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Associations of muscular fitness and body composition in children

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ABSTRACT

Purpose: To examine the associations between muscular fitness (MF) and body composition.

Method: MF was assessed with three tests of FitnessGram test battery. Total body fat percentage (BF%), abdominal fat percentage (AF%) and fat-free mass (FFM) were measured by dual-energy X-ray absorptiometry (DXA). The IOTF body mass index (BMI) cut-offs were used to define healthy weight, overweight, and obesity.

Results: MF was inversely associated with BF% and AF%. The children in the moderate and high MF groups had significantly lower BF% and AF% compared with the children in the low MF group within the same BMI category. After adjusting for cardiorespiratory fitness (CRF), BMI and sex, the differences between the MF groups were significant for BF% but not for AF%.

Conclusion: There were significant inverse associations between MF and DXA -measured adiposity. Within the same BMI category, total and abdominal adiposity were lower in children with moderate or high MF than in children with low MF.

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Adiposity; DXA; health-related fitness; obesity; overweight

Introduction

Over the recent decades, obesity has increased among children and adolescents in most countries worldwide (Di Cesare et al., 2019; NCD, 2017; Ng et al., 2014). Furthermore, declines in physical activity (PA) and physical fitness have also been observed (Aubert et al., 2018; Fühner, Kliegl, Arntz, Kriemler, & Granacher, 2021; Tomkinson & Olds, 2007; Tremblay et al., 2010). This is a very worrying trend because both physical fitness and obesity are strongly related to health status in children and adolescents (Di Cesare et al., 2019; Ortega et al., 2018; Ortega, Ruiz, Castillo, & Sjöström, 2008). In addition, childhood obesity tends to track into adulthood, corresponding to an increased risk of cardiometabolic diseases and mortality later in life (Di Cesare et al., 2019; Reilly & Kelly, 2011; Singh, Mulder, Twisk, van Mechelen, & Chinapaw, 2008).

The treatment of obesity is relatively challenging, and thus the potential of physical fitness to attenuate the negative consequences of obesity has been of interest to researchers (Ortega et al., 2018). Certain components of physical fitness, such as cardiorespiratory fitness (CRF) and muscular fitness (MF), are considered to comprise health-related fitness (American College of Sports Medicine, 2018; Caspersen, Powell, & Christenson, 1985), and among these health-related fitness components,

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CRF has been studied the most. Prior studies have clearly shown that CRF is an indicator of health and is strongly associated with health outcomes, such as obesity and abdominal obesity in youth (Ortega et al., 2018; Raghuvver et al., 2020). In addition, there is evidence that increasing CRF in childhood, regardless of weight status, could reduce the risk of developing cardiometabolic health problems associated with obesity later in life (Schmidt, Magnussen, Rees, Dwyer, & Venn, 2016).

Less is still known about the associations between MF and obesity in childhood and in addition, most of the data available from previous studies, are based on body mass index (BMI) -defined obesity (Smith et al., 2014; Thivel, Ring-Dimitriou, Weghuber, Frelut, & O'Malley, 2016). However, BMI is a proxy measure because it does not distinguish between fat mass and non-fat mass (Marra, Sammarco, & De Lorenzo, 2019), whereas dual-energy X-ray absorptiometry (DXA) is the current reference method for the assessment of body composition, providing accurate estimates of total body fat (BF), abdominal region fat (AF) and fat-free mass (FFM) (Marra et al., 2019). As direct measures of body composition are better indicators of adiposity and health risk (Zeng, Dong, Sun, Xie, & Cui, 2012) and also MF is increasingly thought to be important marker of health, understanding the associations between accurately measured adiposity and MF may contribute to the development of evidence-based interventions to prevent childhood obesity.

The aim of this population-based cross-sectional study of eight-year-old children was to examine the associations between MF and body composition assessed by DXA.

