Original article

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Waist-height ratio and body mass index as indicators of obesity and cardiometabolic risk in Korean children and adolescents

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Purpose: We assessed the clinical relevance of waist-height ratio (WHtR) as an indicator of cardiometabolic risk and body fat mass measured by dual-energy x-ray absorptiometry (DXA) among Korean children and adolescents.
Methods: Data from 1,661 children and adolescents aged 10–18 years who participated in the Korea National Health and Nutrition Examination Survey were analyzed. Unadjusted Pearson correlation, age- and sex-adjusted Pearson correlation, and multiple linear regression analyses were performed to investigate the relationships between WHtR standard deviation score (SDS) and cardiometabolic risk factors, as well as DXA-assessed parameters.
Results: WHtR SDS was correlated with cardiometabolic risk factors, including systolic blood pressure, glucose, total cholesterol, high-density lipoprotein cholesterol, triglyceride, and low-density lipoprotein cholesterol, as well as DXA-assessed parameters such as lean mass SDS, fat mass SDS, and fat mass percentage SDS in both whole body and trunk using an adjusted Pearson correlation analyses among all participants ($P<0.001$). WHtR SDS was strongly correlated with whole-body fat mass and trunk fat mass ($r=0.792$, $P<0.001$ and $r=0.801$, $P<0.001$, respectively) whereas WHtR SDS had a low correlation coefficient with whole-body lean mass and trunk lean mass SDS ($r=0.512$, $P<0.001$ and $r=0.487$, $P<0.001$, respectively). In multiple linear regression analyses, WHtR SDS was significantly associated with whole-body and trunk fat mass after adjustment for confounders.
Conclusion: Cardiometabolic risk factors and body fat mass assessed by DXA in Korean children and adolescents were highly correlated with WHtR. Additionally, WHtR has an advantage in distinguishing fat-free mass. WHtR can be a useful and convenient clinical indicator of cardiometabolic risk factors.

Keywords: Waist-height ratio, Body mass index, Cardiometabolic risk, Obesity

Highlights

- Cardiometabolic risk factors and body fat mass assessed by DXA in Korean children and adolescents were highly correlated with WHtR. WHtR can be a useful and convenient clinical indicator of cardiometabolic risk factors.

Introduction

Obesity refers to excess accumulation of body fat and has become increasingly common worldwide over the past few decades.[1] Anthropometric measurements indicate that the mean weight and body mass index (BMI) of Korean adolescents are increasing.[2-4] In the Asia-Pacific region, including South Korea, obesity is typically defined as a BMI of 25 kg/m^2 or greater.[5]

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Age- and sex-specific BMI percentiles are used in children and adolescents to define obesity. Obesity is a significant health challenge, particularly among children and adolescents, as it can lead to diabetes, heart disease, hypertension, and cancer.[6] Children and adolescents with obesity often experience comorbidities including dyslipidemia, impaired glucose homeostasis, metabolic syndrome, asthma exacerbation, gastrointestinal comorbidities, orthopedic complications, psychosocial problems, early puberty, hyperandrogenism, and polycystic ovary syndrome.[1]

Specifically, metabolic syndrome is more likely in obese individuals, particularly those with central adiposity.[7] While BMI is commonly used to evaluate obesity, other screening tools for abdominal adiposity are recommended, as abdominal obesity is strongly associated with metabolic risk. Several methods can be used to measure body fat mass, such as underwater weighing, bioimpedance analysis (BIA), computed tomography (CT), magnetic resonance imaging (MRI), and dual-energy x-ray absorptiometry (DXA). Among these methods, CT, MRI, and DXA are regarded as gold standard methods to measure body fat mass, but are complicated and expensive.[1,8]

Among alternative, simpler methods of body fat measurement, the National Cholesterol Education Program–Adult Treatment Panel III has recommended waist circumference (WC) rather than BMI to assess the body weight component of the metabolic syndrome.[9] Additional anthropometric indices related to obesity are also being studied, such as the waist-hip ratio and the waist-height ratio (WHtR). WHtR has been suggested as the most reliable anthropometric method of measuring body fat mass[10-12] and is evaluated as an indicator of cardiometabolic risks.[13,14] In this study, we investigate standard deviation score (SDS) of WHtR and BMI as indicators of cardiometabolic risk and body fat composition in Korean children and adolescents.

Materials and methods

We analyzed Korea National Health and Nutrition Examination Survey (KNHANES) data[15] from 2009 to 2011 in this research. KNHANES was initiated in 1998 and was conducted by the Korea Disease Control and Prevention Agency on a 3-year cycle until 2007, after which it has been conducted yearly.[16] KNHANES is a sample survey design with the entire population of Korea as the target population. Body compositions of subjects were measured using DXA from July 2008 to June 2011. Based on the entire KNHANES dataset (n=17,720), subjects aged 10 to 18 years with available anthropometric data were included in this research (n=1,952). Subjects without data regarding laboratory and DXA-assessed variables were excluded (n=239). Subjects with triglyceride (TG) levels greater than 400 mg/dL (n=2) were also excluded. Finally, a total of 1,661 children and adolescents were analyzed in this study (Fig. 1).

