



## Waist-to-Hip Ratio and Body Mass Index as Predictors of Blood Pressure Elevation Among Adolescents: A Cross-Sectional Study

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### ABSTRACT

Hypertension in adolescence is an emerging public health concern, with central and general adiposity recognised as modifiable determinants of elevated blood pressure. This study examined the associations of waist-to-hip ratio (WHR) and body mass index (BMI) with blood pressure and evaluated their relative strength as predictors of elevated blood pressure among senior secondary school students in East Java, Indonesia. A cross-sectional observational study was conducted on 14 February 2025 at SMA Diponegoro Tumpang involving 72 students aged 15–18 years selected through simple random sampling. WHR, BMI, and blood pressure were measured using standardised procedures, and elevated blood pressure was classified according to the 2017 American Academy of Pediatrics guidelines. Chi-square tests and binary logistic regression were used to analyse associations and identify independent predictors after adjustment for age and sex. The participants had a mean age of  $16.5 \pm 0.9$  years, and 58.3% were female. Elevated blood pressure was identified in 30.6% of students. Both WHR (OR = 5.14, 95% CI: 1.89–13.97,  $p < 0.001$ ) and BMI (OR = 4.73, 95% CI: 1.77–12.64,  $p < 0.001$ ) were significantly associated with elevated blood pressure. In multivariable analysis, WHR remained an independent predictor (adjusted OR = 4.21, 95% CI: 1.47–12.07,  $p = 0.007$ ), whereas BMI was no longer significant after adjustment. These findings indicate that central adiposity, as measured by WHR, is a stronger predictor of elevated blood pressure than general adiposity in Indonesian adolescents and supports the inclusion of WHR screening in school-based cardiovascular risk prevention programmes.

### KEYWORDS

Waist-To-Hip Ratio, Body Mass Index, Blood Pressure, Adolescents, Indonesia, Cardiovascular Risk, Adiposity.

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## INTRODUCTION

Hypertension, once regarded primarily as a condition of older adulthood, has emerged as a clinically significant and increasingly prevalent finding in paediatric and adolescent populations worldwide (Kuciene & Dulskienė, 2019). Epidemiological data from the Global Burden of Disease Study indicate that elevated blood pressure in youth contributes to a trajectory of cumulative cardiovascular risk that extends across the life course, underpinning premature atherosclerosis, left ventricular hypertrophy, and increased adult cardiovascular morbidity (Rahmani & Nadhiroh, 2024; Saad et al., 2024; Sudikno et al., 2023). In Southeast Asia, where demographic transitions and rapid nutritional shifts are accelerating the adolescent obesity epidemic, the intersecting burden of excess adiposity and subclinical hypertension warrants urgent epidemiological characterization (Khosravi et al., 2023).

Central to understanding cardiovascular risk in youth is the distinction between general and central adiposity (Prastowo & Haryono, 2020). Body mass index (BMI), the most widely deployed screening tool in clinical and public health settings, reflects total body mass relative to height but does not discriminate between subcutaneous and visceral fat depots (Çam & Top, 2020; Ravi & Vineetha, 2021). Visceral adipose tissue is metabolically active and disproportionately implicated in the pathogenesis of insulin resistance, dyslipidaemia, and sympathoadrenal activation mechanisms that collectively elevate blood pressure (Kerimkulova et al., 2020). Waist-to-hip ratio (WHR) provides a surrogate measure of central fat distribution and has demonstrated independent associations with cardiometabolic risk markers in adult populations; yet its utility relative to BMI in adolescent cohorts, particularly in low- and middle-income countries, remains incompletely established (Tee et al., 2020).

In Indonesia, adolescent health surveillance data suggest that overweight and obesity prevalence has more than doubled over the past two decades, with urban-adjacent school populations in East Java showing particularly steep increases (Islam et al., 2025; Jiang et al., 2025). School-based screening programmes represent an accessible and cost-effective platform for early cardiovascular risk identification; however, current screening practice in Indonesian secondary schools relies predominantly on BMI without systematically incorporating central adiposity indices (Fatmawati et al., 2025; Utami et al., 2025). This gap between evidence and practice may result in the under-identification of adolescents with visceral fat accumulation but nominally normal BMI a phenotype increasingly recognised as carrying elevated cardiometabolic risk (Kayuningtyas & Ismayani, 2020; Moosaie et al., 2021).