Methods

Participants

A random sample ($n = 750$) of eight-year-old children, born in the same year and living in Tampere, Finland, was drawn from the population register. The families of the children were mailed an invitation to participate in the study and informed of the purpose and nature of the study and its measurements. The families willing to participate in the study, responded to the invitation and booked a suitable research time for them. The voluntary children, accompanied by one of their parents, arrived at the UKK-institute research site and both gave their written informed consent upon arrival. The final sample of voluntary children, who provided complete data regarding their MF, CRF, body composition, and anthropometric measurements, consisted of 304, approximately eight years old children (151 girls and 153 boys; mean 8.6 years; range 8.2–9.2 years) The study was approved by the Ethics Committee of Pirkanmaa hospital district (the reference number: R05105).

Muscular fitness (MF) assessments

The assessment of MF was accomplished with three test items from the FitnessGram health-related fitness test battery for children and adolescents, in accordance with the instructions outlined in the test manual (Meredith & Welk, 2010). The chosen test items included a curl-up test, a trunk lift test, and a modified pull-up test. The curl-up test was used to assess abdominal muscle strength and endurance. This test required each participant to perform as many curl-ups as possible following a given cadence. One trial was allowed and the resulting score was the number of curl-ups correctly performed. The trunk lift test was used to assess the strength of the back extensor muscles. This test required each participant to lie prone, lift their upper body off the floor using the extensor muscles of the back, and hold that position while the distance from floor to the child's chin was measured. The resulting score was the distance measured in centimetres. Two trials were allowed and the highest score was recorded. The modified pull-up test was used to assess upper body strength and endurance. This test required each participant to lie in a supine position with their body horizontally straight, grasp a bar placed just out of reach, and pull up toward the bar. One trial was allowed and the resulting score was the number of successfully completed modified pull-ups performed.

The children arrived for MF tests in pairs and before the actual test, the children were given time to practice in pairs but performed the actual test one at a time. Attention was given by the researcher to performance technique during all the tests. Each child was assessed individually by the same experienced researcher (SS). The standardized total MF score was computed from the three test item scores. The three MF test item scores were standardized separately for both sexes, after which the different MF -variables were combined into one variable, and finally divided into the thirds of the obtained variable: low MF (the lowest third), moderate MF (the middle third) or high MF (the highest third).

Cardiorespiratory fitness (CRF) assessment

The assessment of CRF was accomplished with the 20-m shuttle run test (20-mSRT), which involves continuously running between two lines placed 20 m apart, keeping time with a recorded sound signal at a specific pace that grows faster with each minute (Leger, Mercier, Gadoury, & Lambert, 1988; Nevill et al., 2021). We have described the test procedure in detail previously (Stigman et al., 2009). The result of this test was a CRF score, expressed as the number of 20-m-distance laps completed by each participant.

Body composition and anthropometric measurements

The total body fat percentage (BF%), abdominal region fat percentage (AF%), and fat-free mass (FFM) of each participant were measured with DXA (GE Lunar Prodigy Advance, GE Lunar Radiation Corp., Madison, WI). Abdominal region fat, which includes intra-abdominal fat and subcutaneous fat, was evaluated at a manually delineated region of interest that included the soft tissue area of the body between the lowest ribs and the superior border of the iliac crest. Waist circumference (WC) was measured with a measuring tape, midway between the lowest rib and the superior border of the iliac crest. Height was measured to the nearest 0.1 cm and weight was determined using a high-precision electronic scale (F 150S-D2, Sartorius AG, Goettingen, Germany) to the nearest 0.1 kg, and the measurements were used to calculate BMI (kg/m²). The participants were classified as healthy weight, overweight or obese, according to the BMI cut-offs of the International Obesity Task Force (IOTF) for age and sex (Rolland-Cachera, 2011), as recommended by the European Childhood Obesity Group (Jin et al., 2020).

