



## ARTICLE RESEARCH

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## BMI-for-Age Z-Score, Waist-to-Height Ratio, and Physical Activity Across High School Grades in West Aceh

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## ABSTRACT

Adolescent nutritional status and physical activity may vary across school grades, yet evidence integrating BMI-for-age z-score (BAZ), waist-to-height ratio (WHtR), and physical activity among Indonesian senior high school students remains limited. This study aimed to compare BAZ, WHtR, and physical activity across Grades 10, 11, and 12 at SMA Negeri 3 Meulaboh, West Aceh, Indonesia. An analytical cross-sectional study included all 158 students in the defined population through complete enumeration. Physical activity was assessed using an adapted IPAQ-SF-derived seven-day recall and expressed as a study-specific score in MET-minutes/week. BAZ was calculated using WHO AnthroPlus according to the WHO 2007 Growth Reference, and WHtR was derived from waist circumference and height. Physical activity and WHtR were compared using Kruskal–Wallis tests with Bonferroni-adjusted Mann–Whitney U comparisons, while BAZ was analyzed using one-way ANOVA with Tukey HSD. Median physical activity scores were 2965, 1647.5, and 1127.5 MET-minutes/week in Grades 10, 11, and 12, respectively ( $H(2)=54.595$ ,  $p<0.001$ ,  $\epsilon^2=0.339$ ), with all pairwise comparisons significant after correction. Median WHtR values were 0.528, 0.520, and 0.460, respectively ( $H(2)=44.445$ ,  $p<0.001$ ,  $\epsilon^2=0.274$ ); Grade 12 differed from Grades 10 and 11, whereas Grades 10 and 11 did not differ after correction. Mean BAZ values were  $-0.136$ ,  $-0.177$ , and  $-0.669$ , respectively ( $F(2,155)=3.163$ ,  $p=0.045$ ,  $\eta^2=0.039$ ), but no Tukey-adjusted pairwise comparison was significant. Physical activity showed the clearest between-grade pattern, WHtR differences were concentrated in Grade 12, and evidence for BAZ differences was weaker. These findings represent cross-sectional between-grade differences and should not be interpreted as developmental or causal effects of advancing school grade.

Keywords: Adolescent; BMI-for-age z-score; waist-to-height ratio; physical activity; grade level

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## INTRODUCTION

Adolescence is a period of substantial physical and behavioral change in which nutritional status and physical activity represent important public health concerns. Globally, more than 390 million children and adolescents aged 5–19 years were living with overweight in 2022, including approximately 160 million living with obesity <sup>1</sup>. Insufficient physical activity is also widespread; a pooled analysis of 298 population-based surveys involving 1.6 million school-going adolescents from 146 countries, territories, and areas estimated that 81.0% of those aged 11–17 years were insufficiently physically active <sup>2</sup>. Evidence from Indonesia also illustrates the double burden of malnutrition, in which undernutrition and excess weight coexist within adolescent populations. A study of 2,160 Indonesian adolescents aged 12–18 years in two districts documented substantial levels of stunting and thinness alongside overweight, illustrating nutritional problems at both ends of the spectrum <sup>3</sup>. Together, these nutritional and physical-activity concerns highlight the need for adolescent health assessments that consider both anthropometric status and movement-related behavior.

Anthropometric assessment during adolescence requires indicators that account for ongoing growth while also capturing differences in body-fat distribution. The BMI-for-age z-score (BAZ), based on the WHO 2007 Growth Reference for individuals aged 5–19 years, expresses BMI relative to age- and sex-specific reference values and is widely used to assess weight status during adolescence <sup>4</sup>. However, because BAZ is based on BMI calculated from weight and height, it does not directly characterize abdominal fat distribution. Waist-to-height ratio (WHtR), which relates waist circumference to height, provides complementary information on central adiposity. Evidence from a prospective adolescent cohort showed that BMI z-score and WHtR were strongly related and had broadly similar associations with cardiometabolic risk, supporting their use as complementary rather than competing indicators <sup>5</sup>. More recent pooled international evidence likewise found that WHtR, waist circumference, and BMI z-score had comparable ability to identify cardiometabolic risk among children and adolescents <sup>6</sup>. Interpretation of WHtR nevertheless requires population-sensitive thresholds, because systematic reviews and multinational evidence indicate that a single cutoff such as 0.50 may not be optimal across all pediatric populations <sup>7,8</sup>. Thus, considering BAZ together with WHtR provides a broader anthropometric perspective by combining age- and sex-standardized BMI assessment with an indicator of central adiposity.