Trained experts measured anthropometric data, clinical data, and body composition. Height was measured using seca 225 (seca, Hamburg, Germany) with a 1-mm resolution, and weight was measured using a GL-6000-20 (G-tech, Incheon, Korea) with a 0.1-kg resolution. WC was measured on subjects after lifting the examination gown above the waist, lowering the arms comfortably, and bringing the feet together. In the midaxillary plane, the midpoint between the lowest ribs and the iliac crest was identified. Using a seca 200 (seca), waist measurements were taken to the nearest 1 mm while the subject exhale. WHtR was calculated as shown in equation (1).

$$WHtR = C/height \quad (1)$$

Systolic and diastolic blood pressure (SBP and DBP) of subjects were measured using a Baumanometer Desk model 0320 (Baum, Copiague, NY, USA) with 2-mmHg resolution. Blood samples were collected from subjects who had fasted for at least 8 hours. The blood samples were preprocessed and then stored in a refrigerator before being transported to the central laboratory (Neodin Medical Institute, Seoul, Korea). Serum glucose, TC, HDL-C, and TG concentrations were measured using a Hitachi Automatic Analyzer 7600 (Hitachi, Tokyo, Japan). The LDL-C concentration was calculated according to the Friedewald equation[17] as shown below:

$$LDL\_C = TC - HDL\_C - \frac{TG}{5} \quad (2)$$

Body compositions of subjects were measured via DXA using a DISCOVERY-W (Hologic, Marlborough, MA, USA). Lifestyle data were obtained by survey.

The R statistical package version 3.5.1 (R Foundation for Statistical Computing, Vienna, Austria) was used for statistical analysis. Pearson correlation analysis was performed to determine the relationships between WHtR SDS, BMI SDS, and clinical, DXA-assessed parameters.[18,19] The height, weight, BMI, WC, WHtR, and DXA-assessed parameters were converted to SDS and then subjected to statistical analysis.[20] Correlation

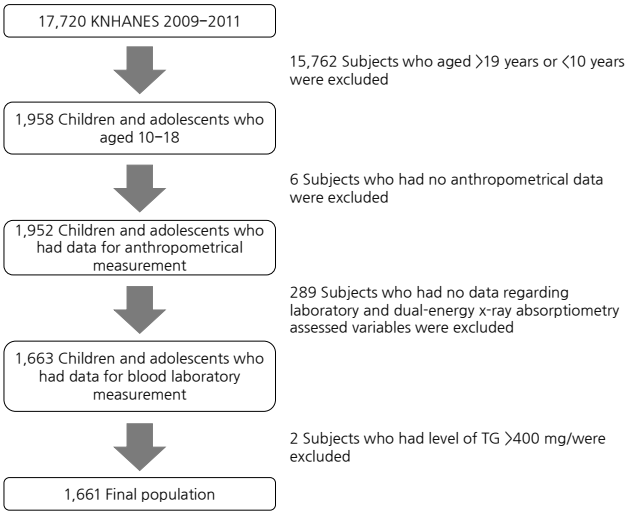

Fig. 1. Flow chart of the study population. KNHANES, Korea National Health and Nutrition Examination Survey; TG, triglyceride.

analysis was performed for all subjects and for sex-specified groups (boys and girls). Then, adjusted correlations were calculated after adjustments for age and sex. Finally, multiple linear regression analysis was performed between WHtR SDS, BMI SDS, and clinical, DXA-assessed parameters. This study was approved by the Institutional Review Board of Ajou University Hospital (AJOUIRB-EX-2023-162). All methods were performed in accordance with relevant guidelines and regulations.

Table 1. Clinical characteristic of the study population (n=1,661)

