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COMPARISON OF VARIOUS ANTHROPOMETRIC INDICES ASSOCIATED WITH ADIPOSITY IN FORECASTING CARDIORESPIRATORY FITNESS IN MACEDONIAN CHILDREN

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(Original scientific paper)

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Abstract

This study investigates anthropometric measures associated with adiposity to forecast cardiorespiratory fitness in Macedonian schoolchildren. The objective was to compare established indices, such as Body Mass Index and Waist-to-Height Ratio, with more contemporary ones, including Relative Fat Mass Pediatric, Tri-Ponderal Mass Index, Waist-to-BMI Ratio, and Grip-to-BMI Ratio. The study was conducted with a sample of 2,197 primary school students, who were grouped according to gender. Data on body weight, height, waist circumference, body fat percentage and cardiorespiratory fitness (assessed by the 20-m shuttle run test), were collected from participants, and regression analyses were carried out to assess the predictive capabilities of the various measures. Results RFMp, Grip-to-BMI Ratio, and BMI were the best CRF predictors. The Grip-to-BMI Ratio was found to be important for males in determining CRF and it was also added into the females category. In boys, BMI and waist circumference were more influential. The conclusion suggests that incorporating new anthropometric indices into clinical practice can enhance the identification of cardiometabolic risk and improve the prevention of health issues in children. These findings support the importance of regular CRF assessments as part of health check-ups.

Keywords: *Cardiorespiratory fitness, Anthropometric indices, Adiposity predictors*

Introduction

A few anthropometric variables like body weight, body fat percentage, waist circumference and anthropometric indices may be potential indicators of risk for various chronic diseases and increased mortality from all causes. Scientific literature from across the globe unequivocally remarks the importance of investigating these variables and indices for the purpose of preventing and addressing metabolic syndrome in children and adolescents, examining cardiometabolic risk factors in children, detecting hypertension in children and adolescents and evaluating the presence of central obesity as a cardiovascular disease risk factor in adults. (Lee et al., 2021; Shen et al., 2017; Wang et al., 2017).

Despite the World Health Organization (WHO) recommendations for the use of the body mass index (BMI) as a standard for assessing adiposity, this index has certain limitations. The most important of these, is that BMI does not show the distribution of fat in the body nor does it make any differentiation between fat free mass and fat mass. In view of these shortcomings, new indices which overcome these limitations of BMI, for example the Triponderal Mass Index (TMI), conicity index (CI), Grip-to-BMI-ratio, relative fat mass pediatric (RFMp) and Waist-BMI ratio are becoming more widely used (Ashwell & Gibson, 2016; Lo et al., 2021).

Cardiorespiratory fitness (CRF) and total body fat percentage are two evaluation criteria that are accepted as important prerequisites of health (Ruiz et al. 2009; Ross & Myers, 2023). For children and young adults, CRF has a profound impact on cardiovascular health, mental health, and academic performance whereas sedentary habits or low CRF tends to have effects similar to obesity and smoking (Franklin et al., 2022; Raghuveer et al., 2020). Due to this, there is a growing consensus among

kinesiologists and other health professionals that CRF should be regularly included in clinical examinations (Ross et al., 2016).

Currently, a combination of field tests such as the 20-meter shuttle run test and CRF predictive equations are widely used alongside body fat percentage screening. These methods are simple, inexpensive, and do not require laboratory conditions (Black et al., 2016; Nevill et al., 2021).

The implementation of anthropometric indicators, including RFMp, TMI, C-index, and Grip-to-BMI ratio, provides supplementary avenues for evaluating the risk of cardiometabolic diseases from a young age (Woolcott & Bergman, 2018; Paek et al., 2019).

The objective of this research is to evaluate the effectiveness of conventional measures for determining body fat, including BMI and WHtR, against with the newer indexes like TMI, waist–BMI ratio, RFMp, C-index, and Grip-to-BMI ratio in forecasting cardiorespiratory fitness in children of school age.

Methods

Participants

The investigation was executed on a cohort comprising 2197 children, sourced from 9 primary educational institutions within the Skopje region of the Republic of North Macedonia. The cohort (mean age 8.1±1.3 years) was stratified into two subsets based on gender: 1096 males and 1101 females. The research encompassed all pupils for whom parental consent was obtained to partake in the study, provided they were psychophysically sound and consistently engaged in physical and health education classes. Participants were treated in compliance with the Helsinki Declaration of 1961 (2013 amendment, Brazil). The research protocols received approval from the Ethics Committee at the University in Skopje.