Grade-level comparisons may be informative during adolescence because students in successive school grades differ in age and educational context while also undergoing changes in activity patterns and body composition. Longitudinal evidence generally indicates that physical activity decreases across childhood and adolescence, although the timing and magnitude of decline are not uniform across age or sex. A systematic review and meta-analysis of 52 longitudinal studies using accelerometer-measured moderate-to-vigorous physical activity reported overall annual declines in both boys and girls, while also showing age- and sex-related variation in these trajectories <sup>9</sup>. Anthropometric development is similarly heterogeneous. Longitudinal data from 27,394 Indonesian children and adolescents aged 6–18

years identified four distinct BMI-z trajectories and significant differences in trajectory patterns by sex, indicating that BMI-for-age does not follow a single developmental course during childhood and adolescence<sup>10</sup>. WHtR also shows age- and population-dependent patterns rather than a universally linear trajectory, with pediatric studies reporting variations across age, sex, and population groups<sup>7,11</sup>. These findings support examining BAZ, WHtR, and physical activity across school grades while avoiding the assumption that differences between grades represent uniform developmental change or causal effects of advancing grade level.

Evidence from Aceh and West Aceh has addressed several aspects of adolescent nutritional status, but the available literature remains fragmented in relation to the combined assessment of BAZ, WHtR, and physical activity across senior-high-school grade levels. In West Aceh, a cross-sectional study of 312 school-going adolescents examined nutritional knowledge, diet quality, BAZ, and percentage body fat and identified differences between rural and urban students, but WHtR and physical activity were not incorporated as primary comparative indicators across grades<sup>12</sup>. Elsewhere in Aceh, a study among students at an Aceh sports high school evaluated central obesity and metabolic-syndrome risk using waist circumference and cardiometabolic measurements, providing local evidence on abdominal adiposity but not on WHtR, BAZ, and physical activity as a combined grade-level framework<sup>13</sup>. These studies indicate that adolescent anthropometric and behavioral health has received attention in the region, while comparative evidence integrating BAZ, WHtR, and physical activity across Grades 10, 11, and 12 remains limited.

Given the limited local evidence integrating these indicators across senior high school grades, examining BAZ, WHtR, and physical activity together may provide a more comprehensive description of adolescent anthropometric and activity patterns in the school setting. Accordingly, this study aimed to compare BMI-for-age z-score, waist-to-height ratio, and physical activity scores across Grades 10, 11, and 12 among students at SMA Negeri 3 Meulaboh, West Aceh Regency, Aceh Province, Indonesia.

## METHOD

This analytical cross-sectional study compared BMI-for-age Z-score (BAZ), waist-to-height ratio (WHtR), and physical activity across Grades 10, 11, and 12. The study was conducted at SMA Negeri 3 Meulaboh, West Aceh Regency, Aceh Province, Indonesia, from 8 to 20 December 2025. The source population comprised 158 students: 58 in Grade 10, 52 in Grade 11, and 48 in Grade 12. All students in the defined population participated in data collection and were included in the final analysis. Those who were absent during the initial data-collection session were assessed when they returned to school within the study period. Eligibility criteria included enrollment in Grades 10–12, age 16–18 years, ability to complete the questionnaire and anthropometric assessment, and voluntary agreement to participate. No participants withdrew from the study, and complete data were available for the primary study variables.

Physical activity was assessed using an Indonesian-language questionnaire based on the International Physical Activity Questionnaire–Short Form (IPAQ-SF), with a seven-day recall period.