Characteristic	Boys (n=891)	Girls (n=770)	*P*-value
Age (yr)	14.34±2.47	14.36±2.47	0.908
Height SDS	0.25±1.03	0.20±1.06	0.316
Weight SDS	0.08±1.23	0.05±1.15	0.542
WC SDS	–0.32±1.13	–0.22±1.12	0.075
BMI SDS	–0.06±1.27	–0.07±1.19	0.927
WHtR SDS	-0.12±1.10	-0.02±1.11	0.062
SBP (mmHg)	108.86±11.20	103.72±9.25	<0.001
DBP (mmHg)	67.28±10.17	65.71±8.00	<0.001
Glucose (mg/dL)	89.57±6.22	88.40±6.35	<0.001
TC (mg/dL)	153.65±27.67	162.60±25.09	<0.001
HDL-C (mg/dL)	48.45±9.37	50.77±9.50	<0.001
Triglyceride (mg/dL)	83.58±48.69	85.17±46.14	0.496
LDL-C (mg/dL)	88.48±23.63	94.79±21.71	<0.001
DXA in whole body			
Lean mass (kg)	42.81±10.86	33.64±5.86	<0.001
Fat mass (kg)	13.54±6.91	16.07±5.91	<0.001
Fat mass percentage	23.47±8.00	31.52±5.86	<0.001
Lean mass SDS	0.29±1.06	0.20±1.01	0.071
Fat mass SDS	0.02±1.00	0.11±1.01	0.068
Fat mass percentage SDS	-0.08±1.00	0.04±1.01	0.017
DXA in trunk			
Lean mass (kg)	19.28±5.17	15.75±2.99	<0.001
Fat mass (kg)	5.78±3.62	6.74±3.19	<0.001
Fat mass percentage (%)	22.07±9.04	28.73±7.30	<0.001
Lean mass SDS	0.29±1.05	0.21±1.00	0.131
Fat mass SDS	0.03±0.99	0.11±1.01	0.136
Fat mass percentage SDS	-0.06±1.00	0.04±1.01	0.065
Physical activity	550 (61.73)	471 (61.17)	0.855
Alcohol drinking	244 (27.38)	176 (22.86)	0.039
Smoking	142 (15.94)	41 (5.32)	<0.001
Household income (≤1 quartile)	115 (12.91)	104 (13.51)	0.774
Rural residence	132 (14.81)	115 (14.94)	>0.999
Hypertension	0 (0)	0 (0)	>0.999
T2DM	0 (0)	1 (0.1)	0.942
Dyslipidemia	0 (0)	0 (0)	>0.999

Values are presented as mean±standard deviation or number (%).
SDS, standard deviation score; WC, waist circumference; BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; TC, total cholesterol; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; DXA, dual-energy x-ray absorptiometry; T2DM, type 2 diabetes mellitus.

Results

Table 1 shows clinical characteristics of the subjects in this study. There were no significant differences between boys and girls in age, height SDS, weight SDS, WC SDS, or BMI SDS. SBP, DBP, and glucose levels were higher in boys than in girls, whereas TC, HDL-C, and LDL-C were higher in girls. Among the DXA-assessed parameters, lean mass (LM) in the whole body and the trunk were higher in boys than in girls. However, fat mass (FM), and percentage body fat mass (PBF) in the whole body and the trunk were higher in girls than in boys.

Table 2 shows the correlations between WHtR SDS, BMI SDS, and clinical, DXA-assessed parameters for all subjects. Except for DBP, clinical data showed correlations with both WHtR SDS and BMI SDS, with all *P*-values less than 0.001. SBP, serum glucose, TC, TG, and LDL-C were positively correlated with WHtR SDS and BMI SDS, while HDL-C was negatively correlated with WHtR SDS and BMI SDS.

FM SDS and PBF SDS obtained by DXA were highly

Table 2. Correlations between WHtR SDS and BMI SDS and clinical and DXA-assessed parameters according to sex (n=1,661)

Variable	WHtR SDS		BMI SDS	
	r	*P*-value	*r*	*P*-value
All participants				
SBP	0.192	<0.001	0.257	<0.001
DBP	-0.007	0.780	0.075	0.002
Glucose	0.067	0.006	0.102	<0.001
TC	0.192	<0.001	0.156	<0.001
HDL-C	-0.232	<0.001	-0.265	<0.001
Triglyceride	0.292	<0.001	0.286	<0.001
LDL-C	0.200	<0.001	0.173	<0.001
DXA in whole body				
Lean mass	0.244	<0.001	0.405	<0.001
Fat mass	0.768	<0.001	0.848	<0.001
Fat mass percentage	0.645	<0.001	0.626	<0.001
Lean mass SDS	0.502	<0.001	0.700	<0.001
Fat mass SDS	0.792	<0.001	0.883	<0.001
Fat mass percentage SDS	0.724	<0.001	0.743	<0.001
DXA in trunk				
Lean mass	0.243	<0.001	0.402	<0.001
Fat mass	0.779	<0.001	0.849	<0.001
Fat mass percentage	0.731	<0.001	0.718	<0.001
Lean mass SDS	0.479	<0.001	0.677	<0.001
Fat mass SDS	0.802	<0.001	0.877	<0.001
Fat mass percentage SDS	0.760	<0.001	0.774	<0.001
Boys				
SBP	0.257	<0.001	0.317	<0.001
DBP	0.014	0.671	0.098	0.004
Glucose	0.119	<0.001	0.145	<0.001
TC	0.264	<0.001	0.227	<0.001
HDL-C	-0.200	<0.001	-0.242	<0.001
Triglyceride	0.330	<0.001	0.325	<0.001
LDL-C	0.253	<0.001	0.228	<0.001

(continued)

Table 2. Correlations between WHtR SDS and BMI SDS and clinical and DXA-assessed parameters according to sex (n=1,661) (continued)

