The cuff was placed tight enough so that only two fingertips could be slipped under the top edge of the cuff. It was made sure that the skin did not pinch when the cuff inflated. The participant was asked to remain quiet as the BP was measured with an automated cuff [22]. Three readings were recorded per participant at 5 min interval. The average of the 2nd and 3rd SBP and DBP measurements was used as the subject's BP, respectively [21]. Similarly, the average of the 2nd and the 3rd RPR

Table 1 Showing characteristics of participants by BMI categories.

Variable	Obese	Overweight	Normal weight	Underweight
	($n = 21$)	($n = 188$)	($n = 387$)	($n = 20$)
Female	($n = 18$)	($n = 166$)	($n = 215$)	($n = 5$)
Male	($n = 3$)	($n = 22$)	($n = 172$)	($n = 15$)
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Age (years)	17.7 (1.6)	15.6 (1.9)	15.5 (2.0)	15.9 (1.9)
NC (cm)	31.9 (1.8)	30.3 (1.7)	29.9 (2.2)	28.8 (1.6)
WHR	0.84 (0.05)	0.76 (0.07)	0.8 (0.08)	0.79 (0.07)
RPR (bpm)	77.9 (6.8)	74.9 (7.0)	75.6 (8.7)	76.4 (13.5)
SBP (mmHg)	117.3 (14.6)	114.3 (7.3)	112.9 (8.9)	107 (14.4)
DBP (mmHg)	75.3 (7.9)	65.8 (7.4)	66.4 (8.1)	66.4 (9.7)

SBP systolic blood pressure, *DBP* diastolic blood pressure, *NC* neck circumference, *WHR* waist height ratio, *RPR* resting pulse rate, *SD* standard deviation.

readings was used as the participants RPR. Those adolescents who had elevated BP in the first session were identified. A re-measurement, using the same procedure was done after 1 week to confirm that BP is truly and constantly elevated. HTN and PreHTN were classified using the 2017 American College of Cardiology guidelines for HTN [23]. Based on these guidelines, a BP ≥ 130/80 mmHg was classified as HTN while an SBP of 120–129 mmHg and DBP < 80 mmHg was classified as PreHTN.

Data management and analysis

Data were analyzed using the Stata software version 13.0 (College Station, Texas, USA). Continuous variables were described as mean ± SD while categorical variables such as sex were described as percentages and frequencies. The outcome variable was BP (both SBP and DBP). Pearson correlation analysis was done to determine the strength of the relationship between BP, RPR, and anthropometric indices. The Pearson correlation coefficients and their 95% CI were reported. Multivariate linear regression analysis was used to control for anthropometric indices in the relationship between RPR and BPs. A p value of less than 0.05 was considered for assessing the statistical significance and 95% CI of the changes in BP values associated with a unit change in RPR was calculated. Receiver operating characteristic (ROC) curve analyses were performed to determine the accuracy of RPR in defining high BP (PreHTN and HTN) among adolescents and identify optimal thresholds of RPR for identifying high arterial BP. Optimal thresholds were selected as the values corresponding to the maximum of Youden's index on the ROC curve. PreHTN and HTN were then redefined by the determined optimal thresholds of RPR. These were compared with the gold standard BP cut-offs in adolescents as stated by the Joint National Committee on HTN guidelines [24]. The sensitivities and specificities and their respective 95% CI were obtained to assess the performance of the determined RPR optimal thresholds. All analyses were stratified by sex because of the physiological difference in RPR between the two groups.

Results

Characteristics of study participants by BMI

A sample of 616 had complete data and was included in the final analysis as was obtained from a larger prevalence study. These were aged between 12 and 19 years; with a mean age of 15.6 ± 2.0 years. The prevalence of HTN was found at 3.1% while PreHTN was estimated at 7.1% [25]. In Table 1, the characteristics of the participants are described according to BMI categories.

