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Relationship between Body Mass Index and Central Fat Accumulation in Adolescents in Surakarta

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ABSTRACT

Introduction: Obesity diagnosis can be determined through the calculation of body mass index (BMI). However, BMI can only serve as a screening tool for obesity and can not measure fat distribution while waist-to-height ratio (WHtR) is considered better for determining central fat distribution in adolescents. The aim of this study is to examine the relationship between body mass index and central fat accumulation in adolescents in Surakarta.
Methods: The method used was cross-sectional, involving measurements of weight, height, and waist circumference. The subjects of this study are tenth-grade adolescents from three high schools in Surakarta, with a total of 83 subjects. The variables in this study are the z-score of BMI-for-age (ratio) with waist circumference (ratio) and waist-to-height ratio (WHtR). Statistical analysis used the Spearman test.
Results: The Spearman correlation analysis demonstrated a significant association between body mass index (BMI) and waist circumference ($p < 0{,}001$; $r = 0{,}777$), as well as BMI and WHtR ($p < 0{,}001$; $r = 0{,}785$).
Conclusion: There is a strong positive relationship between body mass index and central fat accumulation among high school students in Surakarta.

Keywords: adolescents; BMI; central fat; waist circumference; WHtR

INTRODUCTION

Obesity is a condition marked by an excessive buildup of body fat that can harm health, leading to a higher risk of diabetes, heart disease, reproductive problems, and bone-related issues. It can also elevate the likelihood of developing cancer and reduce overall quality of life. In 2022, approximately one in eight people globally were living with obesity, including over 160 million children and adolescents[1]. The global prevalence of obesity has risen more than threefold between 1975 and 2022. By 2024, an estimated 159 million individuals aged 5 to 19 years were classified as obese[2].

Body mass index (BMI) is a tool used to evaluate an individual's potential health risks in the future. Although it reflects the relative amount of body fat, it does not directly measure body fat percentage. Body mass index is determined by dividing an individual's body weight in kilograms by the square of their height measured in meters. The resulting figure is then classified to determine whether the person is underweight, normal weight, overweight, or obese. For adolescents, BMI assessment must be adjusted using a z-score based on age and sex to accurately determine nutritional status[3].

An elevated body mass index is directly correlated with increased body weight. Weight regulation is influenced by long-term energy balance, where an excess of energy intake combined with inadequate energy expenditure leads to energy surplus. This surplus energy is stored in the body as fat and glycogen. On the other hand, prolonged energy deficiency can result in underweight conditions. While weight control is fundamentally tied to energy balance, the process is complex, as it is affected by genetic, physiological, and environmental factors[4].

Body mass index is currently used as a screening tool for nutritional status. According to the National Academies of Sciences, Engineering, and Medicine, BMI is associated with body fat percentage but does not directly measure it. Furthermore, BMI is not consistently related to disease risk, particularly those associated with body fat distribution[5]. Therefore, BMI should not be used as a sole clinical assessment tool.

Body fat can be stored in two main forms: subcutaneous and visceral adipose tissue. Subcutaneous fat is located just beneath the skin, while visceral fat accumulates inside the abdominal cavity around internal organs. An increase in visceral fat results in central obesity and is strongly associated with a higher risk of metabolic syndrome and cardiovascular diseases. Fat accumulation is also influenced by adipocyte differentiation processes—hypertrophy and hyperplasia. Hypertrophy causes fat cells to enlarge, contributing to visceral fat buildup, whereas hyperplasia increases the number of fat cells, leading to subcutaneous fat accumulation and affecting overall fat distribution[6].

Waist circumference can be an alternative measure for assessing fat distribution, particularly central fat. A study showed that bioelectrical impedance analysis (BIA) and quantitative computed tomography (QCT) are more accurate than waist circumference in measuring visceral fat[7]. However, waist-to-height ratio (WHtR) is a better predictor of visceral fat compared to waist circumference (WC) alone[8]. The waist-to-height ratio is a specific and cost-effective tool for measuring body adiposity[9]. This measurement is obtained by dividing waist circumference (in centimeters) by height (in centimeters). The objective of this study is to investigate the association between body mass index (BMI) and visceral fat accumulation among adolescents in Surakarta.

Evidence on the BMI and waist circumference supports recommendations to measure both indicators instead of relying on BMI alone, where it does not provide information about central obesity. A high body mass index with a high waist circumference indicates central obesity. These findings help set targeted interventions for adolescents with central obesity, improving strategies to prevent adult cardiovascular and metabolic disease[10]. This occurs because adolescence is a period where there is increased nutritional needs, hormonal changes, and behavioral transitions that can shape long-term cardiometabolic disease risk[11].