Variable	WHtR SDS		BMI SDS	
	r	*P*-value	*r*	*P*-value
DXA in whole body				
Lean mass	0.244	<0.001	0.411	<0.001
Fat mass	0.820	<0.001	0.884	<0.001
Fat mass percentage	0.763	<0.001	0.727	<0.001
Lean mass SDS	0.519	<0.001	0.725	<0.001
Fat mass SDS	0.826	<0.001	0.883	<0.001
Fat mass percentage SDS	0.771	<0.001	0.755	<0.001
DXA in trunk				
Lean mass	0.230	<0.001	0.394	<0.001
Fat mass	0.815	<0.001	0.871	<0.001
Fat mass percentage	0.810	<0.001	0.777	<0.001
Lean mass SDS	0.500	<0.001	0.707	<0.001
Fat mass SDS	0.835	<0.001	0.882	<0.001
Fat mass percentage SDS	0.794	<0.001	0.779	<0.001
Girls				
SBP	0.145	<0.001	0.187	<0.001
DBP	-0.028	0.432	0.041	0.251
Glucose	0.018	0.618	0.052	0.152
TC	0.090	0.013	0.064	0.076
HDL-C	-0.284	<0.001	-0.298	<0.001
Triglyceride	0.245	<0.001	0.235	<0.001
LDL-C	0.124	<0.001	0.104	0.004
DXA in whole body				
Lean mass	0.456	<0.001	0.602	<0.001
Fat mass	0.718	<0.001	0.838	<0.001
Fat mass percentage	0.665	<0.001	0.725	<0.001
Lean mass SDS	0.489	<0.001	0.670	<0.001
Fat mass SDS	0.753	<0.001	0.886	<0.001
Fat mass percentage SDS	0.669	<0.001	0.731	<0.001
DXA in trunk				
Lean mass	0.414	<0.001	0.552	<0.001
Fat mass	0.741	<0.001	0.840	<0.001
Fat mass percentage	0.725	<0.001	0.776	<0.001
Lean mass SDS	0.460	<0.001	0.638	<0.001
Fat mass SDS	0.763	<0.001	0.873	<0.001
Fat mass percentage SDS	0.719	<0.001	0.771	<0.001

WHtR, waist-height ratio; BMI, body mass index; SDS, standard deviation score; DXA, dual-energy X-ray absorptiometry; SBP, systolic blood pressure; DBP, diastolic blood pressure; TC, total cholesterol; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol.
The correlation coefficients (*r*) and statistical significance (*P*-value) were determined using Pearson correlation analysis between WHtR and BMI SDS and clinical and DXA-assessed parameters.

correlated with WHtR SDS and BMI SDS (r>0.724 for all participants). In all participants, the correlation coefficients of the whole-body LM SDS with WHtR SDS and BMI SDS were 0.502 and 0.700, respectively. The values of the whole-body FM SDS with WHtR SDS and BMI SDS were 0.792 and 0.883, respectively. The whole-body PBF SDS also showed high

Table 3. Adjusted correlations between WHtR SDS and BMI SDS and clinical and DXA-assessed parameters (n=1,661)

Variable	WHtR SDS		BMI SDS	
	r	*P*-value	*r*	*P*-value
All participants[†]				
SBP	0.219	<0.001	0.273	<0.001
DBP	0.001	0.962	0.081	<0.001
Glucose	0.071	0.004	0.106	<0.001
TC	0.187	<0.001	0.159	<0.001
HDL-C	-0.241	<0.001	-0.268	<0.001
Triglyceride	0.291	<0.001	0.289	<0.001
LDL-C	0.195	<0.001	0.176	<0.001
DXA in whole body				
Lean mass	0.411	<0.001	0.611	<0.001
Fat mass	0.796	<0.001	0.887	<0.001
Fat mass percentage	0.721	<0.001	0.727	<0.001
Lean mass SDS	0.512	<0.001	0.712	<0.001
Fat mass SDS	0.792	<0.001	0.884	<0.001
Fat mass percentage SDS	0.724	<0.001	0.744	<0.001
DXA in trunk				
Lean mass	0.402	<0.001	0.602	<0.001
Fat mass	0.805	<0.001	0.881	<0.001
Fat mass percentage	0.772	<0.001	0.777	<0.001
Lean mass SDS	0.487	<0.001	0.688	<0.001
Fat mass SDS	0.801	<0.001	0.878	<0.001
Fat mass percentage SDS	0.760	<0.001	0.775	<0.001
Boys[‡]				
SBP	0.304	<0.001	0.356	<0.001
DBP	0.049	0.145	0.128	<0.001
Glucose	0.107	0.001	0.140	<0.001
TC	0.257	<0.001	0.224	<0.001
HDL-C	-0.219	<0.001	-0.256	<0.001
Triglyceride	0.333	<0.001	0.327	<0.001
LDL-C	0.246	<0.001	0.225	<0.001
DXA in whole body				
Lean mass	0.465	<0.001	0.693	<0.001
Fat mass	0.831	<0.001	0.892	<0.001
Fat mass percentage	0.794	<0.001	0.765	<0.001
Lean mass SDS	0.516	<0.001	0.730	<0.001
Fat mass SDS	0.827	<0.001	0.883	<0.001
Fat mass percentage SDS	0.776	<0.001	0.758	<0.001
DXA in trunk				
Lean mass	0.453	<0.001	0.681	<0.001
Fat mass	0.831	<0.001	0.884	<0.001
Fat mass percentage	0.823	<0.001	0.795	<0.001
Lean mass SDS	0.497	<0.001	0.712	<0.001
Fat mass SDS	0.837	<0.001	0.882	<0.001
Fat mass percentage SDS	0.800	<0.001	0.782	<0.001
Girls[§]				
SBP	0.142	<0.001	0.185	<0.001
DBP	-0.042	0.240	0.031	0.383
Glucose	0.033	0.360	0.066	0.067
TC	0.091	0.012	0.065	0.073
HDL-C	-0.287	<0.001	-0.301	<0.001

