Waist-to-height ratio as a screening tool for obesity and cardiometabolic risk

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The waist-to-height ratio (WHtR), calculated by dividing the waist circumference (WC) by height, has recently gained attention as an anthropometric index for central adiposity. It is an easy-to-use and less age-dependent index to identify individuals with increased cardiometabolic risk. A WHtR cutoff of 0.5 can be used in different sex and ethnic groups and is generally accepted as a universal cutoff for central obesity in children (aged ≥ 6 years) and adults. However, the WHtR has not been validated in preschool children, and the routine use of WHtR in children under age 6 is not recommended. Prospective studies and meta-analysis in adults revealed that the WHtR is equivalent to or slightly better than WC and superior to body mass index (BMI) in predicting higher cardiometabolic risk. In children and adolescents, studies have shown that the WHtR is similar to both BMI and WC in identifying those at an increased cardiometabolic risk. Additional use of WHtR with BMI or WC may be helpful because WHtR considers both height and central obesity. WHtR may be preferred because of its simplicity and because it does not require sex- and age-dependent cutoffs; additionally, the simple message ‘keep your WC to less than half your height’ may be particularly useful. This review article summarizes recent publications on the usefulness of using WHtR especially when compared to BMI and WC as a screening tool for obesity and related cardiometabolic risks, and recommends the use of WHtR in clinical practice for obesity screening in children and adolescents.

Key words: Waist circumference, Abdominal obesity, Pediatric obesity

Introduction

Obesity results from a chronic imbalance between caloric intake and energy expenditure. The prevalence of obesity has been increasing worldwide for the past 30 years, possibly because of increased caloric intake and decreased physical activity. The increasing prevalence of pediatric obesity may be problematic because not only it increases the prevalence of, but also it can advance the age of onset of obesity-related chronic diseases such as type 2 diabetes and cardiovascular diseases. According to the results of a cohort study in American Indians, the death rate before age 55 years from endogenous causes among children in the highest quartile of body mass index (BMI) was more than double that among children in the lowest BMI quartile.

As the prevention and early detection of childhood obesity is critically important for public health, pediatricians should pay attention to changes of adiposity indices in children and alert parents before the onset of obesity-related medical problems. BMI and waist circumference (WC) are commonly used parameters to define obesity and central adiposity. The threshold for increased cardiometabolic risks can differ according to gender and ethnicity, and lower BMI cutoffs are used for Asians, and the use of ethnicity and sex-specific WC cutoffs are recommended. Both BMI and WC are highly age-dependent in
children and adolescents, and clinicians must refer to tables to determine gender- and age-dependent cutoffs. However, it is inconvenient to use tables for each patient in busy outpatient clinic settings, indicating the need for an adiposity index that is reliable but easier to use.

The waist-to-height ratio (WHtR), calculated by dividing WC by height, has recently gained attention as an anthropometric index for measuring central adiposity. WHtR is a more sensitive universal screening tool than BMI to detect health risks and is cheaper and easier to use. It was suggested that a WHtR cutoff of 0.5 can be used in different sex and ethnic groups and that the same cutoff can be applied in children and adults. The message ‘keep your WC to less than half your height’ may be particularly useful for public health as well as in clinical settings.

This review article summarizes recent publications related to the usefulness of WHtR compared to that of BMI and WC, as a screening tool for obesity and related cardiovascular and metabolic risks, and recommends the use of WHtR in clinical practice for screening obesity in children and adolescents.

Limitations of currently used measures of adiposity

1. Body mass index

Age- and sex-specific BMI percentiles have been used in the standard definition for child overweight and obesity worldwide. However, BMI alone cannot distinguish individuals with excess body fat from those with high muscle mass and cannot reflect fat distribution. Although BMI generally correlates well with other measures of adiposity and cardiometabolic risks, indices of abdominal obesity have been reported as better discriminators of cardiovascular risk factors, and the WC is used in the current definition of metabolic syndrome. According to a large European prospective study that reported nearly 15,000 deaths among more than 350,000 subjects, WC was strongly associated with the risk of death after adjusting for BMI. The additional use of WHtR can be helpful when screening for obesity based on BMI in adolescents, as WHtR represents central adiposity. In our recent study, among adolescents with BMI ≥85th percentile, metabolic syndrome was more common in those with a WHtR ≥0.5 than in those with a WHtR <0.5.