Correlation analysis

RPR was positively correlated with both SBP and DBP among adolescents in our study. While the overall linear correlation coefficients of 0.22 [95% CI: 0.14–0.29] for SBP and 0.44 [95% CI: 0.37–0.50] for DBP were statistically significant, they are weak. The correlation of RPR with both SBP and DBP was still significant and positive even after controlling for the sex of participants as shown in Fig. 1. Most of the indices showed positive linear relations with both DBP and SBP among the girls, except for the WHR, which exhibited a negative correlation with SBP as seen in Table 2.

Linear regression analysis

A bivariate linear regression of RPR and BP (SBP and DBP) indicated a significant positive linear relationship between two variables. However, the variability (using the linear regression R squared value) in DBP, which could be explained by RPR, was only 19% compared to 5% for SBP. For the entire

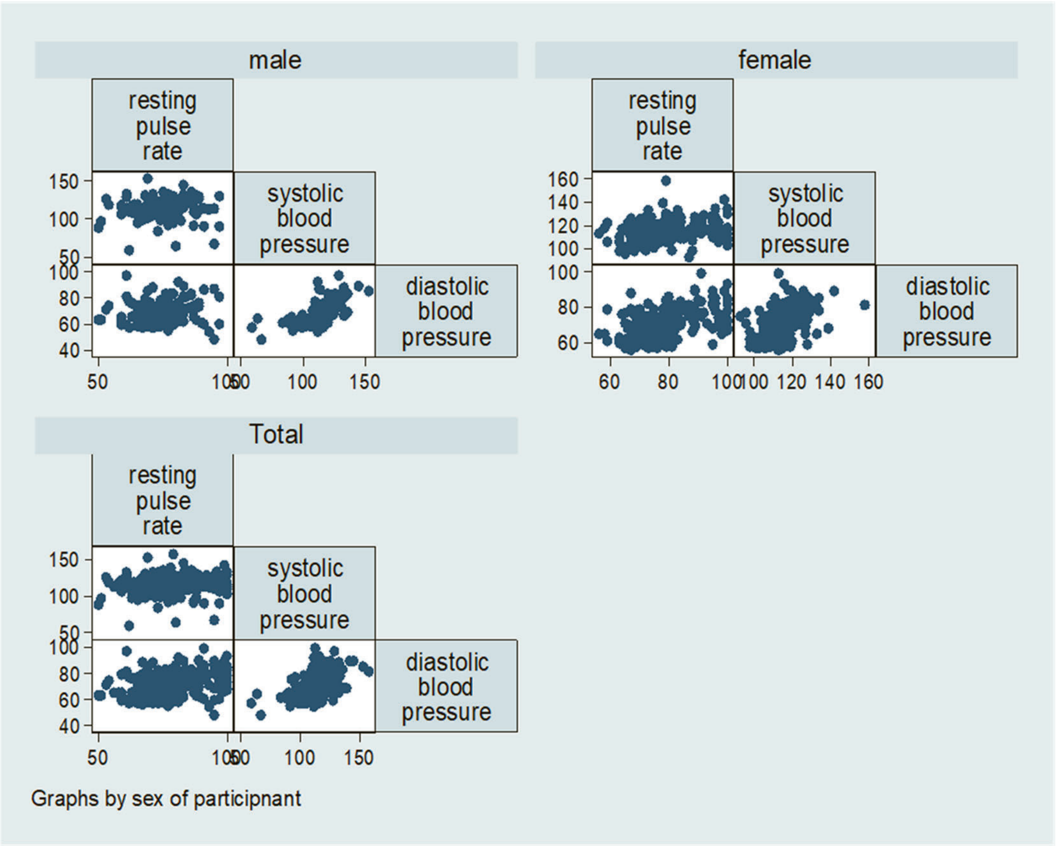

Fig. 1 Showing the Pearson correlation of resting pulse rate with blood pressure of the participants. The graphs are represented as scatter plots resting pulse rate with systolic blood pressure and diastolic blood pressure.