(continued)

Table 3. Adjusted correlations between WHtR SDS and BMI SDS and clinical and DXA-assessed parameters (n=1,661) (continued)

Variable	WHtR SDS		BMI SDS	
	r	*P*-value	*r*	*P*-value
Triglyceride	0.254	<0.001	0.244	<0.001
LDL-C	0.123	<0.001	0.104	<0.001
DXA in whole body				
Lean mass	0.505	<0.001	0.683	<0.001
Fat mass	0.762	<0.001	0.896	<0.001
Fat mass percentage	0.672	<0.001	0.734	<0.001
Lean mass SDS	0.508	<0.001	0.690	<0.001
Fat mass SDS	0.759	<0.001	0.892	<0.001
Fat mass percentage SDS	0.669	<0.001	0.732	<0.001
DXA in trunk				
Lean mass	0.474	<0.001	0.649	<0.001
Fat mass	0.776	<0.001	0.885	<0.001
Fat mass percentage	0.729	<0.001	0.782	<0.001
Lean mass SDS	0.477	<0.001	0.657	<0.001
Fat mass SDS	0.769	<0.001	0.879	<0.001
Fat mass percentage SDS	0.720	<0.001	0.771	<0.001

WHtR, waist-height ratio; BMI, body mass index; SDS, standard deviation score; DXA, dual-energy x-ray absorptiometry; SBP, systolic blood pressure; DBP, diastolic blood pressure; TC, total cholesterol; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol.
[†]In model 1 of the adjusted correlation analysis, the Pearson correlation coefficient (*r*) was determined after adjustment for age and sex among all participants. [‡]In model 2 of the adjusted correlation analysis, the Pearson correlation coefficient (*r*) was determined after adjustment for age among boys. [§]In model 3 of the adjusted correlation analysis, the Pearson correlation coefficient (*r*) was determined after adjustment for age and sex among girls.

correlation coefficients of 0.724 (for WHtR SDS) and 0.743 (for BMI SDS). The correlation coefficients of trunk FM SDS and PBF SDS with WHtR SDS were higher than those of the whole body.

Table 3 presents age- and sex-adjusted correlations of WHtR SDS and BMI SDS between clinical and DXA-assessed parameters. All clinical parameters except for DBP showed significant correlations with both WHtR SDS and BMI SDS, with P-values less than 0.001. The correlation coefficients of DXA-assessed parameters increased slightly after adjustments. The correlation coefficients of the whole-body LM SDS with WHtR SDS increased from 0.502 to 0.512, and the value of the whole-body LM SDS with BMI SDS increased from 0.700 to 0.712 after adjustments for age and sex among all participants. The correlation coefficients of the whole-body FM SDS with WHtR SDS were the same, 0.792, and the value of the whole-body FM SDS with BMI SDS increased from 0.883 to 0.884 after adjustment for age and sex among all participants. The correlation coefficients of the whole-body PBF SDS with WHtR SDS were the same, 0.724, and the value of the whole-body PBF SDS with BMI SDS increased from 0.743 to 0.744 after adjustments for age and sex among all participants. In the trunk, most of the correlation coefficients of LM SDS, FM SDS, and PBF SDS with WHtR SDS and BMI SDS increased similarly to those of the whole body.

Table 4 shows the results of multiple linear regression analysis between WHtR SDS, BMI SDS, and clinical, DXA-assessed parameters. The coefficients of determination (R^2) for the whole-body LM SDS with WHtR SDS and BMI SDS were 0.290 and 0.525, respectively. The coefficients of determination for the whole-body FM SDS and PBF SDS with WHtR SDS were 0.631 and 0.530, respectively, while the coefficients of determination for the whole--body FM SDS and PBF SDS with BMI SDS were 0.784 and 0.560, respectively. The coefficients of determination for the trunk FM SDS and PBF SDS with WHtR were 0.647 and 0.582, respectively, while the coefficients of determination for the trunk FM SDS and PBF SDS with BMI SDS were 0.772 and 0.605, respectively.

