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Structural equation modeling: exploring relationships of body mass index, waist circumference, and hypertension in elderly

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ABSTRACT

Waist circumference (WC) measurements in the elderly are uncommon and erratic. Furthermore, its correlation to hypertension has received less attention in Indonesia. This study attempted to investigate direct and indirect risk factors for high blood pressure in the elderly using structural equation modeling (SEM). A cross-sectional study was conducted in Surakarta, Central Java, Indonesia. The 297 elderly aged ≥60 is eager to take part. The path model of factors associated with blood pressure was analyzed using Stata 13. Male (b=-0.43; 95% CI=-5.67 to 4.81; p=0.872), age (b=0.52; 95% CI=0.12 to 0.93; p=0.012), and WC (b=0.35; 95% CI=0.17 to 0.53; p<0.001) directly affected systolic blood pressure (SBP). Male (b=1.83; 95% CI=-1.17 to 4.82; p=0.231), age (b=-0.03; 95% CI=-0.26 to 0.20; p=0.790), BMI (b=0.40; 95% CI=-0.03 to 0.83; p=0.067), and WC (b=0.04; 95% CI=-0.09 to 0.16; p=0.571) directly affected diastolic blood pressure (DBP). Increasing age, body mass index (BMI), and waist circumference (WC) are the important variables that influence blood pressure in older people. This study supports the evidence that body composition and weight control are necessary to prevent and control blood pressure in the elderly.

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1. INTRODUCTION

Hypertension is a significant global long-term health problem that spans all life stages. Due to the cumulative impact of the majority of risk factors, adults and the elderly are disproportionately affected by this disease. High blood pressure is one of the main causes of premature death worldwide. This is due to the numerous concomitant diseases and the associated risk of damage to vital body organs such as the brain, heart, and kidneys [1]. The global burden of hypertension demonstrated that 972 million (26.4%) individuals have high blood pressure, and the number is expected to rise to 1.56 billion by 2025 [2]. In 2015, hypertension affected one in four men and one in every five women [3]. The importance of cardiovascular disease (CVD) as one of the leading causes of death in adults and older people is becoming increasingly clear [4]. However, a study by Widyaningsih *et al.* [5], in Indonesia, reported on missed opportunities in hypertension screening in Indonesia.

Obesity has a direct relationship to high blood pressure, a significant cardiovascular risk factor [6]. It is estimated that between 65% and 78% of cases of hypertension are due to obesity [7]. Chobanian *et al.* [8] and Han and Lean [9] reported that hypertension occurs in more than two-thirds of people after the age of 65, mainly due to weight gain in adults. Currently, waist circumference is the favored technique for measuring abdominal fat accumulation compared to body mass index (BMI), which has a stronger association to the absolute quantity of intra-abdominal or visceral fat [10]. Waist circumference is frequently utilized as a proxy marker for abdominal fat mass [11], [12]. Waist circumference, which defines abdominal obesity, may pose a health risk, regardless of whether BMI is taken into account or not [13], [14]. It has been found that systolic hypertension is more common in older adults than diastolic hypertension [15]. Elevated systolic blood pressure is a more profound predictor of cardiac target organ damage than elevated diastolic blood pressure [1].

Multiple studies have investigated the correlation between changes in waist circumference (WC) and the incidence of elevated blood pressure among adults and older people [16]–[18], but few have analyzed the relationship between WC variation and changes in blood pressure. Prior investigation in China has highlighted the impact of socioeconomic and lifestyle factors on hypertension among the elderly through structural equation models (SEM). Although previous studies incorporated BMI and waist circumference as variables, these measurements were primarily treated as outcomes, leaving the underlying mechanisms of how BMI and WC contribute to high blood pressure in the elderly unexplored [19], [20]. The present study is expected to provide evidence of the significance of maintaining a healthy body mass index, waist circumference, and blood pressure levels on a regular measurement in older people who visit an integrated health posts [21]. This study aimed to investigate direct and indirect risk factors (age, gender, BMI, and WC) of blood pressure in the elderly and explore its underlying mechanisms using a SEM.