Measurement of Anthropometric Parameters and Fitness Tests

Measurements were executed by qualified personnel, adhering strictly to the established protocol, encompassing the methodologies for evaluating body weight (BW), body height (BH), body fat percentage (%BF), and waist circumference (WC), alongside the assessment of cardiorespiratory fitness (CRF) via the 20-meter shuttle-run test and the handgrip strength test, through which the Grip-to-BMI ratio index was computed as elaborated in detail within other literature (Zadarko-Domaradzka et al., 2023) In summary, BH and waist circumference were quantified with a precision of up to 0.001 m, utilizing a stadiometer and an anthropometric measuring tape. The assessment of body fat percentage was conducted employing the Tanita BC-418MA single frequency (50Hz) apparatus, which operates on the bioelectric impedance analysis (BIA) methodology. The evaluation of CRF was executed utilizing a 20-meter shuttle-run test (Ortega et al., 2024; Wang et al., 2019), which took place in a physical education facility with concurrent testing of seven children.

Statistical Analysis

The indices used to assess adiposity were derived from the anthropometric measurements using the following calculations:

$$\text{BMI} = \text{body weight (kg)}/\text{body height (m)}^2; \quad (1)$$

$$\text{TPI} = \text{body weight (kg)}/\text{body height (m)}^3; \quad (2)$$

$$\text{WHtR} = \text{waist circumference (cm)}/\text{height (cm)}; \quad (3)$$

$$\text{Waist-BMI ratio} = \text{waist circumference (cm)}/\text{ody mass index (kg/m}^2); \quad (4)$$

$$\text{CI} = \text{WC (m)}/ (0.109 * \sqrt{} (\text{BW (kg)}/ \text{BH (m)})); \quad (5)$$

$$\text{Grip-to-BMI Ratio} = \text{Handgrip Strength (kg)} / \text{BMI (kg/m}^2); \quad (6)$$

$$\text{RFMp for girls and boys} = 74 - (22 \times (\text{height/waist})) + (5 \times \text{sex} *); \quad (7)$$

* sex equals 0 for boys and 1 for girls.

For all examined variables, arithmetic means, standard deviations (SD), as well as the minimum (Min) and maximum (Max) values were calculated. These results were presented for the entire sample of participants as a whole, as well as separately for male and female participants to ensure detailed and comprehensive analysis.

To explore the relationships between anthropometric measures, indices used to assess adiposity, the percentage of body fat, and the results of the cardiorespiratory fitness (CRF) assessment test, regression analyses were applied. Distinct regression models were developed for the overall sample and for each gender separately.

Nine models were developed, progressively incorporating anthropometric measures and indices to evaluate their predictive significance. Sex and age were included as control variables to address potential confounding effects. The predictive power of these variables was measured using the coefficient of determination (R^2), indicating the variance explained in the criterion variable.

To identify the most effective multivariate model, stepwise regression methods were employed, using both backward and forward inclusion techniques. This approach aimed to pinpoint the optimal combination of variables that best explained the variance in CRF outcomes. All statistical analyses were carried out using SPSS software version 26.

Results

Table 1 summarizes the characteristics of the participants (N = 2,197), consisting of 1,101 females (mean age 8.0 years, SD = 1.4) and 1,096 males (mean age 8.1 years, SD = 1.4). These include anthropometric measurements, computed indices, and CRF test results (the number of laps completed).

Table 1. The anthropometrics measures and indices of the analyzed group.