Discussion

We investigated the relationships of WHtR SDS with cardiometabolic risk factors and DXA-assessed parameters. We found that WHtR SDS is highly correlated with these factors in both unadjusted and age- and sex-adjusted Pearson correlations. Specifically, the correlation between WHtR SDS and FM is slightly lower than that between BMI SDS and FM, while the correlation between WHtR SDS and LM is significantly lower than that between BMI SDS and LM. Furthermore, in multiple linear regression analysis, WHtR SDS was highly associated with cardiometabolic risks and DXA-assessed parameters.

Most clinical data, such as SBP, serum glucose, and cholesterol, were significantly correlated with BMI SDS and WHtR SDS. SBP was positively correlated with BMI SDS and WHtR SDS, but DBP was not. Blood sample analysis showed that serum glucose, TC, TG, and LDL-C, but not HDL-C, were positively correlated with BMI SDS and WHtR SDS, while HDL-C was negatively correlated. Previous studies reported a strong association between obesity and hypertension in children and adolescents, based on the relationship between BMI and hypertension.[21-23] In the present study, the association between WHtR SDS and hypertension was also analyzed, and the correlation between WHtR SDS and SBP was found to be similar to the correlation between BMI and SBP. The correlation of SBP with BMI and WHtR SDS was significant (P<0.001). Dyslipidemia is also related to obesity in children and adolescents, such as an increase in TGs and a decrease in HDL-C.[24] The correlations of clinical data with BMI SDS and WHtR SDS in the present study are similar to those in the existing literature. Serum glucose, TC, TG, and LDL-C have significant positive correlations with both BMI SDS and WHtR SDS, but HDL-C has a significant negative correlation with both BMI SDS and WHtR SDS.

According to the main results of this study, WHtR SDS and BMI SDS are good predictors for FM SDS and PBF SDS measured by DXA. Both WHtR SDS and BMI SDS showed high correlation coefficients with FM SDS and PBF SDS for all participants (Table 2). The correlation coefficients remained

Table 4. The multiple linear regression analyses between WHtR SDS and BMI SDS and clinical and DXA-assessed parameters (n=1,661)

Variable	WHtR SDS				BMI SDS			
	β	SE	*P*-value	R^2	β	SE	*P*-value	R^2
All participants[†]								
SBP	1.987	0.217	<0.001	0.168	2.235	0.191	<0.001	0.192
DBP	0.007	0.192	0.972	0.143	0.568	0.171	<0.001	0.148
Glucose	0.418	0.135	0.002	0.089	0.544	0.120	<0.001	0.095
TC	4.427	0.577	<0.001	0.078	3.347	0.518	<0.001	0.069
HDL-C	-2.073	0.203	<0.001	0.086	-2.042	0.180	<0.001	0.093
Triglyceride	12.565	1.014	<0.001	0.089	11.010	0.909	<0.001	0.085
LDL-C	3.987	0.497	<0.001	0.065	3.187	0.446	<0.001	0.058
DXA in whole body								
Lean mass	2.503	0.132	<0.001	0.653	3.271	0.102	<0.001	0.739
Fat mass	4.547	0.084	<0.001	0.672	4.517	0.058	<0.001	0.808
Fat mass percentage	4.569	0.108	<0.001	0.650	4.128	0.095	<0.001	0.658
Lean mass SDS	0.473	0.020	<0.001	0.290	0.589	0.014	<0.001	0.525
Fat mass SDS	0.716	0.014	<0.001	0.631	0.714	0.009	<0.001	0.784
Fat mass percentage SDS	0.659	0.015	<0.001	0.530	0.606	0.013	<0.001	0.560
DXA in trunk								
Lean mass	1.147	0.062	<0.001	0.645	1.509	0.445	<0.001	0.729
Fat mass	2.434	0.044	<0.001	0.677	2.379	0.031	<0.001	0.794
Fat mass percentage	5.754	0.116	<0.001	0.659	5.185	0.103	<0.001	0.667
Lean mass SDS	0.446	0.020	<0.001	0.266	0.561	0.015	<0.001	0.492
Fat mass SDS	0.724	0.013	<0.001	0.647	0.708	0.010	<0.001	0.772
Fat mass percentage SDS	0.692	0.015	<0.001	0.582	0.631	0.013	<0.001	0.605
Boys[‡]								
SBP	2.848	0.302	<0.001	0.225	2.891	0.257	<0.001	0.255
DBP	0.395	0.278	0.156	0.207	0.902	0.239	<0.001	0.217
Glucose	0.638	0.183	0.001	0.083	0.696	0.148	<0.001	0.090
TC	6.339	0.804	<0.001	0.103	4.795	0.702	<0.001	0.088
HDL-C	-1.841	0.273	<0.001	0.097	-1.846	0.234	<0.001	0.112
Triglyceride	14.664	1.403	<0.001	0.117	12.405	1.219	<0.001	0.112
LDL-C	5.247	0.694	<0.001	0.083	4.160	0.604	<0.001	0.073
DXA in whole body								
Lean mass	2.963	1.443	<0.001	0.696	3.772	0.129	<0.001	0.800
Fat mass	5.192	0.116	<0.001	0.699	4.819	0.082	<0.001	0.800
Fat mass percentage	5.344	0.138	<0.001	0.684	4.466	0.126	<0.001	0.647
Lean mass SDS	0.493	0.027	<0.001	0.294	0.602	0.019	<0.001	0.551
Fat mass SDS	0.745	0.017	<0.001	0.692	0.688	0.012	<0.001	0.784
Fat mass percentage SDS	0.703	0.019	<0.001	0.608	0.594	0.017	<0.001	0.583
DXA in trunk								
Lean mass	1.345	0.087	<0.001	0.702	1.727	0.062	<0.001	0.800
Fat mass	2.714	0.061	<0.001	0.701	2.495	0.044	<0.001	0.787
Fat mass percentage	6.483	0.151	<0.001	0.704	5.431	0.139	<0.001	0.662
Lean mass SDS	0.469	0.027	<0.001	0.276	0.579	0.019	<0.001	0.522
Fat mass SDS	0.749	0.016	<0.001	0.707	0.684	0.012	<0.001	0.781
Fat mass percentage SDS	0.724	0.018	<0.001	0.647	0.612	0.016	<0.001	0.619
Girls[§]								
SBP	1.156	0.295	<0.001	0.064	1.483	0.271	<0.001	0.081
DBP	-0.326	0.252	0.197	0.074	0.220	0.234	0.349	0.073
Glucose	0.190	0.200	0.343	0.090	0.372	0.185	0.045	0.093
TC	2.046	0.820	0.013	0.017	1.282	0.763	0.093	0.013
HDL-C	-2.457	0.298	<0.001	0.093	-2.391	0.276	<0.001	0.101
Triglyceride	10.557	1.455	<0.001	0.085	9.442	1.354	<0.001	0.080