Statistical analysis

Means and standard deviations were calculated for all variables. Pearson's correlation coefficient was used to assess the correlations between the variables. A one-way analysis of variance (ANOVA) was used to examine differences in participant characteristics across the MF groups. When an ANOVA result was statistically significant ($p < 0.05$), a Tukey's or Tamhane's post hoc comparison tests was used to identify specific between-group differences. The influence of MF on BF% and AF% was determined using an analysis of covariance (ANCOVA). The dependent variables (BF% and AF%) were included in the models in their original continuous scales of measurement, and MF group (low, moderate or high) was entered as a factor variable. All models included BMI, sex, and CRF as covariates, and all models were run separately for BF% and AF%. All statistical analyses were carried out using SPSS version 26.0 (IBM Corp, Armonk, NY, USA), and the level of significance was set at $p = .05$.

Results

According to the BMI cut-offs of the IOTF, 80.9% of the participants were of healthy weight (girls: 81.4%, boys: 80.4%), 17.1% were overweight (girls: 17.9%, boys: 16.3%) and 2.0% were obese (girls: 0.7%, boys: 3.3%).

The participant characteristics are shown in Table 1. DXA-measured body composition differed significantly by sex; specifically, girls had significantly higher BF% and AF% than boys, and boys had significantly higher FFM than girls. There were also statistically significant between-sex differences in the MF test results, in that girls were more proficient than boys in the curl-up and trunk lift tests.

The Pearson's correlations coefficients between body composition (BF%, AF%, and FFM) and MF test item results and total MF scores, are shown in Table 2. When the MF test items were examined separately, the strongest correlations were found (among both sexes) between modified pull-up performance and BF% and between modified pull-up performance and AF%. Furthermore, BF% and AF% were significantly correlated with total MF scores (among both sexes). Statistically significant correlation was found between FFM and modified pull-up performance among boys.

Table 3 shows the body composition characteristics in the low, moderate, and high MF groups by sex. Statistically significant differences in weight, BMI, and WC were found between MF groups among both sexes. Furthermore, BF% and AF% were significantly higher among both sexes in the low MF group compared with the moderate and high MF groups.

The participants' body composition characteristics were examined within the BMI categories (healthy weight, overweight and obese) and compared between the low, moderate, and high MF groups (Table 4). Among the healthy weight children, BF% was significantly higher in the low MF group than in the moderate and high MF groups, and AF% was significantly higher in the low MF group than in the high MF group. Among the overweight and obese children, BF% was significantly higher in the low MF group than in the moderate and high MF groups, and the AF% was significantly higher in the low MF group than in the moderate MF group. Furthermore, weight and BMI differed between the low and moderate MF groups among the overweight and obese children.

When the associations between MF and BF% and AF% were examined, adjusting for CRF, BMI, and sex, the differences between MF groups were statistically significant for BF% ($p = 0.005$) but not for AF% ($p = 0.192$). Specifically, the statistically significant differences in BF% were found between the high and low MF groups ($p = 0.011$) and between the moderate and low MF groups ($p = 0.010$). (Figure 1a and b).

Discussion

The aim of the present study was to examine the associations between MF and accurately assessed body composition in a population-based sample of eight-year-old children. The main finding was that there were strong inverse associations between MF and total body fatness and between MF and abdominal fatness. The children with lower MF had higher total body adiposity and abdominal

Table 1. Characteristics of all the participants by sex. Means (SD).

	All (<i>N</i> = 304)	Girls (<i>n</i> = 151)	Boys (<i>n</i> = 153)	<i>p</i>
Weight (kg)	30.9 (5.6)	30.7 (5.5)	31.2 (5.6)	.482
Height (cm)	134.2 (5.8)	133.8 (5.6)	134.7 (6.0)	.174
BMI (kg/m ²)	17.1 (2.1)	17.1 (2.1)	17.1 (2.2)	.971
Waist circumference (cm)	59.7 (6.2)	59.3 (6.1)	60.1 (6.2)	.286
Total body fat (%)	21.6 (7.7)	24.0 (6.9)	19.2 (7.7)	<.001
Abdominal region fat (%)	23.3 (11.2)	26.5 (10.5)	20.2 (10.9)	<.001
Fat-free mass (kg)	22.7 (2.8)	21.8 (2.5)	23.6 (2.8)	<.001
Muscular fitness tests				
Curl up (reps)	11.0 (11.8)	12.9 (12.4)	9.2 (10.9)	.006
Trunk lift (cm)	14.1 (3.8)	15.5 (3.8)	12.8 (3.4)	<.001
Modified pull-up (reps)	5.5 (4.4)	5.2 (4.0)	5.8 (4.8)	.250
Cardiorespiratory test				
20-m shuttle run test (laps)	22.5 (8.5)	20.6 (7.2)	24.2 (9.5)	<.001