2. Waist circumference

Although the WC is an excellent index for measuring central adiposity, tables for age- and sex-dependent WC cutoffs are required in children and adolescents. An advantage of WHtR is that a single cutoff can be used and it does not require age-dependent cutoffs.

WC is a height-dependent variable, and taller children generally have a larger WC than shorter children. However, height is not taken into account when obesity is defined based on age-dependent WC percentiles. The degree of central adiposity can be overestimated in tall children, whereas it can be underestimated in short children if it is defined only by age-dependent WC cutoffs. Approximately 3% of adolescents with WC <90th percentile had a WHtR of ≥0.5 and were significantly shorter compared to their low-WHtR counterparts, and the prevalence of multiple cardiometabolic risk factors was significantly higher in the WC <90th percentile/WHtR ≥0.5 group compared to that in the WC <90th percentile/WHtR <0.5 group in our recent study. In addition, 16.7% of adolescents with a WC ≥90th percentile had a WHtR of <0.5 and were significantly taller compared to their high-WHtR counterparts, and the prevalence of metabolic syndrome was 7.4% in adolescents with WHtR <0.5 and 19.4% in those with WHtR ≥0.5 among those with a WC ≥90th percentile. Because the WHtR is adjusted for height, it appears to be useful for identifying individuals with cardiometabolic risk, even when used in combination with WC.

Moreover, the cardiometabolic risk may differ between people with the same WC but different heights. It was reported that taller populations have lower mortality from ischemic heart disease and stroke, whereas shorter people have higher metabolic risk than taller people with the same WC. Schneider et al. reported that short subjects were at a higher risk and had a 30% higher prevalence of metabolic syndrome than tall subjects when grouped by WC and not by WHtR, and suggested that WHtR rather than WC should be included in the definition of metabolic syndrome. Both height and central adiposity should be considered when identifying individuals at higher metabolic risk, and the WHtR appears to be the best alternative tool.

Correlation between WHtR and other adiposity indices

The agreement between WC and WHtR was good in United States (US) children aged 6 years or older. WHtR showed a high degree of concordance with percent body fat (calculated from measurements of skin fold thickness) in 6- to 14-year-old Spanish children. The WHtR showed better results than WC and BMI (64% vs. 31% and 32%) for predicting percent body fat, measured by dual energy X-ray absorptiometry, in US children and adolescents aged 8–18 years. However, a recent systemic review comparing measures of body fat in 7- to 10-year-old children reported that BMI and WC were strongly correlated with body fat as measured by bioelectrical impedance or skinfolds, whereas the WHtR showed a moderate positive correlation between body fat estimated by air-displacement plethysmography.
Validity of WHtR for predicting cardiometabolic risks

1. Studies in adults

According to a meta-analysis by Lee et al. (1), which included more than 88,000 adults mainly from Asian countries, WHtR was the best discriminator for hypertension, diabetes, and dyslipidemia in both sexes, whereas BMI was the poorest discriminator for cardiovascular risk factors. In another meta-analysis including more than 300,000 adults, the WHtR was superior compared to BMI and WC in identifying adults with cardiometabolic risks; WC improved the discrimination of adverse outcomes by 3% and WHtR improved discrimination by 4%–5% compared to that by BMI (2).

In a study of Korean adults based on the ‘Korea National Health and Nutrition Examination Survey (KNHANES)’ 2008–2011, WHtR showed better performance than BMI in predicting the presence of metabolic syndrome (3). Kim et al. (4) reported that the area under the curve of WHtR was the highest, followed by WC and BMI, in identifying Korean adults with a 10-year Framingham coronary heart disease risk score of 20% or more, and they suggested the clinical use of WHtR as a marker for obesity.

A prospective study of body size and risk of stroke among more than 45,000 women below age 60 years showed that measures of abdominal obesity (WHtR-WC) were strong predictors of stroke in the 11 years of follow-up, whereas BMI was not significantly associated with stroke (5). In a prospective study of German adults followed up for 5–12 years, stronger associations were found between measures of abdominal obesity (such as WC and WHtR) and incident type 2 diabetes mellitus (DM) compared to that with BMI, and WHtR was the strongest predictor for the development of type 2 DM (6). According to a study in which more than 16,000 male subjects were followed for 14 years and 32,000 female subjects for 5.5 years, WHtR showed the strongest association with cardiovascular disease compared with that by BMI and WC, although the differences were small and likely not clinically important (7).