Table 2 Showing the correlation between blood pressure and anthropometric indices.

Variables	*r* (Pearson correlation) [95% confidence interval]	*p* value
Systolic blood pressure		
BMI (kgm^{-2})	0.10 [0.02–0.18]	0.011
NC (cm)	0.50 [0.44–0.56]	<0.001
WHR	−0.14 [−0.21–0.39]	<0.001
WHtR	0.24 [0.17–0.31]	<0.001
Diastolic blood pressure		
BMI (kgm^{-2})	0.05 [0.03–0.12]	0.265
NC (cm)	0.32 [0.25–0.39]	<0.001
WHR	−0.14 [−0.22–0.07]	<0.001
WHtR	0.15 [0.07–0.23]	<0.001

BMI body mass index, *NC* neck circumference, *WHR* waist hip ratio, *WHtR* waist height ratio.

sample, a multivariate linear regression showed that a unit increase in RPR was significantly associated with increases in BP (SBP and DBP). The predicted change in SBP reduced after adjusting for anthropometric indices as shown in Figs. 2a, b and 3a, b.

Optimal thresholds of RPR for identifying PreHTN and HTN among adolescents

The optimal threshold for identifying PreHTN was determined as RPR ≥ 76 bpm with a sensitivity of 0.737 and specificity of 0.577. The performance of this threshold based on the AUC was 0.652 [CI; 0.583–0.722] as shown in Fig. 4. This optimal threshold classified 58.8% of the participants correctly as prehypertensive. The positive predictive value (PPV) of 0.118 and a negative predictive value (NPV) of 0.882. The optimal threshold for HTN in our study was determined as RPR ≥ 79 bpm, with a sensitivity of 0.737, the specificity of 0.719 and an AUC of 0.728 [CI; 0.624–0.831] as shown in Fig. 5. This threshold classified 71.92% of the participants correctly, with a PPV of 0.077 and NPV of 0.988. Both sensitivity and specificity of RPR were higher for the identification of HTN than PreHTN among our study participants as shown in Table 3.

Discussion

Our study demonstrated a positive linear relationship between RPR and BP (SBP and DBP), even after