Table 2. The Pearson's correlation coefficient between body composition and MF test items and MF total score by sex.

		Curl-up	<i>p</i>	Trunk lift	<i>p</i>	Pull-up	<i>p</i>	Total MF	<i>p</i>
Girls	Total body fat (%)	−.194	.017	−.079	ns	−.550	<.001	−.385	<.001
	Abdominal fat (%)	−.200	.014	−.032	ns	−.524	<.001	−.353	<.001
	Fat-free mass (kg)	−.013	ns	−.102	ns	−.147	ns	−.027	ns
Boys	Total body fat (%)	−.191	.018	.025	ns	−.496	<.001	−.316	<.001
	Abdominal fat (%)	−.196	.015	.047	ns	−.477	<.001	−.299	<.001
	Fat-free mass (kg)	−.091	ns	.102	ns	−.189	.020	−.085	ns

Statistically significant differences are bolded, ns; not significant.

Table 3. Body composition of the girls and boys by thirds of muscular fitness (low, moderate and high MF). Means (SD).

	Girls			Boys		
	Low MF ^a (<i>n</i> = 50)	Mod MF ^b (<i>n</i> = 50)	High MF ^c (<i>n</i> = 51)	Low MF ^a (<i>n</i> = 50)	Mod MF ^b (<i>n</i> = 52)	High MF ^c (<i>n</i> = 51)
Weight (kg)	32.7 (7.2) ^c	30.0 (4.5)	30.0 (4.0) ^a	33.1 (6.5) ^b	30.1 (4.2) ^a	30.4 (5.5)
Height (cm)	134.9 (6.1)	133.0 (5.6)	133.4 (5.1)	136.3 (6.5)	134.2 (5.8)	133.5 (5.5)
BMI (kg/m ²)	17.8 (2.8) ^c	16.9 (1.7)	16.5 (1.5) ^a	17.8 (2.6) ^b	16.6 (1.5) ^a	16.9 (2.2)
WC (cm)	62.0 (7.8) ^{b,c}	58.0 (4.5) ^a	58.0 (4.6) ^a	62.1 (7.2) ^b	58.9 (4.8) ^a	59.3 (6.1)
BF (%)	27.8 (7.5) ^{b,c}	23.0 (5.8) ^a	21.3 (6.9) ^a	22.9 (8.8) ^{b,c}	17.2 (5.6) ^a	17.5 (7.1) ^a
AF (%)	31.6 (11.1) ^{b,c}	25.5 (9.4) ^a	22.6 (9.0) ^a	24.8 (12.8) ^{b,c}	17.7 (7.6) ^a	18.2 (10.7) ^a
FFM (kg)	21.9 (3.1)	21.7 (2.2)	21.9 (2.5)	23.8 (2.9)	23.5 (2.7)	23.5 (2.8)

AF; abdominal region fat, BF; total body fat, FFM; fat-free mass, WC; waist circumference.

Superscripts refer to the MF category from which the relevant variable is significantly different ($p < .05$) according to Tukey or Tamhane post hoc -test.

Table 4. The body composition characteristics within the BMI categories (healthy weight, overweight and obese) by the MF groups. Means (SD).