2. Studies in children and adolescents

WHtR and BMI showed equivalent results in identifying high blood pressure (BP) in German adolescents (8), and BMI-for-age and WHtR showed similar ability in identifying US children aged 5–17 years with cardiovascular risk factors (9). The WHtR and WC percentiles performed similarly to BMI percentile for discriminating elevated insulin and the clustering of risk factors in the HEALTHY study (10). In 6- to 10-year-old children in Brazil, WHtR and BMI area under the curve (AUC) were similar for all cardiometabolic parameters (11), suggesting that WHtR has advantages such as its simplicity, although it may not be superior in discriminating higher metabolic risk in children and adolescents.

Both WC (>90th percentile) and WHtR (>0.5) were used to identify higher metabolic risk among 5- to 15-year-old overweight children classified using International Obesity Task Force BMI cutoffs (12). According to a study in which overweight and obese children categorized based on the BMI percentiles were further stratified by WHtR, overweight and obese children with a WHtR <0.5 had a cardiometabolic risk approaching that of subjects in a normal BMI percentile category (13). An increased WHtR was significantly associated with an increased cardiometabolic risk, even in overweight and obese children, and the authors suggested that WHtR should be included in the routine screening and assessment of overweight and obese children (14).

Prospective studies are important, but enormous efforts are required to perform long-term prospective studies in children and adolescents, and thus few of these studies have been conducted. In an Australian cohort study, both BMI and WHR measured during childhood were associated with cardiometabolic risk factors in adolescents, and a WHR>0.5 at 7–9 years increased the odds of having ≥3 cardiometabolic risk factors in boys by 4.6 (2.6–8.1) (15). In a prospective study in the US, measures of central adiposity were better predictors of premature mortality than BMI, and those with a WHR>0.65 aged 12–39 years were at a 139% greater risk of death before age 55 years compared to those with a WHR<0.5 (16). These findings underscore the importance of obesity control in youths, particularly the early detection and intervention for those with central obesity. Recent publications the validity of WHtR in children and adolescents are summarized in Table 1.

Optimal WHtR cutoff

1. Optimal cutoff in adults

According to a systemic review, the mean boundary values for WHtR covering all cardiometabolic outcomes from studies in 14 different countries and including Caucasian, Asian, and Central American subjects were 0.5 for both men and women (17). In a recent study of Chinese adults, the optimal WHtR cutoff for the CVD cluster was 0.5; the upper boundary values of WHtR for detecting the risk factor cluster with specificity above 90% were 0.55 and 0.58 for men and women, respectively (18). In a recent study based on KNHANES 2007–2010, the optimal WHtR cutoff points for identifying those with high coronary heart disease risk were 0.50 and 0.52 in Korean men and women, respectively (19).

2. Optimal cutoff in children

A WHR cutoff of 0.5 has been suggested as a universal cutoff in children as well as in adults (20). Although it seems that the WHtR is less dependent on age and sex, small variance may present according to ethnic backgrounds. According to a study in

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### Table 1. Summary of recent publications evaluating the validity of WHtR in children and adolescents