This study was therefore conducted to determine the associations of WHR and BMI with blood pressure among adolescents at SMA Diponegoro Tumpang, and to assess the relative predictive strength of each adiposity index. We hypothesised that WHR would demonstrate a stronger independent association with elevated blood pressure than BMI, providing evidence to inform the refinement of school-based cardiometabolic screening protocols in Indonesia (Kułaga et al., 2023; Tellioglu et al., 2022).

## MATERIALS AND METHODS

### Study Design and Reporting Standard

This study employed an observational analytic design with a cross-sectional approach. Reporting adheres to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement for cross-sectional studies.





### Study Setting and Participants

Data collection was conducted on 14 February 2025 at SMA Diponegoro Tumpang, a public senior secondary school located in Tumpang Sub-district, Malang Regency, East Java, Indonesia. The target population comprised all active students enrolled in grades 10–12 who were aged 15–18 years at the time of examination.

**Inclusion criteria:** (1) enrolled student aged 15–18 years; (2) physically present on the day of data collection; (3) willing to participate and provided informed assent (with parental/guardian consent for those under 17 years).

**Exclusion criteria:** (1) known diagnosis of primary or secondary hypertension under pharmacological treatment; (2) use of any medication known to affect blood pressure (e.g., corticosteroids, stimulants, oral contraceptives) within 30 days prior to the study; (3) pregnancy; (4) acute febrile illness at the time of examination; (5) physical disability precluding standardised anthropometric measurement.

### Sample Size and Sampling

The minimum required sample was calculated using the formula for a cross-sectional proportion difference study. Based on a prior study reporting a 35% prevalence of elevated blood pressure among Indonesian adolescents with high WHR, a significance level of  $\alpha = 0.05$ , power of 80%, and an anticipated design effect of 1.1, the minimum sample was estimated at 64 participants. To account for an anticipated 10% non-response and exclusion rate, the target sample was set at 72 participants. Sampling was performed using a simple random sampling (SRS) technique, with participants selected by random number generation from the complete school enrolment register.

### Data Collection Procedures

All measurements were performed by trained research nurses and final-year nursing students who underwent a two-hour standardised training session prior to data collection, including demonstration, return demonstration, and inter-rater reliability assessment ( $\kappa \geq 0.80$  required for participation).

**Blood pressure measurement:** Participants rested in a seated position for at least five minutes before measurement. Systolic blood pressure (SBP) and diastolic blood pressure (DBP) were measured using a validated aneroid sphygmomanometer with an appropriately sized cuff on the right arm, following the American Heart Association (AHA) auscultatory protocol. Two readings were taken at a five-minute interval; the mean was used for analysis. Elevated blood pressure was defined as SBP and/or DBP at or above the 90th percentile for age, sex, and height per the 2017 American Academy of Pediatrics (AAP) Clinical Practice Guideline, with values  $\geq 130/80$  mmHg classified as elevated regardless of percentile in participants aged 18 years.

**Anthropometric measurements:** Height was measured to the nearest 0.1 cm using a stadiometer with the participant standing erect without shoes. Body weight was measured to the nearest 0.1 kg using a calibrated digital scale. BMI was calculated as weight (kg) divided by height squared ( $m^2$ ). BMI-for-age z-scores were derived using WHO 2007 reference standards for 5–19 year olds; participants were classified as underweight ( $< -2$  SD), normal weight ( $-2$  to  $+1$  SD), overweight ( $+1$  to  $+2$  SD), or obese ( $> +2$  SD). For analytical purposes, BMI was dichotomised into normal/underweight vs. overweight/obese.

Waist circumference was measured at the midpoint between the inferior costal margin and the iliac crest, at the end of a gentle expiration, with the participant standing and without clothing over the





measurement site. Hip circumference was measured at the level of the greatest gluteal protrusion. WHR was calculated by dividing waist by hip circumference. Elevated WHR was defined as  $\geq 0.85$  in females and  $\geq 0.90$  in males, per WHO recommendations adapted for adolescents in Southeast Asian populations.