Descriptive Statisticsa	Boys				Girls			
	Mean	SD	Min	Max	Mean	SD	Min	Max
BH	133,0	9,7	110,4	164,0	132,5	10,2	109,8	163,0
BW	33,6	10,3	19,0	85,2	32,5	9,5	18,1	71,7
WC	61,4	9,1	38,8	95,0	59,2	8,2	43,0	96,0
WHtR	0,5	0,1	0,0	0,7	0,4	0,0	0,3	0,7
BMI	18,6	3,7	13,1	36,5	18,2	3,3	12,1	32,9
TPI	14,0	2,4	5,5	27,1	13,7	2,2	6,4	26,4
Waist–BMI-ratio	3,3	0,3	1,3	5,3	3,3	0,3	2,1	4,8
RFMp	73,5	0,1	73,2	73,7	78,5	0,1	78,3	78,7
C-index	1,1	0,1	0,6	2,0	1,1	0,1	0,9	1,6
BF%	23,8	7,9	6,0	44,3	22,9	8,2	5,4	51,2
Grip-to-BMI-ratio	0,7	0,2	0,2	1,4	0,7	0,2	0,2	1,3
20 mSRT (laps)	26,7	13,9	4,0	73,0	20,7	9,5	3,0	70,0

Body weight (BW), body height (BH); body fat percentage (%BF); waist circumference (WC), body mass index (BMI); relative fat mass pediatric (RFMp); tri-ponderal mass index (TMI); waist ircumference (WC); waist-to-height ratio (WHtR); conicity index (C-indeks); handgrip strength kg and BMI kg/m^2 (Grip-to-BMI-ratio).

To address the study's objective, nine regression models were analyzed for the overall sample and separately for males and females, with the number of laps in the 20-m shuttle-run test as the criterion variable. Predictor variables included age, sex, waist circumference, body fat percentage, and anthropometric indices such as BMI, WHtR, TMI, waist-to-BMI ratio, RFMp, C-index, and Grip-to-BMI ratio. For the separate analyses focusing on male and female participants, the variable "sex" was excluded as a predictor to ensure gender-specific insights.

Table 2. Prediction of the CRF test results (laps completed total) through specific specific anthropometric indices - regression analysis results for the entire sample of participants

Models	Factors (Independent)	Regression Models—Statistics		
		R^2	F	p
1	Age, sex, WC	27,1%	268,3	<0.0001
2	Age, sex, BMI	**27,5%**	276,2	<0.0001
3	Age, sex, WHtR	25,7%	249,4	<0.0001
4	Age, sex, TMI	26,1%	256,7	<0.0001
5	Age, sex, waist–BMI ratio	18,1%	158,6	<0.0001
6	Age, sex, RFMp	25,8%	251,2	<0.0001
7	Age, sex, %BF	**30,0%**	289,9	<0.0001
8	Age, sex, CI	17,4%	151,5	<0.0001
9	Age, sex, Grip-to-BMI-ratio	**29,1%**	296,0	<0.0001

Coefficient of determination (R^2); test statistic (F) and p-value for significance of whole model; body mass index (BMI); percentage of body fat (%BF); relative fat mass pediatric (RFMp); tri-ponderal mass index (TMI); waist ircumference (WC); waist-to-height ratio (WHtR); conicity index (C-indeks); handgrip strength kg and BMI kg/m^2 (Grip-to-BMI-ratio)

A detailed examination of Table 2 reveals that, within the overall sample, every predictor variable exhibited a statistically significant effect on the criterion variable. The coefficients of determination for these relationships spanned a range from 17.4% to 30.0%, indicating varying degrees of explanatory power for the predictor variables. Among these, the variables representing the percentage of body fat (%BF), the Grip-to-BMI ratio, and body mass index (BMI) stood out as the most influential, showcasing the highest coefficients of determination. This suggests that these specific variables play a particularly critical role in explaining variations in the criterion variable, reflecting their importance in assessing the underlying dynamics of the analyzed dataset. Their prominence underscores their utility in models predicting outcomes related to physical fitness or health indicators.

For male participants (Table 3), all predictor variables showed statistically significant effects on the criterion variable (number of laps completed in the 20-m shuttle-run test), with coefficients of determination ranging between 13.0% and 28.4%. The variables %BF, WC, and Grip-to-BMI ratio demonstrated the highest coefficients of determination.