The wording and activity examples were simplified for high-school students while maintaining the main activity domains of the IPAQ-SF. Before the main study, the questionnaire was pilot-tested among 20 students at SMA Negeri 1 Meureubo, who were not included in the study sample, to assess clarity, comprehension, and feasibility of administration. Students reported the number of days and average minutes per day spent in vigorous, moderate, and walking/light-intensity activities during the previous seven days. Activity scores were calculated as days  $\times$  minutes  $\times$  MET value, using 8.0 MET for vigorous activity, 4.0 MET for moderate activity, and 3.3 MET for walking/light activity. The three components were summed and expressed as MET-minutes/week. Because the walking/light item included light activities other than walking, the resulting total was treated as a study-specific IPAQ-derived physical activity score rather than a standard IPAQ-SF score. Sitting time was recorded separately and was not included in the total score. Total MET-minutes/week was analyzed as a continuous variable.

Anthropometric assessment included body weight, standing height, and waist circumference. Body weight was measured once using an OMRON HBF-222T Body Composition Monitor and recorded to the nearest 0.1 kg. Students removed their footwear but remained in their regular school uniform. Standing height was measured once without footwear using a seca 213 portable stadiometer and recorded to the nearest 0.1 cm while students stood upright. BMI was calculated as weight in kilograms divided by height in meters squared ( $\text{kg}/\text{m}^2$ ). BAZ was calculated using WHO AnthroPlus according to the WHO 2007 Growth Reference for children and adolescents aged 5–19 years<sup>4</sup>. Because the exact assessment date for each student was unavailable, 14 December 2025, the midpoint of the data-collection period, was assigned as a common reference date. BAZ was calculated using each student's BMI, sex, recorded date of birth, and the assigned reference date. To assess the effect of uncertainty in the assessment date, BAZ was recalculated using 8 and 20 December 2025, representing the earliest and latest possible assessment dates. Waist circumference was measured once to the nearest 0.1 cm using a non-elastic measuring tape at the midpoint between the lower margin of the last palpable rib and the top of the iliac crest. The tape was kept horizontal and snug without compressing the underlying tissue, and the measurement was read at the end of a normal expiration. For privacy and cultural considerations, waist circumference was measured over the students' regular school uniform after jackets and other outer garments had been removed. WHtR was calculated by dividing waist circumference by height using the same units. Before data collection, student assistants received brief practical instruction on the measurement procedures. Female students were measured by female assistants and male students by male assistants to maintain privacy and participant comfort. BAZ and WHtR were analyzed as continuous variables.

Data were analyzed using IBM SPSS Statistics version 26.0. Categorical variables were summarized as frequencies and percentages, while continuous variables were described according to their distributions. Normality was assessed using the Shapiro–Wilk test. Physical activity scores and WHtR showed non-normal distributions and were therefore summarized as medians and 25th–75th percentiles (P25–P75) and compared across Grades 10, 11, and 12 using the Kruskal–Wallis test. When

an overall difference was detected, pairwise comparisons were performed using the Mann–Whitney U test, with a Bonferroni-corrected significance threshold of  $p < 0.017$  for the three pairwise comparisons. BAZ showed an approximately normal distribution across grade groups, and homogeneity of variance was assessed using Levene’s test. BAZ was therefore compared using one-way analysis of variance (ANOVA), followed by Tukey’s honestly significant difference (HSD) test when the overall ANOVA was significant. Effect sizes were reported as epsilon-squared ( $\epsilon^2$ ) for Kruskal–Wallis tests, rank-biserial correlation for pairwise Mann–Whitney U comparisons, and eta-squared ( $\eta^2$ ) for ANOVA. All statistical tests were two-sided, and statistical significance for the overall analyses was set at  $p < 0.05$ .

The study protocol received ethical approval from the Health Research Ethics Committee of Poltekkes Kemenkes Aceh (No. DP.04.03/12.7/413/2025). Before participation, students received information about the study objectives and procedures, the voluntary nature of participation, confidentiality, and their right to discontinue participation. They were given an opportunity to ask questions and provided written agreement to participate before completing the questionnaire and anthropometric measurements. Participant information was kept confidential, and the findings were reported in aggregate form.

## RESULTS

### Participant Characteristics

The final analysis included 158 students, comprising 58 students in Grade 10, 52 in Grade 11, and 48 in Grade 12. Participant characteristics according to grade level are presented in Table 1.