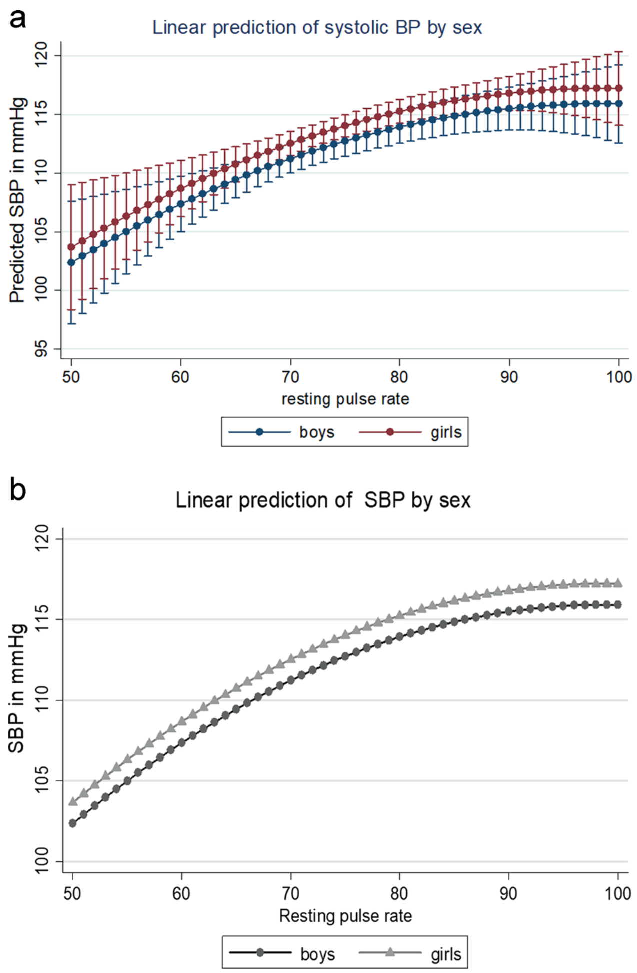

Fig. 2 **a** Showing linear regression of resting pulse rate with systolic blood pressure by sex of the participants. **b** Adjusted linear regression of resting pulse rate with systolic blood pressure by sex of the participants. SBP systolic blood pressure, BP blood pressure, mmHg millimeters of mercury.

adjusting for anthropometric indices and sex. This is in agreement with findings from several studies done among children and adolescents in Nigeria [15], USA [26], and China among others. The association between RPR and elevated BP is believed to be due to alterations in the cardiovascular autonomic tone, including a reduction in cardiac vagal stimulation, increased sympathetic activation, and imbalance in the sympathovagal system [27]. As previously reported, these alterations are associated with the recognized increased risk for HTN among individuals with elevated resting heart rates. Moreover, it has been previously postulated that the effect of elevated heart rate on cardiovascular mortality might be mediated through high BP [28].

Our study also found RPR to be more accurate in defining HTN as opposed to defining PreHTN among adolescents. The AUC of 0.609–0.854 suggested a high and robust discriminatory accuracy of RPR in identifying HTN among

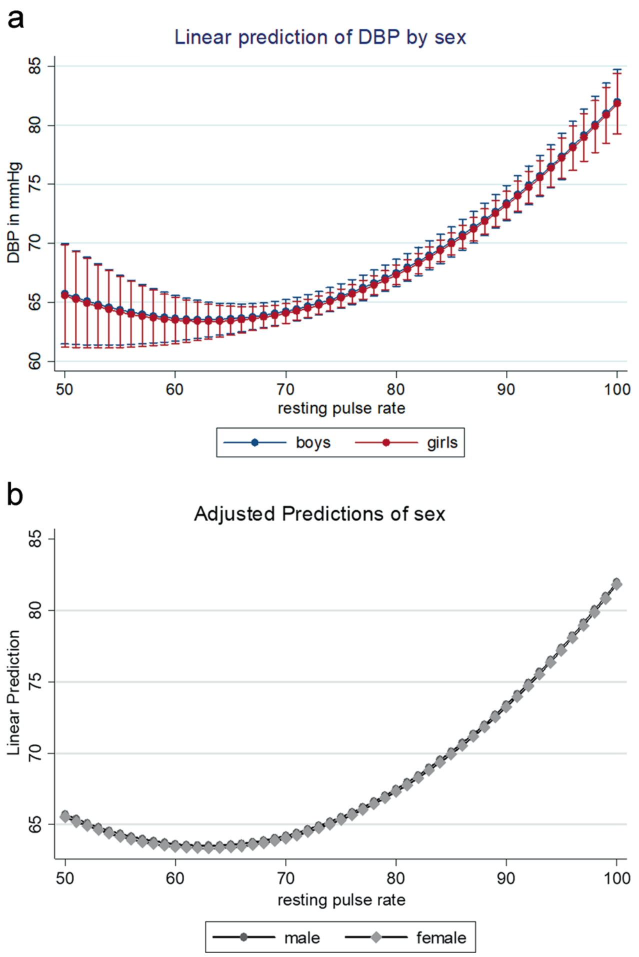

Fig. 3 **a** Showing linear regression of resting pulse rate with systolic blood pressure by sex of the participants. **b** Adjusted linear regression of resting pulse rate with diastolic blood pressure by sex of the participant. DBP diastolic blood pressure, mmHg millimeters of mercury.