	Healthy weight			Overweight and obese		
	Low MF ^a (<i>n</i> = 69)	Mod MF ^b (<i>n</i> = 86)	High MF ^c (<i>n</i> = 91)	Low MF ^a (<i>n</i> = 31)	Mod MF ^b (<i>n</i> = 16)	High MF ^c (<i>n</i> = 11)
Weight (kg)	29.8 (4.4)	29.0 (3.7)	28.9 (3.4)	39.7 (6.2) ^b	35.6 (3.1) ^a	38.8 (6.0)
Height (cm)	134.5 (6.3)	133.3 (5.8)	133.1 (5.2)	138.1 (5.7)	135.4 (4.9)	137.0 (4.9)
BMI (kg/m ²)	16.4 (1.4)	16.3 (1.2)	16.3 (1.1)	20.9 (2.3) ^b	19.4 (0.8) ^a	20.5 (2.2)
WC (cm)	58.4 (4.2)	57.1 (3.6)	57.6 (4.0)	70.0 (6.9)	65.6 (3.1)	67.6 (7.6)
BF (%)	21.4 (6.8) ^{b,c}	18.8 (5.8) ^a	18.1 (5.7) ^a	34.1 (4.1) ^{b,c}	27.0 (4.9) ^a	30.2 (4.7) ^a
AF (%)	22.3 (9.4) ^c	19.6 (8.3)	18.5 (8.3) ^a	41.3 (7.0) ^b	31.9 (7.9) ^a	36.2 (9.8)
FFM (kg)	22.0 (2.9)	22.2 (2.5)	22.3 (2.3)	24.8 (2.9)	24.7 (2.3)	25.7 (3.2)

AF; abdominal region fat, BF; total body fat, FFM; fat-free mass, WC; waist circumference.

Superscripts refer to the MF category from which the relevant variable is significantly different ($p < .05$) according to Tukey or Tamhane post hoc -test.

adiposity compared to the children with higher MF. These associations were observed among both sexes. The present results are consistent with and expand upon previous findings of associations between MF and obesity as a health outcome, for which obesity has mainly been defined based on BMI or abdominal obesity indicated by WC (Ortega et al., 2008; Smith et al., 2014; Thivel et al., 2016). However, making comparisons between the studies of these associations is challenging because there are no standard procedures for the assessment of MF in children. Assessments of MF with lower body weight bearing tests have consistently been shown to be inversely associated with adiposity, which is commonly measured by BMI or WC (Ortega et al., 2008; Smith et al., 2014; Thivel et al., 2016). Contrary to these findings, positive associations have been found between muscle strength and adiposity, when muscle strength has been assessed with the handgrip test (Ortega et al., 2008; Smith et al., 2014; Thivel et al., 2016).

Adiposity and especially increased abdominal adiposity (measured by DXA) have been shown to be independently associated with increased cardiometabolic health risk in obese children and