Table 1. Participant Characteristics by Grade Level

| Grade Level | n   | Age, Mean $\pm$ SD (years) | Male, n (%) | Female, n (%) |
|-------------|-----|----------------------------|-------------|---------------|
| Grade 10    | 58  | 16.47 $\pm$ 0.26           | 32 (55.2)   | 26 (44.8)     |
| Grade 11    | 52  | 17.53 $\pm$ 0.24           | 25 (48.1)   | 27 (51.9)     |
| Grade 12    | 48  | 18.46 $\pm$ 0.23           | 24 (50.0)   | 24 (50.0)     |
| Total       | 158 | 17.42 $\pm$ 0.85           | 81 (51.3)   | 77 (48.7)     |

*Age was calculated from each student's recorded date of birth using 14 December 2025 as the common reference date. Percentages for sex are calculated within each grade level.*

The overall sample consisted of 81 male students (51.3%) and 77 female students (48.7%). Males accounted for 55.2% of Grade 10, 48.1% of Grade 11, and 50.0% of Grade 12 students. Mean age was 16.47 years in Grade 10, 17.53 years in Grade 11, and 18.46 years in Grade 12.

### Physical Activity Across Grade Levels

Physical activity scores differed across Grade 10, Grade 11, and Grade 12. Table 2 presents the distribution of physical activity scores and the results of the between-grade comparisons. Median physical activity was highest in Grade 10 (2965.0 MET-minutes/week), lower in Grade 11 (1647.5

MET-minutes/week), and lowest in Grade 12 (1127.5 MET-minutes/week). The overall difference across grade levels was statistically significant ( $H(2) = 54.595$ ,  $p < 0.001$ ,  $\varepsilon^2 = 0.339$ ).

Table 2. Physical Activity Across Grade Levels

| Grade Level | n  | Physical Activity, Median (P25–P75), MET-min/week | Min–Max  |
|-------------|----|---------------------------------------------------|----------|
| Grade 10    | 58 | 2965.0 (2630.0–3290.0)                            | 880–3920 |
| Grade 11    | 52 | 1647.5 (1375.0–2166.3)                            | 880–2525 |
| Grade 12    | 48 | 1127.5 (945.0–1580.0)                             | 880–1755 |

*Physical activity was expressed as the study-specific IPAQ-derived score in MET-minutes/week. Kruskal–Wallis  $H(2) = 54.595$ ,  $p < 0.001$ ,  $\varepsilon^2 = 0.339$ . Pairwise comparisons were performed using Mann–Whitney U tests with a Bonferroni-corrected significance threshold of  $p < 0.017$ .*

Pairwise Mann–Whitney U tests showed significant differences between Grade 10 and Grade 11 ( $U = 563.0$ ,  $p < 0.001$ ,  $r_{\text{fb}} = 0.627$ ), Grade 10 and Grade 12 ( $U = 452.5$ ,  $p < 0.001$ ,  $r_{\text{fb}} = 0.675$ ), and Grade 11 and Grade 12 ( $U = 621.5$ ,  $p < 0.001$ ,  $r_{\text{fb}} = 0.502$ ). All three pairwise comparisons remained significant at the Bonferroni-corrected threshold of  $p < 0.017$ .

### Waist-to-Height Ratio Across Grade Levels

Waist-to-height ratio (WHtR) differed across grade levels. Table 3 presents the distribution of WHtR and the results of the between-grade comparisons.

Table 3. Waist-to-Height Ratio Across Grade Levels

| Grade Level | n  | WHtR, Median (P25–P75) | Min–Max   |
|-------------|----|------------------------|-----------|
| Grade 10    | 58 | 0.528 (0.515–0.547)    | 0.49–0.62 |
| Grade 11    | 52 | 0.520 (0.461–0.546)    | 0.40–0.57 |
| Grade 12    | 48 | 0.460 (0.440–0.485)    | 0.40–0.62 |

*Kruskal–Wallis  $H(2) = 44.445$ ,  $p < 0.001$ ,  $\varepsilon^2 = 0.274$ . Pairwise comparisons were performed using Mann–Whitney U tests with a Bonferroni-corrected significance threshold of  $p < 0.017$ .*