2. METHOD

3.1. Study design and participants

This cross-sectional study was carried out in Surakarta, Central Java, Indonesia, from October to November 2022. This study used the rule of thumb of 100 or 200-sample minimum that has previously been suggested for SEMs [22], [23]. A sample of 297 elderly aged ≥60 years old who are attending integrated health posts (*posyandu*) for elder people were recruited consecutively. Subjects who had a severe cognitive impairment, such as dementia or stroke, were excluded from the study.

3.3. Study variables

The dependent variables were systolic and diastolic blood pressure. The independent variables included age, gender, BMI, and waist circumference. The participants' body weight and height were measured to determine their level of obesity in terms of BMI. Physical measurements included weight (measured using digital scales), body height, and waist circumference. Body weight is stated in kilograms (kg), height expressed in centimeters (cm), and waist circumference in centimeters (cm). BMI was calculated as body weight (kg)/height(m^2). The waist circumference was measured at the midpoint between the lower edge of the last rib and the apex of the ilium in a horizontal plane with units of 0.1 cm. A digital sphygmomanometer was used to take the subject's blood pressure twice while they were seated, with a 5-minute gap between readings. The results were reported as the mean of the two measures. The standardized measurement of blood pressure, waist circumference, and body mass index adheres to the WHO guidelines (WHO) [24], [25].

3.4. Statistical analysis

To describe the characteristics of the study respondents, categorical data was presented as percentages (%) and frequency (n), while continuous variables were given as mean, standard deviation (SD), minimum, and maximum. The independent t-test was used to compare the age, waist circumference, and BMI of the male and female groups for continuous variables. We used SEM with path analysis to assess the relationship between independent variables and potential mediators (path) adjusted for covariates [12]. This multivariable analysis is capable to mitigate the effects of confounders [26] by adjusting for age and gender. Direct effects are shown by an arrow originating from an exogenous variable (exposure) leading and pointing to an endogenous variable (outcome). An indirect effect is not only portrayed as a mediating variable with an arrow pointing to it from an exogenous, but also points to another endogenous [12].

A non-insignificant chi^2 value ($p>0.05$) indicates a good model fit. The preferred value of the goodness of fit (GoF) indices of models in SEM, including normed fit index (NFI), comparative fit index (CFI), Tucker-Lewis index (TLI), is 0.90 or higher [27], [28]. A good fit can be determined with an RMSEA value of <0.05, while a score of up to 0.08 is considered acceptable [29]–[31]. The "Akaike information criterion" (AIC) and "Bayesian (or Schwarz) information criterion" (BIC) are applicable to assess te fit of difference models rather than to judge it in absolute terms. Smaller values suggest a better fit [32]. The results are presented as path coefficient (b) and 95% confidence interval (CIs). All reported two-sided p-values <0.050 were interpreted as statistically significant. All analyses run on Stata 13.

3.5. Ethical Considerations

All study participants gave their written consent after having been informed in detail about the study objectives and procedures of the study prior to participation. Anthropometric measurements were performed as part of a general health examination, and participants were informed of the results. Before enrollment, this study was reviewed and approved by the Research Ethics Committee of the Faculty of Medicine, Universitas Muhammadiyah Surakarta, under number 4333/B.2/KEPK-FKUMS/VI/2022.

3. RESULTS AND DISCUSSION

The sample characteristics of study subjects are summarized in Table 1. Two hundred and ninety-seven elderly were included in this study. Among them, 60.61% (n=180) were female. Participants had an average age of 66 years (Mean=66.69; SD=6.35), BMI of 25 kgBW/m^2 (Mean=25.07; SD=4.01), waist circumference of 92 cm (Mean=92.49; SD=14.26), systolic blood pressure of 140 mmHg (Mean=140.34; SD=23.23), and diastolic blood pressure of 86.70 mmHg (Mean=86.70; SD=12.92).