| Study design          | Age (yr) | No. (M:F) | Country | Outcomes                                                                 | Results                                                                 | Reference                  |
|-----------------------|----------|-----------|---------|---------------------------------------------------------------------------|-------------------------------------------------------------------------|----------------------------|
| Cross-sectional       | 6–14     | 2,319 (1,158:1,161) | Spain   | Percent body fat (calculated from skin fold thickness measurements)       | High degree of concordance between WHtR and percent body fat            | Marrodán et al. (2014)    |
| Cross-sectional       | 8–18     | 2,339 (1,221:1,118) | USA     | Percent body fat (by DEXA)                                                | WHtR better than WC and BMI (64% vs. 31% and 32%) in predicting percent body fat | Brambilla et al. (2013)   |
| Cross-sectional       | 3–7      | 136 (50:86) | The Netherlands | Percent body fat by $^3$H$_2$ and $^3$H$_3$ O isotope dilution, bioelectrical impedance, cardiometabolic risk factors | WHtR was not superior to BMI or WC in estimating body fat, nor was WHtR better correlated with cardiometabolic risk factors than WC or BMI in overweight/obese children | Sijtsma et al. (2014)    |
| Cross-sectional       | 11–17    | 6,813 (3,492:3,321) | Germany | WHtR 90P for age, hypertension (BP >90P)                                   | Very good agreement between WHtR 0.5 vs. WHtR 90P, WHtR and BMI equivalent in identifying hypertension | Kromeyer-Hauschild et al. (2013) |
| Cross-sectional       | 10–13    | 6,097 (2,092:3,195) | USA     | Elevated insulin and clustering of ≥3 risk factors (among glucose, total cholesterol, BP, triglycerides, LDL-C, HDL-C, and insulin) | WHtR and WC percentile performed similarly (not superior) to BMI percentile for discriminating elevated insulin and clustering of risk factors | Bauer et al. (2015)       |
| Cross-sectional       | 6–10     | 175 (88:77), including 87 overweight or obese | Brazil | Insulin resistance (HOMA-IR >2.5), any risk factors (LDL-C ≥100 mg/dL, HDL-C <45 mg/dL, TG ≥100 mg/dL or BP>90P) | BMI and WHtR AUC similar for all cardiometabolic risk factors, WHtR >0.47 sensitive for screening insulin resistance and any of the cardiometabolic risk factors | Kuba et al. (2013)         |
| Cross-sectional       | 7–17     | 16,914 (8,843:8,071) | China   | General obesity (by BMI), central obesity (by WC), metabolic syndrome (≥3 risk factors) | Optimal WHtR cutoff 0.47 in boys, 0.45 in girls for identifying general obesity and central obesity, Sensitivity 85.8%/specificity 82.5% in boys and Sensitivity 86.4%/specificity 81.2% for identifying metabolic syndrome | Zhou et al. (2014)        |
| Cross-sectional       | 4–17     | 1,080 (513:567) | Italy   | Metabolic syndrome (≥3 risk factors), prediabetes (IFG or IGT by OGTT)      | WHtR >0.6 linked to higher risk for metabolic syndrome and prediabetes in obese subjects (BMI >95P) | Santoro et al. (2013)     |