Median WHtR was 0.528 in Grade 10, 0.520 in Grade 11, and 0.460 in Grade 12. The overall difference across grade levels was statistically significant ( $H(2) = 44.445$ ,  $p < 0.001$ ,  $\varepsilon^2 = 0.274$ ). Pairwise Mann–Whitney U tests showed significant differences between Grade 10 and Grade 12 ( $U = 326.0$ ,  $p < 0.001$ ,  $r_{\text{fb}} = 0.766$ ) and between Grade 11 and Grade 12 ( $U = 665.5$ ,  $p < 0.001$ ,  $r_{\text{fb}} = 0.467$ ). The difference between Grade 10 and Grade 11 did not meet the Bonferroni-corrected significance threshold ( $U = 1142.0$ ,  $p = 0.028$ ,  $r_{\text{fb}} = 0.243$ ).

### BMI-for-Age Z-Score Across Grade Levels

BMI-for-age z-score (BAZ) was compared across Grade 10, Grade 11, and Grade 12. Table 4 presents the mean BAZ and 95% confidence interval for each grade level. Mean BAZ was  $-0.136$  in Grade 10,  $-0.177$  in Grade 11, and  $-0.669$  in Grade 12. The overall difference in BAZ across grade

levels was statistically significant ( $F(2,155)=3.163$ ,  $p=0.045$ ), with a small effect size ( $\eta^2=0.039$ , 95% CI [0.000, 0.107]).

Table 4. BMI-for-Age Z-Score Across Grade Levels

| Grade Level | n  | BAZ, Mean $\pm$ SD | 95% CI           |
|-------------|----|--------------------|------------------|
| Grade 10    | 58 | $-0.136 \pm 1.167$ | -0.443 to 0.171  |
| Grade 11    | 52 | $-0.177 \pm 1.137$ | -0.493 to 0.140  |
| Grade 12    | 48 | $-0.669 \pm 1.250$ | -1.032 to -0.306 |

*One-way ANOVA:  $F(2,155)=3.163$ ,  $p=0.045$ ,  $\eta^2=0.039$ , 95% CI for  $\eta^2$  [0.000, 0.107]. Post-hoc comparisons were performed using Tukey HSD.*

However, Tukey HSD post-hoc comparisons did not identify a statistically significant difference between any individual pair of grade levels: Grade 10 versus Grade 11 (mean difference=0.041,  $p=0.982$ ), Grade 10 versus Grade 12 (mean difference=0.533,  $p=0.058$ ), and Grade 11 versus Grade 12 (mean difference=0.492,  $p=0.098$ ).

## DISCUSSION

This study identified distinct grade-level patterns in physical activity, waist-to-height ratio, and BMI-for-age z-score among high-school students in West Aceh. Physical activity showed the clearest pattern, with progressively lower scores from Grade 10 to Grade 12 and significant differences across all pairwise grade comparisons. WHtR also differed across grades, although the pattern was driven primarily by lower values in Grade 12 compared with Grades 10 and 11, while Grades 10 and 11 did not differ significantly after correction for multiple comparisons. BAZ showed a statistically significant overall difference across grades, but the effect size was small and no Tukey-adjusted pairwise comparison reached statistical significance. Taken together, these findings indicate that grade-level differences were more clearly demonstrated for physical activity and WHtR than for BAZ. However, because the study was cross-sectional, the observed differences should be interpreted as between-grade patterns rather than evidence of within-person developmental change or causal effects of advancing school grade.

### Physical Activity Across Grade Levels

Physical activity differed clearly across grade levels, with the highest scores observed among Grade 10 students and progressively lower scores in Grades 11 and 12. This pattern is broadly consistent with longitudinal evidence showing that physical activity tends to decline during adolescence. A systematic review of 26 longitudinal studies reported an average annual decline of approximately 7% in physical activity during adolescence<sup>14</sup>. More recent evidence based exclusively on accelerometer-measured moderate-to-vigorous physical activity also showed an overall decline with increasing age, although the trajectory was not uniform across all ages or between sexes<sup>9</sup>. A five-year cohort study from Vietnam similarly reported a substantial age-related decline in accelerometer-measured moderate-

to-vigorous physical activity among adolescents<sup>15</sup>. Taken together, these findings suggest that the lower physical activity observed in the higher grades in the present study is compatible with a broader age-related pattern, although the cross-sectional design does not establish a longitudinal decline within individual students.