Table 1. Sample characteristics

Variables	N	Mean	SD	Minimum	Maximum
Age (year)	297	66.69	6.35	60	91
Body weight (kg)	297	59.68	10.69	36	100
Body height (cm)	297	154.21	7.50	135	182
Body mass index (kgBW/m^2)	297	25.07	4.01	16.41	37.44
Waist circumference (cm)	297	92.49	14.26	64	195
Systolic blood pressure (mmHg)	297	140.34	23.23	78	226
Diastolic blood pressure (mmHg)	297	86.70	12.92	57	149

3.1. SEM model

We created two types of path analysis models for our research and included all variables in the two models. Figure 1 standardized SEM model of factors related Figure 1 (a) and (b) show the final SEM model of factor related to SBP and DBP. Tables 2 and 3 show the coefficients and standard errors of the direct and indirect effects of the variables on systolic and diastolic blood pressure, respectively.

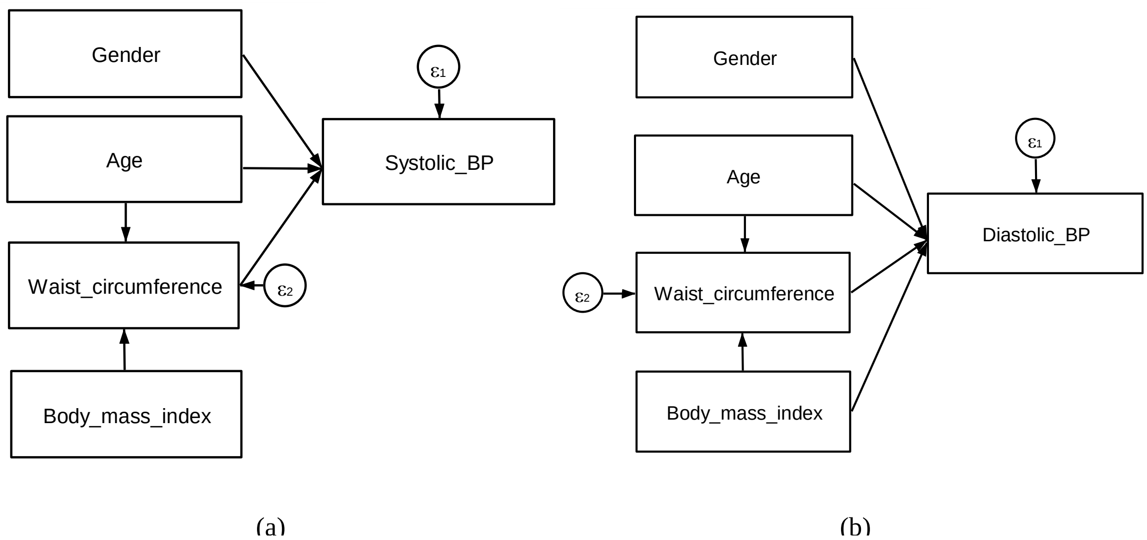

Figure 1. Standardized SEM model of factors related to (a) systolic blood pressure and (b) diastolic blood pressure

Figure 1(a) shows that three pathways that directly influence systolic blood pressure are gender, age, and waist circumference. The remaining variables (body mass index and age) showed variable indirect effects on systolic blood pressure via waist circumference. Figure 1(b) shows that there are four pathways that directly influence diastolic blood pressure, namely gender, age, body mass index, and waist circumference. However, the path model also showed that body mass index and age indirectly influence diastolic blood pressure in older people via waist circumference.

Table 2 reported the results of unstandardized and standardized coefficients of path analysis model using SEM on factors related to systolic blood pressure in elderly. Table 2 showed that systolic blood pressure was directly affected by age, gender, and waist circumference. Systolic blood pressure was indirectly affected by age and body mass index through waist circumference. Male had lower systolic blood pressure than female, but it was statistically non-significant (β=-0.01;95% CI=-0.12 to 0.10; p=0.872). Age (β=0.14; 95% CI=0.03 to 0.25; p=0.011) and waist circumference directly increased systolic blood pressure (β=0.21; 95% CI=0.11 to 0.32; p<0.001).