| Cross-sectional       | 6–12     | 236 (102:134), including 214 overweight or obese | Mexico  | Metabolic syndrome (≥3 risk factors)                                       | WHtR and WC AUC similar for predicting metabolic syndrome, WHtR cutoff of 0.59 as a predictor of metabolic syndrome (sensitivity 81.8%/specificity 78.5%); WHtR >0.50 shows low specificity (sensitivity 100%/specificity 22.7%) | Elizondo-Montemayor et al. (2011) |
| Cross-sectional       | 8–16     | 110 (48:62) | Mexico  | Metabolic syndrome (≥3 risk factors)                                       | BMI percentile: AUC 0.651 (P=0.008) and cutoff >99P; WC: AUC 0.704 (P<0.001), cutoff >90 cm, WHtR: AUC 0.652 (P=0.008) and cutoff ≥0.60 for predicting MS | Rodea-Montero et al. (2014) |
| Cross-sectional       | 5–18     | 14,193 (7,280:6,913) | USA     | lipid profiles, CRP, liver transaminases, BP>90P, and metabolic syndrome (≥3 risk factors) | BMI ≥85P with a WHtR <0.5 had a cardiometabolic risk approaching that of subjects with BMI <85P. Increasing WHtR significantly associated with increased cardiometabolic risk in subjects with BMI ≥85P, with the greatest associations in those with BMI ≥95P | Khoury et al. (2013)       |
| Cross-sectional       | 10–19    | 4,068 (2,139:1,929) | Korea   | ≥2 Risk factors (among glucose, triglycerides, HDL-C, SBP ≥130 or DBP ≥80), Metabolic syndrome (WC 90P + ≥2 risk factors) | Metabolic syndrome more common in adolescents with BMI≥85P/WHtR ≥0.5 than in those with BMI<85P/WHtR<0.5; prevalence of ≥2 risk factors higher in those with BMI<85P/WHtR<0.5 than in those with BMI<95P/WHtR<0.5; metabolic syndrome more common in adolescents with WC≥90P/WHtR<0.5 than in those with WC<90P/WHtR<0.5; prevalence of ≥2 risk factors higher in those with WC<90P/WHtR<0.5 than in those with WC<90P/WHtR<0.5 | Chung et al. (2016)        |
| Cross-sectional       | 7–15     | 2,710 (1,317:1,393) | Australia | ≥3 Risk factors (among triglycerides, LDL-C, HDL-C, insulin, glucose, SBP and DBP) | Both BMI and WHtR measured at age 7-9 were associated with cardiometabolic risk factors at age 15. WHtR ≥0.5 at age 7-9 increased the odds by 4.6 (2.6-8.1) of having ≥3 risk factors at age 15 in boys | Graves et al. (2014)      |
New Zealand children aged 5–14 years, although a WHr>0.5 was more common in Pacific and Maori children than in those of other ethnicities and ethnicity influenced the relationship between BMI and WHr, the differences were clinically insignificant and WHr values for a given BMI were similar (WHr of 0.47 in Maori, 0.46 in Pacific, and 0.48 in European boys at the 85th percentile). The WHr cutoff of 0.5 showed very good agreement with age- and sex-specific WHr 90th percentiles in German adolescents. However, sex- and ethnicity-specific WHr cutoff values may improve sensitivity and specificity for identifying those at higher metabolic risk. In Korean children aged 6–18 years, the WHr cutoffs for overweight (85th percentile≤BMI≤95th percentile) were 0.48 in boys and 0.47 in girls and those for obesity (BMI≥95th percentile) were 0.51 in boys and 0.49 in girls. In Chinese children aged 7–17 years, the optimal WHr cutoffs for identifying those with general and central obesity were 0.47 in boys and 0.45 in girls.