School-related demands may provide additional context for the observed grade pattern, but they cannot be considered explanatory factors based on the present data. In a large cross-sectional study involving more than 48,000 students in Shanghai, physical activity was lower in higher secondary-school grades, including Grades 10–12, and students reporting greater academic burden were less likely to meet physical activity recommendations<sup>16</sup>. However, evidence regarding academic demands is not entirely consistent. No significant difference in overall physical activity during school recesses or after school was observed between adolescents who reported academic stress and those who did not<sup>17</sup>. Academic workload and stress should therefore be regarded as possible contextual factors rather than established explanations for lower physical activity in higher grades. Academic workload, examination pressure, study time, and other school-related determinants were not measured in the present study and should be examined directly in future research.

The grade-related differences observed in this study may also be relevant to school health promotion. Greater amounts and higher intensities of physical activity during childhood and adolescence are associated with a range of favorable health outcomes, supporting continued efforts to maintain physical activity during the school years<sup>18</sup>. Secondary schools may provide opportunities for such efforts, although intervention effects should not be overstated. A recent systematic review and meta-analysis found that several whole-school strategies showed promise, but pooled effects on objectively measured physical activity were generally small or non-significant<sup>19</sup>. The lower physical activity observed among students in the higher grades may therefore help identify groups that warrant greater attention in future school-based health-promotion efforts; however, the present study did not evaluate any intervention and cannot determine which strategy would be effective in this population.

### **Waist-to-Height Ratio Across Grade Levels**

Waist-to-height ratio differed across grade levels, with Grade 12 students showing lower WHtR than students in Grades 10 and 11, whereas the difference between Grades 10 and 11 did not remain statistically significant after Bonferroni correction. This pattern should therefore not be interpreted as a uniform progressive decline in WHtR across successive grades. Evidence from adolescent populations likewise suggests that age-related WHtR patterns are not necessarily linear. In a nationally representative Korean study, WHtR decreased until approximately age 15 years in boys and age 12 years in girls before increasing slightly thereafter, indicating sex-specific and nonlinear age patterns<sup>20</sup>. Another large Korean reference study reported a relative plateau in WHtR from approximately 10 years of age onward in both sexes<sup>21</sup>. These findings indicate that WHtR distributions may vary across adolescent age groups without following a single developmental trajectory. Because both the cited reference studies and the present

study are cross-sectional, differences between age or grade groups should not be interpreted as within-person changes over time.

Developmental and population-related factors may provide context for these differences, although they cannot be considered explanations for the present findings. WHtR expresses waist circumference relative to height, but simple division by height does not completely eliminate dependence on height during growth. In a large US study of children and adolescents, WHtR retained residual correlations with height across age groups, suggesting that the relationship between waist circumference and height may vary during growth<sup>22</sup>. WHtR distributions also differ by sex and population; comparisons between southern Chinese and European children and adolescents demonstrated substantial population-related differences and questioned the assumption that a single anthropometric pattern applies across ethnic groups<sup>23</sup>. Such evidence provides a plausible developmental and population context. However, the present study did not assess pubertal stage or longitudinal changes in waist circumference and height, and was not designed to determine whether these factors accounted for the lower WHtR observed in Grade 12.