Table 3. Prediction of the CRF test results (laps completed total) through specific specific anthropometric indices - regression analysis results for female participants

Models	Factors (Independent)	Regression Models—Statistics		
		R^2	F	p
1	Age, WC	17,4%	115,0	<0.0001
2	Age, BMI	**19,0%**	128,4	<0.0001
3	Age, WHtR	16,6%	106,6	<0.0001
4	Age, TMI	18,4%	122,9	<0.0001
5	Age, waist–BMI ratio	12,4%	77,3	<0.0001
6	Age, RFMp	16,7%	109,0	<0.0001
7	Age, %BF	**24,2%**	162,1	<0.0001
8	Age, C-indeks	10,1%	61,2	<0.0001
9	Age, Grip-to-BMI-ratio	**22,2%**	155,2	<0.0001

Coefficient of determination (R^2); test statistic (F) and p-value for significance of whole model; body mass index (BMI); percentage of body fat (%BF); relative fat mass pediatric (RFMp); tri-ponderal mass index (TMI); waist ircumference (WC); waist-to-height ratio (WHtR); conicity index (C-indeks); handgrip strength kg and BMI kg/m^2 (Grip-to-BMI-ratio).

Likewise, for female participants (Table 4), each predictor variable demonstrated a significant impact on the criterion variable, measured as the number of laps completed in the 20-m shuttle-run test. The coefficients of determination for these relationships ranged from 10,1% to 24.2%, highlighting the varying levels of influence exerted by the predictors.The highest coefficients of determination were noted for the variables %BF, Grip-to-BMI ratio, and BMI.

Table 4. Prediction of the CRF test results (laps completed total) through specific anthropometric indices- regression analysis results for male participants

Models	Factors (Independent)	Regression Models—Statistics		
		R^2	F	p
1	Age, WC	**27,9%**	208,7	<0.0001
2	Age, BMI	27,1%	200,1	<0.0001
3	Age, WHtR	25,8%	187,1	<0.0001
4	Age, TMI	24,8%	179,0	<0.0001
5	Age, waist–BMI ratio	13,0%	79,9	<0.0001
6	Age, RFMp	26,8%	196,8	<0.0001
7	Age, %BF	**28,4%**	201,4	<0.0001
8	Age, C-indeks	14,3%	89,0	<0.0001
9	Age, Grip-to-BMI-ratio	**27,7%**	206,0	<0.0001

Coefficient of determination (R^2); test statistic (F) and p-value for significance of whole model; body mass index (BMI); percentage of body fat (%BF); relative fat mass pediatric (RFMp); tri-ponderal mass index (TMI); waist ircumference (WC); waist-to-height ratio (WHtR); conicity index (C-indeks); handgrip strength kg and BMI kg/m^2 (Grip-to-BMI-ratio).

Multivariate regression analysis was used to identify the best model for predicting CRF test results, incorporating adiposity indices (BMI, WHtR, TMI, waist-to-BMI ratio, RFMp, C-index, Grip-to-BMI ratio) and controlling for sex and age to account for performance differences by gender and age group.

The optimal model was identified through stepwise regression, employing both forward and backward selection techniques. From several alternative models, the final model, as shown in Table 4, was selected. For the overall sample of participants, the regression analysis—adjusted to account for confounding variables such as age and sex—revealed that the number of laps completed in the CRF test decreased with higher values of the indices RFMp, BMI, and waist-to-BMI ratio, while it increased with elevated Grip-to-BMI ratio values.

Table 5. One regression model for the whole test group.

Independent Variables	Laps R^2=34,6%; F=227,1; p < 0.0001				
	B	(95% CI)		p	β
Intercept	115,12	98,51	131,73	<0.0001	x
Grip-to-BMI-ratio	22,10	19,12	25,08	<0.0001	0,33
RFMp	-1,10	-1,27	-0,92	<0.0001	-0,22
Age (years)	2,16	1,74	2,58	<0.0001	0,24
BMI	-1,21	-1,39	-1,03	<0.0001	-0,34
Waist–BMI-ratio	-5,67	-7,62	-3,72	<0.0001	-0,14

Coefficient of determination ($R2$); test statistic (F) and p-value for significance of whole model; regression coefficient with 95% CI (B); value for significance of each regression coefficient (p); value of the standardized coefficient (β); relative fat mass pediatric (RFMp).

In the subsequent step, models enabling the prediction of cardiorespiratory fitness (CRF) were determined separately for girls (Table 5) and boys (Table 6). However, these results demonstrated relatively lower predictive power compared to the combined model, with the model's fit being significantly lower for girls (R^2 = 25.2% for girls and R^2 = 36.4% for boys).