Different criteria and study methods may also increase the variance in optimal cutoffs between studies, and caution should be used when interpreting different study results. A WHr cutoff of >0.47 was sensitive for screening insulin resistance (Homeostatic Model of Assessment-Insulin Resistance≥2.5) and any cardiometabolic risk factors (low density lipoprotein-cholesterol≥100 mg/dL, high density lipoprotein-[HDL]-cholesterol<45 mg/dL, triglycerides≥100 mg/dL, or BP>90th percentile) in 6– to 10-year-old Brazilian children, whereas a WHr cutoff of 0.59 was suggested as a predictor of metabolic syndrome (≥3 risk factors among WC≥90th percentile, glucose≥110 mg/dL, HDL-cholesterol<40 mg/dL, triglycerides≥110 mg/dL, or systolic or diastolic BP≥90th percentile) in 6– to 12-year-old Mexican children. Thus, a higher WHr cutoff (0.6 or 0.65) may be useful in high-risk populations to identify individuals with even higher cardiometabolic risk. A WHr>0.6 was linked to a higher risk of metabolic syndrome and prediabetes among obese Italian children and adolescents, and those with WHr>0.65 at age 12–39 years were at a 139% greater risk of death before age 55 years than those with WHr<0.5.

## Limitations and controversies

### 1. Use of WHr in infants and preschool children

The relationship between WHr and other obesity indices or cardiometabolic risk factors in younger children have not been validated, and the routine use of WHr in children under age 6 years cannot be recommended. The agreement between the WC 90th percentile versus WHr cutoff of 0.5 was poor for 2– to 5-year-olds in the US, and a WHr cutoff of 0.5 may overestimate central obesity in very young children. WHr significantly decreased with age in Korean children, and values were more age-dependent in the 2– to 5-year-old age group. In Dutch children aged 3–7 years, WHr was not superior compared to BMI or WC in estimating body fat; the correlation of WHr with cardiometabolic risk factors was not better than that of WC or BMI in overweight/obese children.

### 2. Methodology for WC measurements

It was reported that the reliability of WC measurement is lower than that of weight and height measurement, and WC showed significant interobserver differences. It is essential to standardize the methodology in order to decrease measurement error, and acceptable intra- and interobserver agreement can be achieved by training the participating staff.

Different techniques for conducting WC measurements may result in different WC and WHr values. WC should be measured using plastic or metal tape in the standing position over bare skin or light undergarments. It is most commonly measured at the narrowest part of the trunk, but can be measured at the midpoint, umbilicus, or iliac crest level. A systematic review of 120 studies suggested that the WC measurement protocol has no substantial influence on the association between mortality, CVD, and diabetes.