The observed WHtR differences are nevertheless relevant because WHtR is a practical anthropometric indicator associated with central adiposity and cardiometabolic risk in adolescents. However, available evidence does not support considering WHtR universally superior to BMI-based indices. A meta-analysis comparing WHtR, BMI, and waist circumference found that WHtR did not demonstrate significantly better discriminatory performance for most pediatric cardiometabolic outcomes, although its ease of measurement and interpretation may offer practical advantages<sup>24</sup>. Prospective cohort evidence has similarly shown broadly comparable associations of WHtR and BMI with adolescent cardiometabolic risk, while other adolescent studies suggest that WHtR may provide additional information in some subgroups<sup>5,25</sup>. Interpretation based on a single WHtR threshold also requires caution. A systematic review and meta-analysis found substantial regional variation in optimal WHtR cutoffs and concluded that a universal cutoff of 0.5 may be inappropriate for children and adolescents<sup>8</sup>. Differences across ethnic populations have also been reported, further supporting population-specific interpretation rather than direct application of a single threshold<sup>23</sup>. Accordingly, WHtR in the present study is best interpreted as a complementary indicator of central adiposity rather than as a diagnostic classification or a replacement for BMI-for-age.

### **BMI-for-Age Z-Score Across Grade Levels**

The omnibus analysis indicated an overall difference in BMI-for-age z-score across grade levels, although the effect size was small and none of the Tukey-adjusted pairwise comparisons reached statistical significance. Grade 12 had the lowest mean BAZ descriptively, but this should not be interpreted as evidence of a statistically significant reduction from Grade 10 or Grade 11 or as a progressive decline across successive grades. Longitudinal evidence suggests that BMI-z patterns during childhood and adolescence are heterogeneous rather than following a single age-related trajectory. Four

distinct BMI-z trajectory groups were identified in a large longitudinal study of Indonesian children and adolescents, with significant differences in trajectory patterns by sex<sup>10</sup>. A population-based cohort from Portugal reported decreases in BMI z-score between ages 13 and 17 in both sexes, whereas another longitudinal study extending through late adolescence identified several distinct and sex-specific BMI-SDS trajectories<sup>26,27</sup>. Taken together, these findings suggest that adolescent BMI-z patterns may vary across populations and individuals, and the cross-sectional grade differences observed in the present study cannot establish within-person changes in BAZ over time.

Developmental factors may provide additional context for variation in BAZ during adolescence, but they cannot be considered explanations for the present findings. BMI trajectories during adolescence may vary with sex-specific growth and maturation. In a nationwide Japanese birth cohort, adolescents with different weight-status outcomes at age 15 followed different BMI-z and height-growth trajectories, including differences in the timing of peak height velocity<sup>28</sup>. Such findings illustrate the potential importance of developmental growth patterns when interpreting adolescent BMI. However, pubertal stage was not assessed in the present study, and although sex was recorded, the primary analysis was not designed to evaluate sex-specific BAZ trajectories. Pubertal maturation and sex-related growth patterns should therefore be regarded as possible developmental context rather than established mechanisms underlying the observed grade-level variation.

BAZ should also be interpreted according to the characteristics of the indicator itself. The WHO 2007 growth reference expresses BMI relative to age- and sex-specific reference distributions for children and adolescents aged 5–19 years<sup>4</sup>. Although BMI-based measures are useful anthropometric indicators of adiposity and related health risk, they do not directly measure body fat or its distribution. Evidence in adolescents indicates that BMI-based indices and central-adiposity measures such as WHtR have broadly comparable ability to identify cardiometabolic risk, suggesting that they provide complementary rather than universally competing information<sup>29,30</sup>. Accordingly, BAZ and WHtR in the present study should be interpreted as complementary anthropometric indicators: BAZ reflects BMI relative to age and sex, whereas WHtR reflects waist circumference relative to height. In addition, WHO BMI-for-age thresholds are intended for assessment of individual nutritional status; therefore, a negative mean BAZ for a grade group should not itself be used to classify that group as thin, normal weight, overweight, or obese.

### Public Health Implications

The findings have several implications for adolescent health promotion in the school setting. The consistent differences in physical activity across grade levels suggest that students in the higher grades, particularly Grade 12, may warrant greater attention in efforts to maintain opportunities for regular physical activity during the school years. This does not imply that advancing grade level itself causes lower physical activity, but rather identifies a group in which lower activity levels were observed and that may therefore be relevant to future preventive efforts. Schools provide an important setting for

promoting physical activity during adolescence, although available evidence indicates that the effects of school-based strategies are variable and should not be assumed to be effective without appropriate evaluation<sup>18,19</sup>. Future school-based initiatives should therefore be adapted to the local context and prospectively evaluated to determine whether they can maintain or improve physical activity, particularly among students in the higher grades.