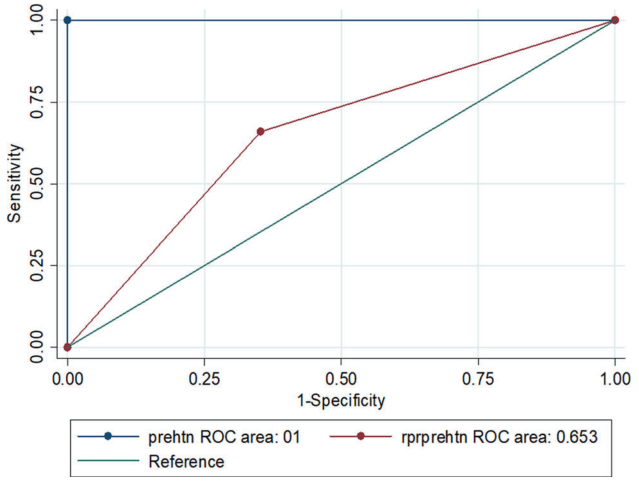

Fig. 4 **ROC curve sowing the overall prehypertension definition by resting pulse rate among adolescents.** prehtn prehypertension, rprprehtn resting pulse rate in defining prehypertension, ROC receiver operating characteristic curve.

secondary school adolescents in our study setting. In defining PreHTN, the AUC was lower but well above 0.6 which is the recommended minimum. Besides, the much higher NPVs of the cut off for HTN indicated that our test is unlikely to omit adolescents with HTN and PreHTN. However, due to the low prevalence of HTN in our study, the PPVs of our optimal cut-offs were also low. This showed that many adolescents with both HTN and PreHTN would be misclassified as not having PreHTN or HTN. This makes RPR not the best substitute for the commonly used age, gender, and height BP percentiles for diagnosing HTN. However, it can be used for screening adolescents at high risk of high BP in populations with a high prevalence of high BP and in resource-limited settings. The study findings are in agreement with those as reported by Tjugen et al. [29], which involved elderly subjects to determine whether the heart rate itself was a risk factor for the development of HTN or just a marker of sympathetic overactivation. It was found that a high heart rate was a strong predictor of cardiovascular disease and a reliable predictor for the development of HTN [29]. The study also addresses recommendations for further research on the use of RPR in defining HTN among adolescents from China [30], Hong Kong [31] among others. Thus, this study responds to such recommendations with fair news, showing that RPR may be useful in discriminating people who are at risk of developing elevated BP; however, it may not be used as the basis for the diagnosis of the condition. Nonetheless, our findings contribute to the existing body of evidence that proposes the use of RPR as a useful clinical measurement and as a risk factor for cardiovascular disease as was reported from the WHO Cardiovascular Disease and Alimentary Comparison Study [32].

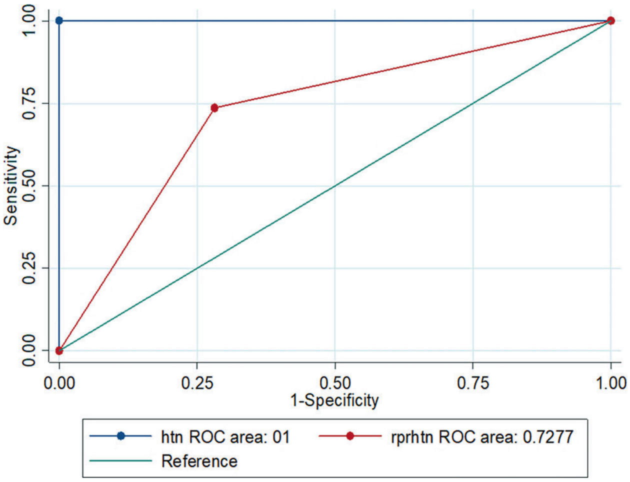

Fig. 5 ROC curve showing the overall AUC of resting pulse rate in defining hypertension among adolescents. htn hypertension, rprhtn resting pulse rate in defining hypertension, ROC receiver operating characteristic curve.