## Conclusions

WHr is a reliable, easy-to-use, and less age-dependent index.
for identifying children and adolescents with increased cardiometabolic risk related to central adiposity. A WHtR cutoff of 0.5 is generally accepted as a universal cutoff for central obesity in children aged ≥6 years as well as in adults. However, the WHtR has not been validated in infants and preschool children. Even in older children, sex- and ethnicity-specific WHtR cutoffs may improve sensitivity and specificity for identifying those at higher metabolic risk. The additional use of WHtR with BMI or WC also appears to be helpful for screening those with higher cardiometabolic risk. Most recent studies now include the WHtR as a major adiposity index, regarding it as a validated and universal index of central adiposity.23-31

Prospective studies and meta-analyses of adults have revealed that the WHtR is equivalent to or slightly better than WC and superior to BMI in predicting higher cardiometabolic risk. Studies in children and adolescents showed that WHtR is similar to both BMI and WC for identifying those with increased cardiometabolic risk. Additional large-scale prospective studies are needed to confirm the usefulness of WHtR for predicting comorbidities of obesity in children and adolescents.

Conflict of interest

No potential conflict of interest relevant to this article was reported.

References

1. Hall KD, Sacks G, Chandramohan D, Chow CC, Wang YC, Gortmaker SL, et al. Quantification of the effect of energy imbalance on body weight. Lancet 2011;378:826-37.
2. Swinburn BA, Sacks G, Hall KD, McPherson K, Finegood DT, Moodie ML, et al. The global obesity pandemic: shaped by global drivers and local environments. Lancet 2011;378:804-14.
3. Wang YC, McPherson K, Marsh T, Gortmaker SL, Brown M. Health and economic burden of the projected obesity trends in the USA and the UK. Lancet 2011;378:815-25.
4. Pavkov ME, Bennett PH, Knowler WC, Krakoff J, Sievers ML, Nelson RG. Effect of youth-onset type 2 diabetes mellitus on incidence of end-stage renal disease and mortality in young and middle-aged Pima Indians. JAMA 2006;296:421-6.
5. Franks PW, Hanson RL, Knowler WC, Sievers ML, Bennett PH, Looker HC. Childhood obesity, other cardiovascular risk factors, and premature death. N Engl J Med 2010;362:485-93.
6. WHO Expert Consultation. Appropriate body-mass index for Asian populations and its implications for policy and intervention strategies. Lancet 2004;363:157-63.
7. Zimmet P, Alberti KG, Kaufman F, Tajima N, Silink M, Arslanian S, et al. The metabolic syndrome in children and adolescents - an IDF consensus report. Pediatr Diabetes 2007;8:299-306.
8. August GP, Caprio S, Fennoly L, Freemark M, Kaufman FR, Lustig RH, et al. Prevention and treatment of pediatric obesity: an endocrine society clinical practice guideline based on expert opinion. J Clin Endocrinol Metab 2008;93:4576-99.
9. Hsieh SD, Yoshinaga H. Abdominal fat distribution and coronary heart disease risk factors in men-waist/height ratio as a simple and useful predictor. Int J Obes Relat Metab Disord 1995;19:585-9.
10. Ashwell M, Hsieh SD. Six reasons why the waist-to-height ratio is a rapid and effective global indicator for health risks of obesity and how its use could simplify the international public health message on obesity. Int J Food Sci Nutr 2005;56:303-7.
11. Ashwell M, Gunn P, Gibson S. Waist-to-height ratio is a better screening tool than waist circumference and BMI for adult cardiometabolic risk factors: systematic review and meta-analysis. Obes Rev 2012;13:275-86.
12. Ashwell M, Gibson S. A proposal for a primary screening tool: 'Keep your waist circumference to less than half your height'. BMC Med 2014;12:207.
13. Cole TJ, Bellizzi MC, Flegal KM, Dietz WH. Establishing a standard definition for child overweight and obesity worldwide: international survey. BMJ 2000;320:1240-3.
14. Yajnik CS, Yudkin JS. The Y-Y paradox. Lancet 2004;363:163.
15. Lee CM, Huxley RR, Wildman RP, Woodward M. Indices of abdominal obesity are better discriminators of cardiovascular risk factors than BMI: a meta-analysis. J Clin Epidemiol 2008;61:646-53.
16. Spolidoro JV, Pirez Filho ML, Vargas LT, Santana JC, Pirez E, Hauschild JA, et al. Waist circumference in children and adolescents correlate with metabolic syndrome and fat deposits in young adults. Clin Nutr 2013;32:93-7.
17. Pischon T, Boeing H, Hoffmann K, Bergmann M, Schulze MB, Overvad K, et al. General and abdominal adiposity and risk of death in Europe. N Engl J Med 2008;359:2105-20.
18. Chung IH, Park S, Park MJ, Yoo EG. Waist-to-height ratio as an index for cardiometabolic risk in children: Results from the 1998-2008 KNHANES. Yonsei Med J 2016;57:658-63.
19. Kromeeyer-Hauschild K, Neuhauer H, Schaffrath Rosario A, Schienkiewitz A. Abdominal obesity in German adolescents defined by waist-to-height ratio and its association to elevated blood pressure: the KiGGS study. Obes Facts 2013;6:165-75.
20. Barker DJ, Osmond C, Golding J. Height and mortality in the counties of England and Wales. Ann Hum Biol 1990;17:1-6.
21. Hsieh SD, Yoshinaga H. Do people with similar waist circumference share similar health risks irrespective of height? Tohoku J Exp Med 1999;188:55-60.
22. Schneider HJ, Klotsche J, Silber S, Stalla GK, Wittchen HU. Measuring abdominal obesity: effects of height on distribution of cardiometabolic risk factors risk using waist circumference and waist-to-height ratio. Diabetes Care 2011;34:e7.
23. Li C, Ford ES, Mokdad AH, Cook S. Recent trends in waist circumference and waist-height ratio among US children and adolescents. Pediatrics 2006;118:e1390-8.
24. Marrodán M, Alvarez JM, de Espinosa MG, Carmenate M, López-Ejeda N, Cabañas M, et al. Predicting percentage body fat through waist-to-height ratio (WtHR) in Spanish schoolchildren. Public Health Nutr 2014;17:870-6.
25. Brambilla P, Bedogni G, Hao M, Pietrobelli A. Waist circumference-to-height ratio predicts adiposity better than body mass index in children and adolescents. Int J Obes (Lond) 2013;37:943-6.
26. Jensen NS, Camargo TF, Bergamaschi DP. Comparison of methods to measure body fat in 7-to-10-year-old children: a systematic review. Public Health 2016;133:3-13.
27. Kang SH, Cho KH, Park JW, Do JY. Comparison of waist to height ratio and body indices for prediction of metabolic disturbances in