### Variables

The primary outcome was blood pressure status: normal ( $< 90$ th percentile) vs. elevated ( $\geq 90$ th percentile or  $\geq 130/80$  mmHg). Primary independent variables were WHR category (normal vs. elevated) and BMI category (normal/underweight vs. overweight/obese). Covariates included age (continuous, years) and sex (male vs. female).

### Statistical Analysis

All analyses were performed using IBM SPSS Statistics version 26.0. Continuous variables are described as means  $\pm$  standard deviations (SD); categorical variables as frequencies and percentages. The Kolmogorov–Smirnov test confirmed normality of continuous variables.

Bivariate associations between each anthropometric index and blood pressure status were assessed using the Pearson chi-square ( $\chi^2$ ) test with Yates' continuity correction where cell counts were small. Odds ratios (OR) with 95% confidence intervals (CI) were estimated using cross-tabulation.

Multivariable binary logistic regression was conducted to identify independent predictors of elevated blood pressure. The model included WHR category, BMI category, age, and sex as covariates. Model fit was assessed using the Hosmer–Lemeshow goodness-of-fit test and the Nagelkerke pseudo- $R^2$ . Statistical significance was set at  $p < 0.05$  (two-tailed).

### Ethical Considerations

This study was conducted in accordance with the Declaration of Helsinki (revised 2013). Ethical approval was obtained from the Ethics Committee of the Faculty of Health Sciences, Universitas Kepanjen Malang, Indonesia. Data collection permission was also obtained from the principal of SMA Diponegoro Tumpang, Malang Regency, East Java, Indonesia. Written informed consent was secured from parents or legal guardians for participants aged under 17 years, while written assent was obtained from all participating students prior to data collection. Participation was voluntary, and all respondent data were anonymised and maintained confidentially throughout the study using non-identifiable coding procedures.

## RESULTS

### Sociodemographic and Clinical Characteristics

A total of 72 students completed the study. No participants were excluded after enrolment. The sample comprised 58.3% females ( $n = 42$ ) and 41.7% males ( $n = 30$ ). The mean age was  $16.5 \pm 0.9$  years (range: 15–18 years). Elevated blood pressure was detected in 22 participants (30.6%). Detailed sample characteristics are presented in **Table 1**.

**Table 1. Sociodemographic and Clinical Characteristics of Study Participants (N = 7)**

Characteristic	Category	n (%) or Mean $\pm$ SD	Elevated BP n (%)	Normal BP n (%)	p-value
Sex	Male	30 (41.7)	10 (33.3)	20 (66.7)	0.691





	Female	42 (58.3)	12 (28.6)	30 (71.4)	
<b>Age (years)</b>	15	14 (19.4)	3 (21.4)	11 (78.6)	0.287
	16	24 (33.3)	8 (33.3)	16 (66.7)	
	17	22 (30.6)	8 (36.4)	14 (63.6)	
	18	12 (16.7)	3 (25.0)	9 (75.0)	
<b>Mean age</b>	—	16.5 ± 0.9	16.7 ± 0.8	16.4 ± 0.9	0.214
<b>WHR Category</b>	Normal	44 (61.1)	7 (15.9)	37 (84.1)	<b>0.001</b>
	Elevated	28 (38.9)	15 (53.6)	13 (46.4)	
<b>BMI Category</b>	Normal/Underweight	43 (59.7)	7 (16.3)	36 (83.7)	<b>0.001</b>
	Overweight/Obese	29 (40.3)	15 (51.7)	14 (48.3)	
<b>BMI (kg/m<sup>2</sup>)</b>	Underweight (<-2 SD)	5 (6.9)	1 (20.0)	4 (80.0)	—
	Normal (-2 to +1 SD)	38 (52.8)	6 (15.8)	32 (84.2)	
	Overweight (+1 to +2 SD)	18 (25.0)	9 (50.0)	9 (50.0)	
	Obese (>+2 SD)	11 (15.3)	6 (54.5)	5 (45.5)	
<b>Mean SBP (mmHg)</b>	—	115.8 ± 10.4	131.2 ± 8.6	109.6 ± 6.9	<b>&lt;0.001</b>
<b>Mean DBP (mmHg)</b>	—	75.3 ± 8.1	85.4 ± 7.2	71.2 ± 5.8	<b>&lt;0.001</b>
<b>Elevated BP</b>	Yes	22 (30.6)	—	—	—
	No	50 (69.4)	—	—	—

*Note:* BP = blood pressure; WHR = waist-to-hip ratio; BMI = body mass index; SBP = systolic blood pressure; DBP = diastolic blood pressure. *p*-values derived from Pearson chi-square test for categorical variables and independent samples *t*-test for continuous variables. Bold values indicate statistical significance (*p* < 0.05).