Table 2. Structural equation model of factors related to systolic blood pressure in elderly (n=297)

Dependent variable		Independent variable	Unstandardized path coef. (b)	95% Confidence Interval (CI)		p	Standardized path coef. (β)	95% Confidence Interval (CI)		p
				Lower limit	Upper limit			Lower limit	Upper limit	
Direct effect										
SBP (mmHg)	←	Gender (male)	-0.43	-5.67	4.81	0.872	-0.01	-0.12	0.10	0.872
	←	Age (year)	0.52	0.12	0.93	0.012	0.14	0.03	0.25	0.011
	←	WC (cm)	0.35	0.17	0.53	<0.001	0.21	0.11	0.32	<0.001
WC	←	BMI (kgBW/m^2)	1.89	1.55	2.23	<0.001	0.53	0.46	0.61	<0.001
	←	Age	0.29	0.08	0.51	0.008	0.13	0.04	0.22	0.007
Indirect effect										
SBP	←	Age	0.10	0.01	0.19	0.029				
	←	BMI	0.66	0.30	1.02	<0.001				
Total effect										
SBP ← WC ← Age			0.62	0.21	1.03	0.003				
SBP ← WC ← BMI			0.66	0.30	1.02	<0.001				

Table 3 reported the results of unstandardized and standardized coefficients of path analysis model using SEM on factors related to diastolic blood pressure in elderly. Table 3 showed that diastolic blood pressure was directly affected by age, gender, body mass index, and waist circumference. Diastolic blood pressure was indirectly affected by age and body mass index through waist circumference. Males had higher diastolic blood pressure (DBP) than females, although the difference was not statistically significant (β=0.07;95% CI=-0.04 to 0.18; p=0.230). Age directly lowered of diastolic blood pressure by 0.02 units (β=-0.02; 95% CI=-0.13 to 0.10; p=0.790). Waist circumference directly raised diastolic blood pressure by 0.04 units, but the effect was statistically non-significant (β=0.04; 95% CI=-0.09 to 0.17; p=0.570). Body mass index directly and significantly increased diastolic blood pressure by 0.12 units (β=0.40; 95% CI=-0.01 to 0.26; p=0.064).

3.2. Goodness of fit indices for SEM models

Table 4 describes the goodness-of-fit statistics of the model. The final model in this study had a good fit. The key finding of recent study was that waist circumference was directly associated with systolic blood pressure. Meanwhile, BMI had direct correlation with diastolic blood pressure. Previous findings showed a consistent and strong association between WC gain and blood pressure increase [11], [20] However, those study did not explain whether this association induced systolic or diastolic blood pressure alone, or both simultaneously. Nevertheless, several studies have provided an explanation of the mechanism of waist circumference and its effect on blood pressure increases. A study by Tran *et al.* [11] found that WC independently associated with blood pressure. Bamaiyi *et al.* study [33] similarly indicated non-significant differences in the independent interactions between waist circumference and blood pressure, as demonstrated by a multiple logistic regression test. In comparison to other research, our study uniquely contributes by providing a detailed understanding of the mechanisms underlying the effects of BMI and WC on both systolic and diastolic blood pressure in the elderly. Compared to other studies, our research makes a distinctive contribution by offering a nuanced understanding of the mechanisms that underscore the impact of BMI and waist circumference on both systolic and diastolic blood pressure in the elderly.