Our study has some limitations as outlined; First, the participants were not objectively evaluated secondary causes of high BP and elevated heart rate. Nevertheless, we did exclude adolescents with a self-reported history of other endocrine disorders and those with acute febrile conditions. Additionally, we assessed adolescents with high BP and elevated RPR on more than one occasion before confirming the diagnosis. Second, we conducted the study in a few selected secondary schools, because of logistical concerns. This limits the generalization of our findings to adolescent populations outside the peri-urban secondary schools of Mbarara municipality, southwestern Uganda. Lastly, our BP was measured using an automated BP monitor and not by brachial pulse palpation and yet the results could be different. We thus recommend larger surveys in a wider population to corroborate our findings. Furthermore, our analysis was based on the AUC from ROC analysis and this is generally affected by the prevalence of the disease among the study population. Thus, the results here may not apply to areas with very high prevalence of HTN. Finally, we cannot assess the temporal relationship between RPR and BP in our study population, because of the cross-sectional nature of our study design. Future longitudinal studies in larger adolescent populations are needed to explore this relationship.

Table 3 Optimal thresholds of RPR for identifying PreHTN and HTN among adolescents.

Category	Threshold	PPV	NPV	Se	Sp	AUC [95% CI]
Overall						
PreHTN	≥76 bpm	0.117	0.965	0.727	0.577	0.653 [0.583–0.722]
HTN	≥79 bpm	0.077	0.989	0.737	0.719	0.728 [0.624–0.831]
Boys						
PreHTN	≥75 bpm	0.167	0.975	0.722	0.608	0.685 [0.558–0.811]
HTN	≥76 bpm	0.154	0.993	0.700	0.629	0.674 [0.470–0.877]
Girls						
PreHTN	≥76 bpm	0.141	0.966	0.769	0.545	0.623 [0.515–0.731]
HTN	≥78 bpm	0.053	0.100	0.100	0.620	0.822 [0.739–0.905]

PreHTN prehypertension, *HTN* hypertension, *Se* sensitivity, *Sp* specificity, *PPV* positive predictive value, *NPV* negative predictive value, *AUC* area under the curve.

Conclusions

Our study demonstrated a positive linear relationship between RPR and BP among adolescents after controlling for anthropometric indices and sex. RPR was found to be more accurate in defining HTN than PreHTN in our study population. These data highlight RPR as a potential tool for screening adolescents, for high BP. Future larger studies among adolescents in the region are warranted to corroborate our findings.

Summary

What is known about the subject

- The definition of hypertension among children and adolescents is age-gender and height specific, which makes it complex. Resting pulse rate was found to be highly and positively correlated with blood pressure and, was found higher in hypertensive subjects.

What the study adds

- Resting pulse rate is simple and accurate for screening for prehypertension and hypertension among secondary school adolescents aged 12–19 years in southwestern Uganda.

Data availability

The dataset is available on request from the corresponding other.

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Author contributions GK, RM, and DCA: conceptualization of work and its realization, wrote the manuscript, checked the references, compiled the literature sources, data collection, statistical analysis, and interpretation of data, and wrote the manuscript and is the corresponding author. RN, DCA, RM: mentored the conceptualization of work and its realization, compiling literature sources and statistical analysis, helped in data interpretation, guided manuscript writing, checked the references. AN, AM, MAK: assent and consent form administration, data collection, data entry, and analysis. All authors read and approved the study manuscript.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethics approval and consent to participate The study was approved by the research ethics committee of Mbarara University of Science and Technology (IRB No. 18/03–18) We also obtained permission to collect data from the school headteachers. The class teachers were informed about the purpose of the study and all potential participants were first sensitized about study procedures, possible benefits, and risks. Adolescents of 12–17 years freely assented, and consent for their participation was obtained through their teachers. We obtained written informed consent from adolescents aged 18–19 years.

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