(continued)

Table 4. The multiple linear regression analyses between WHtR SDS and BMI SDS and clinical and DXA-assessed parameters (n=1,661) (continued)

Variable	WHtR SDS				BMI SDS			
	β	SE	*P*-value	R^2	β	SE	*P*-value	R^2
LDL-C	2.391	0.707	<0.001	0.024	1.785	0.658	0.007	0.019
DXA in whole body								
Lean mass	2.269	0.136	<0.001	0.506	2.815	0.106	<0.001	0.648
Fat mass	3.746	0.114	<0.001	0.659	4.072	0.073	<0.001	0.839
Fat mass percentage	3.485	0.139	<0.001	0.484	3.537	0.118	<0.001	0.567
Lean mass SDS	0.454	0.028	<0.001	0.286	0.575	0.022	<0.001	0.496
Fat mass SDS	0.691	0.021	<0.001	0.583	0.753	0.014	<0.001	0.799
Fat mass percentage SDS	0.615	0.025	<0.001	0.454	0.624	0.021	<0.001	0.541
DXA in trunk								
Lean mass	1.043	0.068	<0.001	0.528	1.309	0.054	<0.001	0.650
Fat mass	2.092	0.061	<0.001	0.657	2.209	0.042	<0.001	0.813
Fat mass percentage	4.753	0.161	<0.001	0.548	4.735	0.136	<0.001	0.630
Lean mass SDS	0.421	0.028	<0.001	0.256	0.540	0.023	<0.001	0.446
Fat mass SDS	0.703	0.021	<0.001	0.597	0.745	0.015	<0.001	0.775
Fat mass percentage SDS	0.663	0.023	<0.001	0.524	0.659	0.020	<0.001	0.600

WHtR, waist-height ratio; BMI, body mass index; SDS, standard deviation score; DXA, dual-energy x-ray absorptiometry; SBP, systolic blood pressure; DBP, diastolic blood pressure; TC, total cholesterol; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol.