METHOD

This study was conducted under the Research Group (RG) on Nutrition, Metabolism, and Medicine (TRIMED) at the Faculty of Medicine, Universitas Sebelas Maret, using an observational research design with a cross-sectional approach. A purposive sampling method was utilized, with participant criteria established based on the overarching umbrella research framework. Adolescents selected as subjects because this life stage is a crucial period of rapid growth where adverse exposures can increase the risk of cardiometabolic disease[11]. The criteria in this study included adolescents in grade X and not taking any medicines with side effects of increasing body weight. The number of samples was calculated using the Lemeshow proportion formula with a total of 83 samples. Data were collected through measurements of height, body weight, and waist circumference. The data was processed with the help of WHO Anthroplus, Ms.Excel, and SPSS applications.

The variables in this study were BMI-for-age z-score, waist circumference, and waist circumference to height ratio (WHtR). The normality of the BMI-for-age z-score data was assessed using the Kolmogorov–Smirnov test. Since the data were not normally distributed, the Spearman correlation test was applied to analyze the relationships among variables. The test results were said to be significant if the p-value <0,05 with the strength of the relationship is said to be strong if the r-value is close to 1. This study was conducted in July-September of 2024 in 3 high schools in Surakarta with ethical approval number 1.768/VII/HREC/2024 from Dr. Moewardi Hospital Surakarta.

RESULT

Based on the results of univariate analysis, the subjects consisted of 65 females and 19 males.

Table 1. Characteristics of Research Subjects

Characteristics	N	Mean±SD
Waist circumference (WC)	83	82,383±11,610
Males	18	87,572±11,242
Females	65	80,946±11,378
WHtR (*Waist to height ratio*)	83	0,528±0,071
Males	18	0,527±0,069
Females	65	0,528±0,072

Table 2. Analysis of the Relationship of BMI with WC and WHtR

Variable	BMI-for-age z-score	
	r-value	p-value
Waist circumference (WC)	0,777	<0,001
Males	0,866	<0,001
Females	0,740	<0,001
WHtR	0,785	<0,001
Males	0,938	<0,001
Females	0,738	<0,001

According to Table 2, the analysis revealed a significant association between body mass index (BMI) with waist circumference, and waist-to-height ratio (WHtR). Increases in BMI corresponded with increases in both waist circumference and WHtR, and vice versa, demonstrating a strong Spearman correlation coefficient (r = 0,777 and 0,785) and high significance (p <0,001). This shows a positive correlation direction between body mass index and central fat accumulation. The strong positive correlation indicates that an increased body mass index also shows an increase in central fat accumulation significantly. In addition, the analysis results were obtained in the form of Spearman coefficient values in females of 0,740 and 0,738 while in males of 0,866 and 0,938. This shows that the relationship between body mass index and central fat accumulation in males is higher than in females, indicating that BMI is more closely related to central adiposity in males.

DISCUSSION

Waist circumference (WC) and WHtR are methods of identifying excess adiposity, especially in the central part of adolescents. According to Pinho et al., waist circumference can predict visceral fat adiposity better than subcutaneous fat adiposity[12]. In line with research conducted by Limbong and Malinti that high levels of fat in the body have a linear effect on body mass index[13]. Body mass index, waist circumference (WC) and waist-to-height ratio (WHtR) are all adiposity indicators, but WC and WHtR is more directly related to visceral fat and metabolic risk than total body alone[14].

An elevated body weight corresponds to an increased body mass index. In metabolically healthy obese individuals, adipose tissue expansion occurs through the recruitment of adipocyte precursor cells, resulting in adipose hyperplasia. However, when this adaptive mechanism reaches its limit, surplus caloric energy is redirected toward fat accumulation within visceral organs[15]. According to Horwitz and

Birk, when adipocyte hyperplasia reaches its limit, the body will deposit fat in the form of hypertrophy so that it is transferred to the area of visceral organs[6].

Persistent energy surplus promotes hypertrophy of abdominal adipocytes and expansion of visceral fat depots, particularly once the storage capacity of subcutaneous adipose tissue is surpassed[16]. Hypertrophic visceral adipocytes exhibit hypoxia and cellular stress, which in turn trigger adipocyte apoptosis or necrosis, fibrotic remodeling of the depot, and increased infiltration of pro-inflammatory immune cells into the adipose tissue[17].