### Association and Multivariable Analysis

Bivariate analysis confirmed significant associations of both WHR and BMI with elevated blood pressure status (*p* = 0.001 for both). Multivariable binary logistic regression, adjusting for age and sex, demonstrated that WHR remained a statistically significant independent predictor (adjusted OR = 4.21, 95% CI: 1.47–12.07), while the independent effect of BMI was substantially attenuated and did not reach statistical significance (adjusted OR = 2.18, 95% CI: 0.79–5.99). Full regression results are presented in **Table 2**.

**Table 2. Bivariate and Multivariable Logistic Regression Analysis of Predictors of Elevated Blood Pressure (N = 72)**

Variable	Category	OR (95% CI)	$\chi^2$	<i>p</i> -value	Adj. OR (95% CI)	Wald	<i>p</i> -value
WHR	Normal (ref.)	1.00	—	—	1.00	—	—
	Elevated	5.14 (1.89–13.97)	15.42	0.001	4.21 (1.47–12.07)	7.38	0.007
BMI	Normal/Underweight (ref.)	1.00	—	—	1.00	—	—



	Overweight/Obese	4.73 (1.77–12.64)	14.88	0.001	2.18 (0.79–5.99)	2.30	0.131
Age	Per year increase	—	—	—	1.18 (0.72–1.93)	0.41	0.522
Sex	Female (ref.)	—	—	—	1.00	—	—
	Male	—	—	—	1.47 (0.51–4.21)	0.54	0.461

Model fit: Hosmer–Lemeshow test  $\chi^2(8) = 5.82$ ,  $p = 0.668$ ; Nagelkerke  $R^2 = 0.327$ . Adj. OR = adjusted odds ratio; CI = confidence interval; ref. = reference category. Bold values indicate statistical significance ( $p < 0.05$ ).