Table 6. Regression model for girls.

Independent Variables	Laps R^2=25,2%; F=91,1; p < 0.0001				
	B	(95% CI)		p	β
Intercept	20,29	10,49	30,10	<0.0001	x
Grip-to-BMI-ratio	17,90	14,27	21,54	<0.0001	0,34
BMI	-0,73	-0,94	-0,51	<0.0001	-0,26
Age (years)	1,28	0,79	1,78	<0.0001	0,19
Waist–BMI-ratio	-2,69	-4,98	-0,40	0.0020	-0,08

Coefficient of determination (R^2); test statistic (F) and p-value for significance of whole model; regression coefficientwith 95% CI (B); value for significance of each regression coefficient (p); value of the standardized coefficient (β).

For girls, the findings revealed a clear relationship between anthropometric indices and performance in the CRF test. Specifically, the number of laps completed decreased when the Grip-to-BMI ratio was lower, indicating diminished physical capacity in such cases. In contrast, performance improved as BMI and waist-to-BMI ratio decreased, indicating a positive link between leaner body composition and enhanced fitness levels. Among all the predictors, the Grip-to-BMI ratio proved to have the strongest influence, as demonstrated by its highest standardized coefficient β, underscoring its critical role in determining cardiorespiratory fitness levels in girls. These results highlight the importance of considering body composition and strength-related metrics when evaluating fitness.

Table 7. Regression model for boys.

Independent Variables	Laps R^2=36,4%; F=151,5; p < 0.0001				
	B	(95% CI)		p	β
Intercept	44,29	44,29	44,29	<0.0001	x
Grip-to-BMI-ratio	26,21	26,21	26,21	<0.0001	0,34
Age (years)	3,37	3,37	3,37	<0.0001	0,32
BMI	-1,76	-1,76	-1,76	<0.0001	-0,45
Waist–BMI-ratio	-9,44	-9,44	-9,44	<0.0001	-0,20

Coefficient of determination (R2); test statistic (F) and p-value for significance of whole model; regression coefficientwith 95% CI (B); value for significance of each regression coefficient (p); value of the standardized coefficient (β).

In boys, fewer laps in the CRF test were associated with a lower Grip-to-BMI ratio, as well as higher values of BMI and waist-to-BMI ratio, highlighting these variables as significant contributors to reduced performance. Among these, BMI demonstrated the strongest impact on the number of laps completed, as indicated by the highest value of the standardized coefficient β. Additionally, the model's predictive capacity was notably greater for boys compared to girls, with an overall coefficient of determination reaching 36.4%, reflecting its higher accuracy in explaining the observed outcomes

Discussion

To our knowledge there are very few studies have looked at the Relative Fat Mass Index (RFM), Tri-Ponderal Mass Index (TMI), Waist-to-BMI Ratio, Grip-to-BMI Ratio and Conicity Index (CI) as predictors of cardiorespiratory fitness (CRF) (Manzano-Carrasco, 2023; Zadarko-Domaradzka et al., 2023; Laga-Govori et al., 2024). So we wanted to see which anthropometric measures and indexes are best at predicting cardiorespiratory fitness in 6-10 year olds. This will add to the evidence that anthropometric measures and indices can predict future health or disease and are useful for public health in children.

Gender-specific analyses revealed distinct patterns. Among male participants, %BF, waist circumference (WC), and Grip-to-BMI Ratio emerged as the strongest predictors of CRF (R^2 values up to 28.4%). In contrast, among female participants, Grip-to-BMI Ratio, BMI, and %BF were the dominant predictors, albeit with slightly lower predictive power (R^2 values up to 24.2%). These findings emphasize the need to consider biological and physiological differences between genders when interpreting fitness assessments and developing intervention strategies (Raghuveer et al., 2020).

The inclusion of novel indices such as RFMp and Grip-to-BMI Ratio provided additional predictive value beyond traditional measures like BMI and WHtR. Notably, Grip-to-BMI Ratio demonstrated a consistent positive association with CRF across all models, highlighting its potential as a practical and accessible indicator for assessing functional fitness in children. These results align with previous studies suggesting the utility of strength-to-weight indices in capturing aspects of physical fitness that are not reflected by traditional adiposity metrics (Nevill et al., 2021; Manzano-Carrasco et al., 2003; Llagjeviq-Govori et al., 2004).