https://doi.org/10.3345/kjp.2016.59.11.425
the Korean population: the Korean National Health and Nutrition Examination Survey 2008–2011. BMC Endocr Disord 2015;15:79.
28. Kim SH, Choi H, Won CW, Kim BS. Optimal cutoff points of anthropometric parameters to identify high coronary heart disease risk in Korean adults. J Korean Med Sci 2016;31:61–6.
29. Lu M, Ye W, Adami HO, Weiderpass E. Prospective study of body size and risk for stroke amongst women below age 60. J Intern Med 2006;260:442-50.
30. Hartwig S, Klutig A, Tiller D, Frick J, Müller G, Schipf S, et al. Anthropometric markers and their association with incident type 2 diabetes mellitus: which marker is best for prediction? Pooled analysis of four German population-based cohort studies and comparison with a nationwide cohort study. BMJ Open 2016;6:e009266.
31. Gelber RP, Gaziano JM, Orav EJ, Manson JE, Buring JE, Kurth T. Measures of obesity and cardiovascular risk among men and women. J Am Coll Cardiol 2008;52:605-15.
32. Freedman DS, Kahn HS, Mei Z, Grummer-Strawn LM, Dietz WH, Srinivasan SR, et al. Relation of body mass index and waist-to-height ratio to cardiovascular disease risk factors in children and adolescents: the Bogalusa Heart Study. Am J Clin Nutr 2007;86:33–40.
33. Bauer KW, Marcus MD, El ghormli L, Ogden CL, Foster GD. Cardiovascular risk screening among adolescents: understanding the utility of body mass index, waist circumference and waist-to-height ratio. Pediatr Obes 2015;10:329–37.
34. Kuba VM, Leone C, Damiani D. Is waist-to-height ratio a useful indicator of cardio-metabolic risk in 6-10-year-old children? BMC Pediatr 2013;13:91.
35. Maffei C, Banzato C, Talamini G; Obesity Study Group of the Italian Society of Pediatric Endocrinology and Diabetology. Waist-to-height ratio, a useful index to identify high metabolic risk in overweight children. J Pediatr 2008;152:207-13.
36. Khoury M, Manlhiot C, McCrindle BW. Role of the waist/height ratio in the cardiometabolic risk assessment of children classified by body mass index. J Am Coll Cardiol 2011;62:742-51.
37. Graves L, Garnett SP, Cowell CT, Baur LA, Ness A, Sattar N, et al. Waist-to-height ratio and cardiometabolic risk factors in adolescence: findings from a prospective birth cohort. Pediatr Obes 2014;9:327–38.
38. Saydah S, Bullard KM, Imperatore G, Geiss L, Gregg EW. Cardiovascular metabolic risk factors among US adolescents and young adults and risk of early mortality. Pediatrics 2013;131:e679-86.
39. Browning LM, Hsieh SD, Ashwell M. A systematic review of waist-to-height ratio as a screening tool for the prediction of cardiovascular disease and diabetes: 0.5 could be a suitable global boundary value. Nutr Res Rev 2010;23:247–69.
40. Peng Y, Li W, Wang Y, Bo J, Chen H. The cut-off point and boundary values of waist-to-height ratio as an indicator for cardiovascular risk factors in Chinese adults from the PURE Study. PLoS One 2015;10:e0144539.
41. Goulding A, Taylor RW, Grant AM, Parnell WR, Wilson NC, Williams SM. Waist-to-height ratios in relation to BMI z-scores in three ethnic groups from a representative sample of New Zealand children aged 5–14 years. Int J Obes (Lond) 2010;34:1188–90.
42. Gil JH, Lee MN, Lee HA, Park H, Seo JW. Usefulness of the waist circumference-to-height ratio in screening for obesity in Korean children and adolescents. Korean J Pediatr Gastroenterol Nutr 2010;13:180-92.
43. Zhou D, Yang M, Yuan ZP, Zhang DD, Liang L, Wang CL, et al. Waist-to-height ratio: a simple, effective and practical screening tool for childhood obesity and metabolic syndrome. Prev Med 2014;67:35–40.
44. Elizondo-Montemayor L, Serrano-González M, Ugład-Pas PA, Bustamante-Careaga H, Cuello-García C. Waist-to-height: cutoff matters in predicting metabolic syndrome in Mexican children. Metab Syndr Relat Disord 2011;9:183-90.
45. Rodea-Montero ER, Evia-Viscarra ML, Apolinar-Jiménez E. Waist-to-height ratio is a better anthropometric index than waist circumference and BMI in predicting metabolic syndrome among obese Mexican adolescents. Int J Endocrinol 2014;2014:199407.
46. Santoro N, Amato A, Grandone A, Brienza C, Savarese P, Tartaglione N, et al. Predicting metabolic syndrome in obese children and adolescents: look, measure and ask. Obes Facts 2013;6:48–56.
47. Sjøtsma A, Bocca G, L’abée C, Liem ET, Sauer PJ, Corpelein E. Waist-to-height ratio, waist circumference and BMI as indicators of percentage fat mass and cardiometabolic risk factors in children aged 3-7 years. Clin Nutr 2014;33:311-5.
48. Ulijaszek SJ, Kerr DA. Anthropometric measurement error and the assessment of nutritional status. Br J Nutr 1999;82:165-77.
49. Stomfai S, Ahrens W, Bammann K, Kovács É, Márild S, Nichols M, et al. Intra- and inter-observer reliability in anthropometric measurements in children. Int J Obes (Lond) 2011;35 Suppl 1:S54-51.
50. Ross R, Berentzen T, Bradshaw AJ, Janssen I, Kahn HS, Katzmarzyk PT, et al. Does the relationship between waist circumference, morbidity and mortality depend on measurement protocol for waist circumference? Obes Rev 2008;9:312–25.
51. Khoury M, Manlhiot C, Gibson D, Chahal N, Stearne K, Dobbin S, et al. Universal screening for cardiovascular disease risk factors in adolescents to identify high-risk families: a population-based cross-sectional study. BMC Pediatr 2016;16:11.
52. De Henauw S, Huybrechts I, De Bourdeaudhuij I, Bammann K, Barba G, Lissner L, et al. Effects of a community-oriented obesity prevention programme on indicators of body fatness in preschool and primary school children. Main results from the IDEFICS study. Obes Rev 2015;16 Suppl 2:S16–29.
53. Petroff D, Kromeyer-Hauschild K, Wiegand S, l’Allemann-Jander D, Binder G, Schwab KO, et al. Introducing excess body weight in childhood and adolescence and comparison with body mass index and waist-to-height ratio. Int J Obes (Lond) 2015;39:52-60.