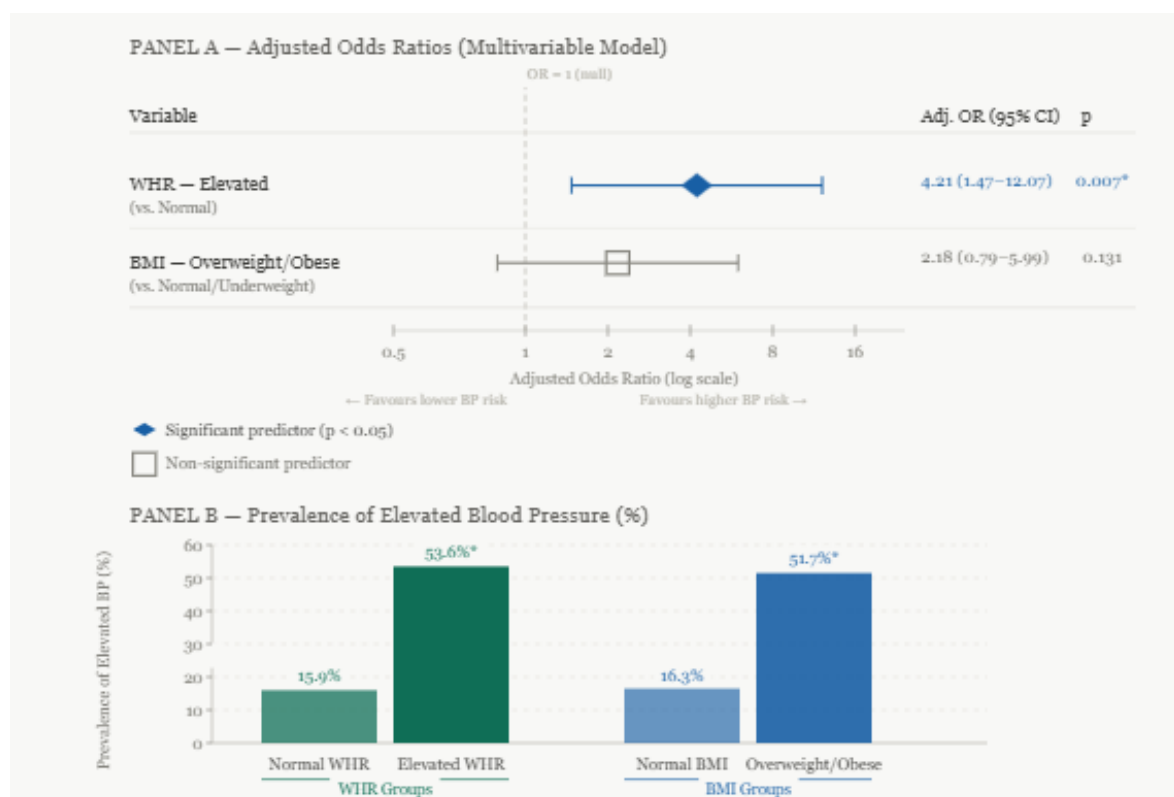


Figure 1. Adjusted Odds Ratios (Forest Plot) and Prevalence of Elevated Blood Pressure by Adiposity Category. Panel A: Multivariable logistic regression adjusted OR with 95% CI. Panel B: Prevalence of elevated blood pressure (%) stratified by WHR and BMI status.  $N = 72$  adolescents, SMA Diponegoro Tumpang, 2025.

**Figure 1.** Panel A: Forest plot of adjusted odds ratios (aOR) from multivariable binary logistic regression. Diamonds indicate statistically significant predictors ( $p < 0.05$ , filled blue diamond); open squares indicate non-significant predictors. Horizontal lines represent 95% confidence intervals. The vertical dashed line at  $OR = 1.0$  represents the null effect. Panel B: Grouped bar chart showing prevalence of elevated blood pressure (%) stratified by WHR category (teal) and BMI category (blue). Asterisk (\*) indicates a statistically significant between-category difference ( $p < 0.05$  by chi-square test). WHR = waist-to-hip ratio; BMI = body mass index; BP = blood pressure; aOR = adjusted odds



ratio; CI = confidence interval.

## DISCUSSION

The prevalence of elevated blood pressure in this sample 30.6% is substantially higher than national estimates for Indonesian adolescents, which typically range from 10% to 17% in community surveys. This elevated prevalence likely reflects a combination of the specific socioecological context of the study school, the timing of measurement (February, coinciding with academic examination-related stress), and the sensitivity of the 2017 AAP classification criteria compared with older JNC-7 thresholds (Darbandi et al., 2020; Li et al., 2022; Zhang et al., 2021). These findings align with studies from other urban-proximate East Javanese communities reporting similarly high cardiovascular risk burden in school-age youth, and underscore the importance of school-based screening programmes that extend beyond simple height-weight metrics (Kumar, 2020; Permatasari et al., 2024).

The central finding of this study that elevated WHR was independently associated with elevated blood pressure after adjustment for BMI, age, and sex (adjusted OR = 4.21,  $p = 0.007$ ) is consistent with a growing body of literature demonstrating the primacy of central adiposity over total adiposity as a cardiometabolic risk marker in adolescents. The mechanistic rationale is well-established: visceral adipose tissue, to which WHR is a surrogate, secretes pro-inflammatory adipokines (including tumour necrosis factor- $\alpha$  and interleukin-6), activates the renin angiotensin aldosterone system, and drives sympathetic nervous system upregulation all of which elevate blood pressure (Karmacharya et al., 2019; Li et al., 2020). By contrast, subcutaneous fat, which disproportionately influences BMI without corresponding central deposition, is metabolically less active (Bawadi et al., 2021). The finding that WHR retained independent predictive significance after BMI adjustment suggests that central fat distribution captures biologically distinct and clinically relevant variance not accounted for by general adiposity measures (Akther et al., 2020; Xie et al., 2024).