†In model 1, multiple linear regression analysis was conducted after adjustment for age, sex, alcohol consumption, smoking, physical activity, rural residence, household income, and diagnosis of hypertension, type 2 diabetes mellitus (T2DM), and dyslipidemia among all participants. ‡In model 2, multiple linear regression analysis was conducted after adjustment for age, alcohol consumption, smoking, physical activity, rural residence, household income, and diagnosis of hypertension, T2DM, and dyslipidemia among boys. §In model 2, multiple linear regression analysis was conducted after adjustment for age, alcohol consumption, smoking, physical activity, rural residence, household income, and diagnosis of hypertension, T2DM, and dyslipidemia among girls.

high after the adjusting confounding factors (Table 3). The correlations of BMI SDS and WHtR SDS with FM SDS were higher than those with PBF SDS. The correlation differences between WHtR SDS and BMI SDS for FM SDS and PBF SDS were insignificant. However, the difference for LM SDS was quite significant. The correlation coefficient of WHtR SDS for LM SDS was 0.512, while that of BMI SDS for LM SDS was 0.712. BMI is calculated using the subject's weight, which includes not only FM but also fat-free mass. Therefore, BMI is correlated with fat-free mass. However, WHtR SDS has a significantly lower correlation with LM SDS compared to BMI SDS, so WHtR SDS has the advantage of discriminating FM from LM. In a multiple linear regression analysis of all participants, WHtR SDS and BMI SDS also showed high determination coefficients for FM SDS and PBF SDS. Specifically, the coefficient of determination for FM SDS was higher than that for PBF SDS for both indicators. Similar to the adjusted correlation results, WHtR SDS showed a lower coefficient of determination for LM SDS than BMI SDS.

DXA is a well-known and accurate measurement method for FM and PBF, but is expensive and should be applied only by well-trained experts. Anthropometric methods are more accessible. BMI is one of the most widely used methods to evaluate obesity because it is convenient to measure. Some previous studies have reported the relationships between anthropometric measurements and the body fat in Korean children and adolescents,[8,25-27] but they focused on BMI or other anthropometric indices such as WC and tri-ponderal mass index (TMI).

Several systematic reviews have shown that WHtR offers a reasonably good clinical proxy for obesity, in addition to BMI.[28,29] A US National Health and Nutrition Examination Survey-based study[10] demonstrated that WHtR is a better predictor of adiposity than WC and BMI in US children and adolescents. When adjusted for age and sex, the WHtR explained 64% of PBF and even 80% of PBF in that previous study. A cohort study[11] performed by Portuguese researchers with 2,531 7-year-old children used principal component analysis and showed that WHtR is a good proxy for total fat. Two independent body fat patterns were identified: fat quantity and fat distribution. WHtR characterizes fat quantity with BMI and BIA-FMI, and has a correlation coefficient of 0.82 with FM index. A cross-sectional study[12] conducted among Brazilian children showed that WC and WHtR can identify excess android fat measured by DXA. WC and WHtR have areas under the receiver-operating characteristic curve greater than 0.816 for identifying excess android fat.

However, the relationship between WHtR and cardiometabolic risk may vary with age. Sijtsma et al.[30] reported that WHtR is not superior to WC or BMI for estimating PBF in young children aged 3–7 years. Correlations between WHtR and cardiometabolic risk factors were not higher than WC or BMI in overweight/obese children. Sardinha et al.[31] reported similar magnitudes of association of BMI, WC, and WHtR with

cardiometabolic risk factors in children and adolescents aged 8–17 years. Ashwell et al.[32] conducted a systematic review of anthropometric screening tools for cardiometabolic risk factors among more than 300,000 adults from several ethnic groups. That review suggested that WHtR is superior to WC and BMI for detecting cardiometabolic risk factors in adults. The results of the present study, which included a large sample of Korean children and adolescents aged 10–18 years drawn from the KNHANES dataset, are in good agreement with the previous literature.[31] Park et al.[26] showed that the correlation coefficients of TMI for FM and PBF are comparable to those of BMI, but TMI had a lower correlation with fat-free mass than BMI. Those researchers suggested that TMI is a better anthropometric index than BMI for assessing body fat because TMI has intrinsic value for discriminating fat-related body status and health outcomes. Likewise, the correlation coefficients of WHtR SDS with cardiometabolic risk factors in the present study were similar to those of BMI SDS. In addition, WHtR SDS was less correlated with LM than BMI SDS, which is an advantage for discriminating fat-free mass. WHtR is a better anthropometric index than BMI for assessing body fat.

The present research has limitations. While we observed an association between WHtR SDS and cardiometabolic risks and FM, causality or longitudinal questions cannot be addressed since it was a cross-sectional study. Additionally, the association between WHtR SDS and cardiometabolic risks and FM was found to differ by sex, but similar results were observed for other anthropometric indices such as BMI SDS. Furthermore, we did not adjust data to account for puberty among participants, but adjustments for age were made in statistical analyses to address this limitation.

In conclusion, in the present study, we investigated the relationships between anthropometric indices and cardiometabolic risk factors. Cardiometabolic risk factors and body FM assessed by DXA in Korean children and adolescents were highly correlated with WHtR. Additionally, WHtR was better for discriminating fat-free mass. WHtR is a useful and convenient clinical indicator of cardiometabolic risk factors. We recommend that clinicians should measure WC along with height during medical checkups.

Notes

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