Table 3. Structural equation model of factors related to diastolic blood pressure in elderly (n= 297)

Dependent variable		Independent variable	Unstandardized path coef. (b)	95% CI Lower limit	95% CI Upper limit	p	Standardized path coef. (β)	95% CI Lower limit	95% CI Upper limit	p
Direct effect										
DBP	←	Gender (male)	1.83	-1.17	4.82	0.231	0.07	-0.04	0.18	0.230
	←	Age (year)	-0.03	-0.26	0.20	0.790	-0.02	-0.13	0.10	0.790
	←	BMI (kgBW/m^2)	0.40	-0.03	0.83	0.067	0.12	-0.01	0.26	0.064
	←	WC (cm)	0.04	-0.09	0.16	0.571	0.04	-0.09	0.17	0.570
WC	←	BMI	1.89	1.55	2.23	<0.001	0.53	0.46	0.61	<0.001
	←	Age	0.29	0.08	0.51	0.008	0.13	0.04	0.22	0.007
Indirect effect										
DBP	←	BMI	0.07	-0.16	0.30	0.571				
	←	Age	0.01	-0.03	0.05	0.579				
Total effect										
DBP	←	BMI	0.47	0.10	0.83	0.012				
	←	Age	-0.02	-0.25	0.21	0.855				

Table 4. The results of goodness-of-fit statistics for SEM of factors related to systolic and diastolic blood pressure in elderly

Goodness of fit	SEM model of factors related to systolic blood pressure	SEM model of factors related to diastolic blood pressure	Accepted range
Chi^2	0.20	0.18	N/A
P	0.906	0.669	>0.050
Root Mean Square Approximation (RMSEA)	<0.001	<0.001	<0.080
Akaike's information criterion (AIC)	9,040.77	8,708.923	N/A
Bayesian information criterion (BIC)	9,074.01	8,745.86	N/A
Comparative fit index (CFI)	1.00	1.00	≥0.90
Tucker-Lewis index (TLI)	1.05	1.06	≥0.95
Standardized root mean squared residual (SRMR)	0.005	0.005	0
Coefficient of determination (CD)	0.31	0.30	1
Log likelihood	-4,511.38	-4,344.46	N/A

High levels of waist circumference and intra-abdominal adipose tissue (IAAT) increase the risk of cardiometabolic illness [11], [34]. Ross *et al.* [35] declared that numerous studies demonstrate a significant association between waist circumference, morbidity, and risk of death in epidemiological cohorts. Notably, individuals with normal BMI (20.0-24.9 kg/m^2) had a higher risk of all-cause death when their waist circumference exceeded the criteria [36]. The Atherosclerosis Risk in Communities research, which followed 14,699 black people for nine years, indicated that waist circumference increased the risk of coronary heart disease (RR=1.37; 95% CI=1.21 to 1.56) [37]. A study by Sun *et al.* [10] highlighted the relationship between waist circumference and (pre) hypertension risk in a representative United States population. This study found that a favorable association between waist circumference and pre-hypertension in individuals over 45 years old (OR=1.23; 95%CI=1.15 to 1.33; p<0.001).

Central or abdominal obesity disrupts both the endocrine and immune systems, posing an elevated risk for insulin resistance, diabetes, hypertension, and cardiovascular diseases [38]–[40]. According to Kotsis *et al.* [41], weight-induced blood pressure increase occurs due to sympathetic nervous system activation. The buildup of abdominal visceral adipose tissue was found to be one of the pathways between WC and high blood pressure. Increased WC may lead to blood pressure changes independent of BMI increases [20]. Other studies have also proposed mechanisms to elucidate why assessments of central obesity are better than BMI in predicting cardiometabolic risk [42], [43]. The accumulation of excess fat in adipose tissue and other locations leads to compromised adipogenesis, dysregulation of adipokines, elevated proatherogenic inflammatory factors, increased levels of circulating free fatty acids, oxidative stress, and lipotoxicity. This sequence of events contributes to the development of atherosclerosis and dysfunction in endothelial cells, ultimately leading to cardiometabolic diseases. These conditions influence risk of hypertension [44], [45].