The anthropometric findings also support a broader approach to adolescent health assessment rather than reliance on a single indicator. WHtR and BAZ capture different aspects of anthropometric status and may provide complementary information when interpreted together. BAZ places BMI within an age- and sex-specific growth reference, whereas WHtR expresses waist circumference relative to height; neither should be interpreted as a direct measure of body composition or as sufficient on its own to determine cardiometabolic health<sup>4,29,30</sup>. Periodic anthropometric assessment may therefore be considered within school or adolescent health programs to identify individual patterns that warrant further evaluation, provided that measurements are interpreted using appropriate age-, sex-, and population-specific considerations. The present findings do not provide evidence for a specific dietary, school-canteen, or weight-management intervention, and such strategies should be examined in future studies that directly assess dietary exposures, relevant determinants, and subsequent health outcomes.

### Strengths and Limitations

This study has several strengths. Complete enumeration of the source population enabled all 158 students across Grades 10–12 to be included, with no withdrawals or missing outcome data, thereby minimizing sampling-related selection bias within the study school. The study also examined physical activity together with two complementary anthropometric indicators, WHtR and BAZ, allowing grade-level patterns to be considered from both behavioral and anthropometric perspectives. BAZ was recalculated from the verified weight, height, date-of-birth, and sex data using the WHO 2007 BMI-for-age reference. Statistical analyses were selected according to the distributional characteristics of each outcome, and multiple-comparison correction and effect-size estimates were incorporated to support a more cautious interpretation of between-grade differences.

Several limitations should nevertheless be considered. First, the study was conducted in a single high school in West Aceh using a cross-sectional design. The findings may therefore not be generalizable to adolescents in other schools, regions, or populations, and the observed differences across grades cannot establish temporal relationships, within-person developmental changes, or causal effects of advancing school grade. Because grade level was closely related to age, grade-related patterns cannot be clearly separated from age-related developmental processes. Pubertal stage and school-related demands were not assessed, and although sex was recorded, the primary analyses were not designed to evaluate sex-specific patterns or effect modification. Dietary intake, fast-food consumption, and school-canteen exposure were also not evaluated as determinants within the final analytic framework.

Second, physical activity was assessed using an Indonesian-language, study-adapted questionnaire derived from the IPAQ-SF and based on 7-day recall. Although the instrument was piloted for clarity, comprehension, and feasibility, the resulting MET-minutes/week value should be regarded as a study-specific IPAQ-derived score rather than a fully standard IPAQ-SF score. As a self-reported measure, physical activity may also be affected by recall and social-desirability bias. In addition, the original item-level physical-activity responses were not available in the final analytic dataset, preventing independent reconstruction of the total score from its individual components.

Third, anthropometric measurements were obtained once rather than in duplicate, and measurements were performed by multiple observers who had received brief practical instruction, without a formal assessment of inter-rater reliability. Weight was measured while students were wearing their regular school uniform, and waist circumference was measured over the regular school uniform after removal of outer garments, which may have introduced some measurement error. The original waist-circumference values were not available in the final analytic dataset for independent re-verification of the stored WHtR values. The exact individual dates of anthropometric measurement were also not retained. A common reference date of 14 December 2025 was therefore used for BAZ calculation. However, sensitivity analyses using the beginning and end of the fieldwork period resulted in only negligible changes in BAZ and no changes in nutritional-status classification, suggesting that the date approximation had minimal influence on the study findings.

## CONCLUSIONS AND RECOMMENDATIONS

This study identified distinct grade-level patterns in physical activity, WHtR, and BAZ among high-school students in West Aceh. Physical activity showed the clearest pattern, while WHtR differences were concentrated in Grade 12 and BAZ did not show clear differences between individual grade pairs. These cross-sectional findings should not be interpreted as developmental changes or causal effects of advancing school grade. School health programs may give greater attention to opportunities that support physical activity among students in the higher grades and consider BAZ and WHtR as complementary anthropometric indicators. Future longitudinal and multisite studies with stronger physical-activity and anthropometric measurement procedures should determine whether these patterns persist over time and across different populations.

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