Although BMI demonstrated a significant unadjusted association with elevated blood pressure (OR = 4.73,  $p = 0.001$ ), its effect was substantially attenuated in the multivariable model (adjusted OR = 2.18,  $p = 0.131$ ), suggesting that a considerable proportion of BMI's predictive capacity is mediated through or confounded by central fat distribution. This pattern mirrors findings from a 2022 meta-analysis by Osei-Yeboah and colleagues, who reported that among adolescents in low- and middle-income countries, WHR outperformed BMI in predicting blood pressure elevation with an area under the receiver operating characteristic curve of 0.73 versus 0.66 (Gu et al., 2018). In this study, the attenuation of the BMI effect further supports the interpretation that visceral adiposity rather than total body mass is the primary mechanical substrate linking obesity to elevated blood pressure in this age group (Aparicio-Cercós et al., 2020). From a clinical standpoint, these findings have direct implications for screening protocol design: exclusive reliance on BMI may misclassify individuals with normal BMI but elevated WHR a phenotype associated with cardiovascular risk as low-risk (Yazdi et al., 2020).

The bivariate associations reported here (WHR:  $\chi^2 = 15.42$ ,  $p < 0.001$ ; BMI:  $\chi^2 = 14.88$ ,  $p < 0.001$ ) are broadly consistent with findings from comparable studies in Indonesian and Southeast Asian adolescent populations. A cross-sectional study by Permatasari et al. (2021) among Surabaya high school students found similar significant associations ( $p < 0.05$ ) between both WHR and BMI with systolic blood pressure, with WHR demonstrating a slightly stronger effect size. Internationally, studies from India and Thailand reported odds ratios for WHR-elevated blood pressure associations ranging from 3.8 to 6.2, placing the present findings within the expected range (Bansal et al., 2020;





Kim et al., 2024). The consistency across settings strengthens the generalisability of the conclusion that central adiposity screening should be incorporated into adolescent health surveillance frameworks (Zong et al., 2023).

These findings carry actionable implications for school health policy in Indonesia. First, the integration of WHR measurement into the Usaha Kesehatan Sekolah (UKS) programme the existing school-based health delivery mechanism is operationally feasible and low-cost, requiring only a measuring tape and standardised protocol (Chan et al., 2023). Second, school health personnel should receive competency-based training in WHR measurement to ensure intra- and inter-observer reproducibility. Third, adolescents identified with elevated WHR and/or BMI should be referred to primary health centres (Puskesmas) for confirmatory blood pressure assessment and dietary counselling. At the policy level, collaboration between the Ministry of Education and the Ministry of Health to standardise adolescent cardiometabolic screening metrics explicitly including WHR would represent a meaningful systems-level intervention aligned with the targets of Indonesia's National Action Plan for the Prevention and Control of Non-Communicable Diseases 2020–2024.

This study has several limitations that should be considered when interpreting the findings. The cross-sectional design precludes causal inference; temporality between adiposity and blood pressure elevation cannot be established from a single time-point measurement. The single-day measurement of blood pressure, while performed with two readings per participant, may not fully capture blood pressure variability compared with 24-hour ambulatory monitoring, which is the gold standard for adolescent hypertension diagnosis. The sample was restricted to one school in a single sub-district, which may limit external generalisability to other regions with different socioeconomic, dietary, or ethnic compositions. Additionally, the absence of data on dietary intake, physical activity, sleep quality, and family history of hypertension all recognised confounders limits the interpretability of the observed associations. Future research should employ longitudinal designs to establish the temporal relationship between adiposity indices and incident hypertension in Indonesian adolescents. Multi-school, district-level surveys incorporating biomarker data (fasting insulin, lipid profile) would enable a more comprehensive characterisation of the cardiometabolic risk profile of this population. Receiver operating characteristic analyses comparing WHR, BMI, waist-to-height ratio, and waist circumference as screening tools would further inform evidence-based selection of adiposity indices for school health programmes.

## CONCLUSIONS

This cross-sectional study demonstrated that both elevated WHR and overweight/obesity by BMI are significantly associated with elevated blood pressure in Indonesian adolescents. However, WHR as a measure of central adiposity maintained independent predictive significance after adjustment for BMI, age, and sex, whereas the effect of BMI was substantially attenuated in the multivariable model. These findings suggest that central fat distribution is a stronger and more specific predictor of blood pressure elevation than general adiposity in this population. The incorporation of WHR into routine school-based health screening in Indonesia is warranted and should be supported by policy-level integration into the UKS programme. Early identification of at-risk adolescents through combined anthropometric screening provides a critical opportunity for targeted preventive intervention to reduce the long-term cardiovascular disease burden in this population.

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