Body mass is commonly partitioned into two primary components, fat mass and lean mass. Fat mass represents energy storage and lean mass comprises skeletal muscle, visceral organs, and bone tissue. Elevated one or more of those components lead to an increase body weight[18]. A sustained positive energy balance, in which habitual energy intake exceeds total energy expenditure, results in progressive increase in body weight. Evidence on overfeeding trials indicates that approximately 60-70% of the accrued body mass is adipose tissue, particularly when the excess energy is derived from high-carbohydrate or high-fat diets with relatively low protein content[19,20].

A BMI-for-age z-score is a standardized index that quantifies an individual child's or adolescent's BMI relative to a reference population of the same age and sex. In adolescents, BMI exhibits physiological variation across childhood and puberty. Therefore, its interpretation should be based on age specific reference charts rather than adult threshold values[21]. Across childhood, BMI typically decreases to a low point, then increases again at adiposity rebound and throughout puberty. The timing of puberty also shapes BMI patterns, as children with higher BMI in mid-childhood are more likely to experience earlier pubertal onset, and earlier puberty is frequently associated with higher BMI values during adolescence[22].

During puberty, males experience a disproportionate gain in lean tissue, whereas females accrue both fat mass and lean mass, with a relatively greater increase in fat stores. Consequently, a rise in BMI among males often reflects expanded muscle mass in addition to some fat, while an equivalent BMI level in females are more indicative of increased adiposity[23]. In this study, the correlation between BMI and central fat accumulation was higher in males than in females. The correlation between them shows that males appear to have a stronger tendency for higher BMI to be expressed as central fat. This finding is consistent with the evidence that males tend to exhibit greater fat deposition in the abdominal region, whereas females show relatively higher fat accumulation in the gluteofemoral area[24].

Fat distribution in males is dominant in the abdominal area and females in the gluteofemoral area[25]. Males have twice the tendency to deposit visceral fat than females. This is due to endocrine variations that include estrogen, androgen, growth hormone (GH), and insulin-like growth factor (IGF-1). Therefore, males have a higher risk of developing metabolic syndrome than females.

In a study conducted by Kurylowicz, it was stated that females have higher adiposity than males[26]. However, adipose accumulation in this context primarily occurs in subcutaneous regions, which is associated with a reduced risk of obesity-related comorbidities. This distribution pattern is influenced by elevated estrogen levels in females. Moreover, subcutaneous adipose tissue in metabolically healthy females contains a greater number of preadipocyte cells that promote hyperplasia compared to males. Conversely, low androgen concentrations are linked to increased visceral fat deposition. Males with lower visceral fat levels typically exhibit higher testosterone concentrations, whereas postmenopausal females tend to develop central obesity as a result of declining estrogen levels and elevated testosterone levels[27].

Growth hormone (GH) plays a pivotal role in adipocyte maturation, growth, and differentiation through the regulation of insulin-like growth factor 1 (IGF-1) synthesis. Insulin-like growth factor 1, in conjunction with insulin, promotes preadipocyte proliferation and adipocyte differentiation. In individuals, reduced GH levels are associated with increased total body fat, a higher proportion of visceral adiposity, and decreased muscle mass. Furthermore, diminished GH concentrations lead to lower IGF-1 levels, given GH's regulatory function in IGF-1 production. Reduced IGF-1 levels, in turn, are linked to an elevated risk of metabolic syndrome[28].

A strong positive correlation between BMI with WC and WHtR shows that BMI can be used as an initial simpe screening tool, but adding WC or WhtR helps detect central obesity, including for adolescents with normal BMI[29]. Higher WC and WHtR are associated with high blood pressure and cardiometabolic abnormalities in adolescents[30]. This finding supports to including central obesity measurements as a school or clinic screening programs for adolescents.

The observed correlation between BMI with central fat accumulation does not imply a causal relationship, although these parameters tend to increase concurrently. This study has several limitations, including its cross-sectional design, restriction to a single geographic region, unequal sex distribution, and the lack of detailed control for pubertal stage, dietary patters, and measurement variability. Suggestions for future research can use tools such as BIA and QCT that are more accurate to predict fat distribution. Future research should employ longitudinal designs to determine whether increases in BMI can predict subsequent central obesity, the development of metabolic syndrome, and investigate the influence of pubertal maturation on central fat accumulation in adolescents.

CONCLUSION

A strong positive correlation was observed between body mass index (BMI) and central fat accumulation among high school adolescents in Surakarta. Furthermore, higher correlation between BMI with waist circumference and waist-to-height ratio in males than females shows that males have a stronger tendency for higher BMI to be expressed as abdominal fat.

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CONFLICT OF INTEREST

There is no conflict of interest in this study.

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