Cheng *et al.* [46] discovered that abdominal fat may contribute to hypertension development through nonmetabolic processes such as activation of the sympathetic nerve system (SNS) or the reninangiotensin-aldosterone system (RAAS) [47], [48]. They observed a positive and significant association between waist circumference and prevalence of hypertension in the normal-weight and overweight individuals with normal cardiometabolic profiles (adjusted OR=1.24; 95% CI=1.09 to 1.40). In our both SEM models, body mass index is reported positively affected waist circumference. To our knowledge, BMI tends to rise during the latter part of adult life, and this is associated with increases in both fat mass and muscle mass. Accumulating studies suggested that there is a strong linear correlation between BMI and waist circumference values [49]–[51]. At later ages, although muscle mass decreases, fat mass frequently increases [52]. Cartwright *et al.* [53] noted that the redistribution of fat from subcutaneous to visceral depots was observed. They also presented that age-related decreases in adipose depot sizes were accompanied by fat deposition outside adipose tissue and loss of lean body mass. As a result, the proportion of body mass stored as fat may remain constant. However, fat accumulates in bone marrow, muscle, the liver, and other places, potentially contributing to an age-related tissue dysfunction. This accumulation could be attributed to pre-adipocyte's diminished ability to mature into fully functional adipocytes as they age. Therefore, this research highlights the importance of considering waist circumference in anthropometric assessments as an additional tool for screening hypertension in the elderly.

Our study found that age was directly increased SBP but there was no significant effect on DBP. The most common type of hypertension among those over the age of 50 is an increase in systolic but not diastolic pressure [54]. According to Pinto *et al.* [54], the arterial vasculature undergoes various structural and functional changes as people age. The arteries stiffen over time, shattering the elastic lamellae and revealing intimal hyperplasia in the aortic wall. Stiffened arteries have lower capacitance and restricted rebound, making it difficult to tolerate volume variations throughout the cardiac cycle. SBP and DBP both rise with age, however around 60 years, central arterial stiffness takes over, causing SBP to rise while DBP decreases.

Blood pressure escalation is an unavoidable consequence of aging. The increase in systolic blood pressure with age is commonly influenced by structural changes in the arteries and especially with large artery stiffness (LAS). LAS is the result of arteriosclerotic structural changes and calcification. While, the increase in DBP up to the age of 50 is mostly due to increased peripheral vascular resistance (PVR) in small vessels [54]. Chrysant and Chrysant [55] explained that blood pressure changes with age, shifting from mostly DBP in the young to predominantly SBP in the elderly. This shift is caused by the replacement of elastic fibers with collagen fibers in the body's major arteries, leading in the stiffening of these vessels, loss of compliance, and elastic recoil.

This SEM, employing path analysis, also reported that gender showed no significant correlation with SBP or DBP. The roles of sex and gender in blood pressure have not been systematically clarified, and earlier research has indicated that these mechanisms are more difficult to grasp than the presence or absence of sex hormones or the sex chromosomal complement. Both sex steroids and chromosomes most likely influence the mechanisms of blood pressure at various levels [56], [57]. However, in a longitudinal study, it was observed that females reported a significantly sharper incline in blood pressure starting from the third decade of life. This implies underlying distinctions in the factors contributing to elevated blood pressure between genders and advocates for a convergence in hypertension prevalence later in life. The specific causes of these differences, whether rooted in biological sex (such as sex hormones, chromosomal complement, pregnancy, or epigenetic changes) or sociocultural gender factors (such as psychosocial traits like relative economic deprivation), remain uncertain [58]–[60]

4. CONCLUSION

In conclusion, BMI and waist circumference are stronger predictor for elevated blood pressure. Waist circumference is directly increased SBP. Meanwhile, body mass index is directly increased DBP in elderly. This finding highlighting the need to combine measures in obesity-related risk assessment to identify hypertension in elderly. This study provides implications that waist circumference measurements are simple, cost-effective, and effective in identifying hypertension risk factors in the elderly, it is imperative to include waist circumference assessments as part of routine health checks for elderly individuals, alongside traditional BMI measurements.

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