This study is an important contribution with consequences for public health as well as clinical settings. The significant association of CRF with anthropometric indices including BMI and %BF indicates the necessity for regular ′monitoring of these parameters in school-aged children. CRF is an established marker of cardiometabolic health and associated with long-term morbidity and mortality (Ortega et al., 2008; Ruiz et al., 2009).This, together with other CRF assessments performed during routine health check-ups for children, could enable early recognition of participants who are at risk and, therefore, guide interventions in a more targeted manner.

Second, the superior predictive power of novel indices such as Grip-to-BMI Ratio and RFMp suggests that these measures can complement traditional indices in clinical practice. Unlike BMI, which does not distinguish between fat and lean mass, these new indices provide a more nuanced understanding of body composition. Their inclusion in children's health assessments can enhance the accuracy of risk stratification and improve the effectiveness of health promotion strategies.

Several studies have examined various indices to determine their effectiveness in predicting CRF in children. These indices include BMI, waist circumference (WC), waist-to-height ratio (WHtR), and others. The findings from these studies provide insights into which measures and indices are most predictive of CRF and how they can be utilized in health assessments.

Domaradzka et al. (2023) analyzed six anthropometric indices (BMI, WHR, WHtR, TMI, Waist-BMI Ratio, and RFMp) to evaluate their predictive value for cardiorespiratory fitness in children aged 10 to 15 years. Their results indicated that RFMp was the strongest predictor (R^2 = 51.1%) of cardiorespiratory fitness, as assessed by the 20-m shuttle-run test. Similarly, Morina et al. (2022) found that children with high levels of CRF tended to have lower total and abdominal fat, even among those classified as overweight or obese. This suggests that maintaining high CRF can mitigate some of the adverse effects of excess fat (Morina et al., 2022).

In the Macedonian pediatric population, CRF, as measured by the 20-m shuttle-run test, demonstrated high discriminatory power in identifying body fat levels. Specific VO_2 peak cut-off points established in the research indicated that children with lower levels of CRF were significantly more likely to exhibit obesity, defined by waist circumference and waist-to-height ratio (Elezi et al., 2022)

The studies by Manzano-Carrasco et al. (2013) and Llagjeviq-Govori et al. (2024) indicate that the Grip-to-BMI Ratio positively correlates with physical fitness components in both sexes. Similarly, research conducted by Bekoli et al., (2024) Sylejmani et al., (2024), Steffl et al., (2017) and Gontarev et al. (2020) emphasizes the utility of the Grip-to-BMI ratio as a valuable indicator for identifying children who may be at risk of developing sarcopenic obesity.

The relationship between CRF and adiposity is also influenced by other factors, such as lifestyle and diet, with CRF showing strong associations with various fat indicators, including body fat percentage and fat mass (Badrić et al., 2024). Among preschool children, excess body fat has been associated with lower CRF, emphasizing the importance of early intervention.

Despite the excellent findings offered by this study, there are numerous limitations to consider. First, because to the study's cross-sectional methodology, causal correlations between anthropometric indices and CRF cannot be established. Longitudinal studies are needed to validate these correlations and investigate the indices' potential for predicting future health outcomes.

Furthermore, while the 20-m shuttle-run test is a realistic way to quantify CRF, it may not fully capture the multidimensional character of fitness. Additional fitness measurements, such as VO_2 max or muscular endurance tests, may offer a more comprehensive assessment of CRF.

Future research should also explore the applicability of these findings to diverse populations. The sample in this study, consisting of children aged 6–10 years, limits the generalizability of the results to other age groups or ethnic communities. Investigating the utility of these indices among younger children, adolescents, and adults could expand their relevance and applicability.

Conclusion

In conclusion, this study highlights the utility of both traditional and novel anthropometric indices in predicting CRF among school-aged children. The findings emphasize the importance of incorporating body composition metrics into health assessments and support the integration of new indices, such as RFMp and Grip-to-BMI Ratio, into clinical practice. By utilizing these tools, kinesiologists and public health practitioners can enhance the early detection of cardiometabolic risk and promote healthier outcomes for the pediatric population.

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