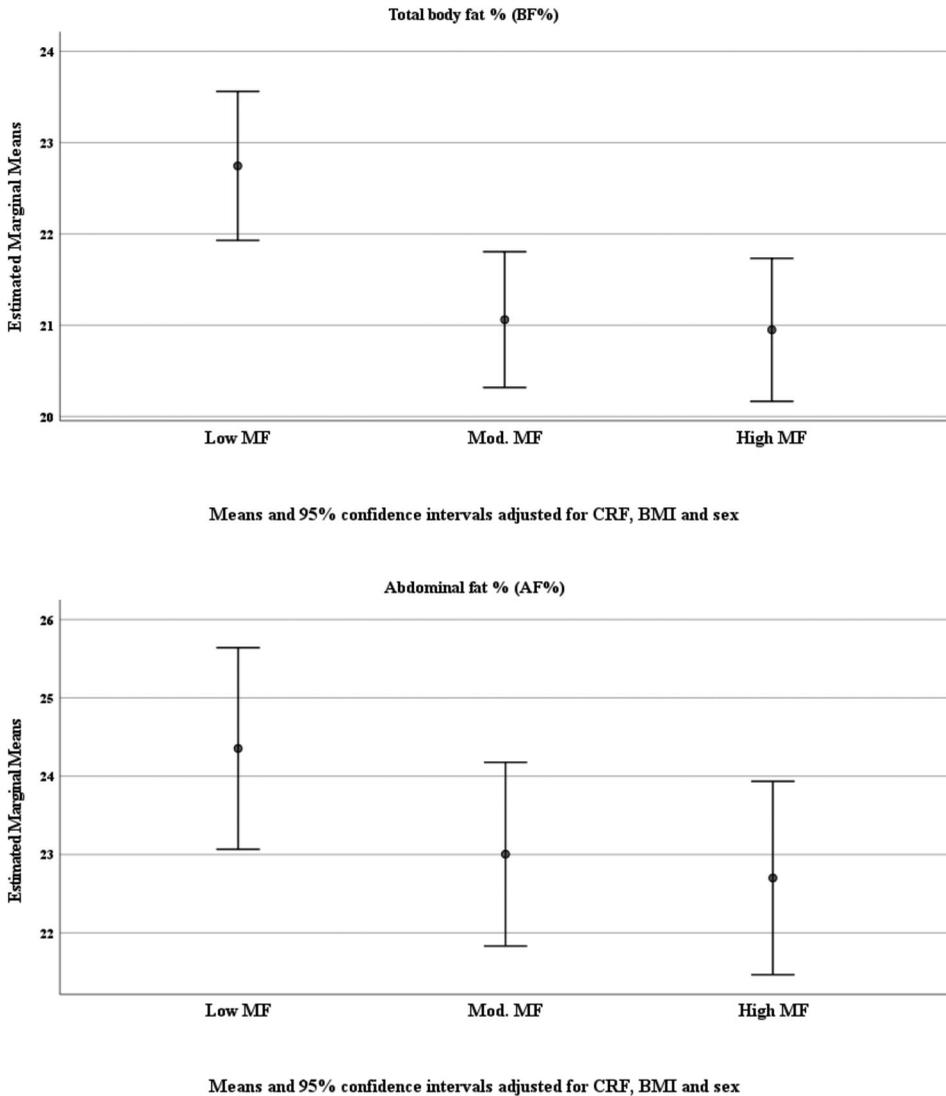


Figure 1. Mean cardiorespiratory fitness (CRF), body mass index (BMI), and sex adjusted values for low, moderate and high muscular fitness (MF) groups, for total body fat percentage (BF %) and abdominal region fat percentage (AF %).

adolescents (Jin et al., 2020). Conversely, there is accumulating evidence that health-related fitness, especially CRF, is associated with adiposity and may counteract the negative consequences of obesity in childhood (Ortega et al., 2018; Schmidt et al., 2016). Less is still known about the effect of MF in children and adolescents (Ortega et al., 2018). In longitudinal studies (García-Hermoso, Ramírez-Campillo, & Izquierdo, 2019) MF has been found to be inversely associated with adiposity and cardiometabolic risk. However, none of these studies assessed body composition with sophisticated methods. It is not possible to estimate whether MF attenuates the obesity-related future health risks of the children in the present cross-sectional research. However, the overweight and obese children with higher MF had significantly lower total and abdominal adiposity than the children with lower MF at the same BMI category. The similar association was observed among the healthy-weight children. Regardless of BMI category, higher MF was associated with lower total and abdominal adiposity.

The present study examined the associations between MF and DXA -measured adiposity after adjusting for CRF, BMI and sex, it was found that children with higher MF had lower total adiposity compared to children with lower MF, but no statistically significant differences were found in abdominal adiposity between MF groups. Further studies of children, using sophisticated methods of body composition measurement are needed to determine whether higher MF contributes to lower total and abdominal adiposity or whether higher MF counteracts the negative health consequences of obesity.

The main strength of this study was the use of an accurate method (DXA) to assess body composition. Another strength was that all the participating children were born in the same year and recruited from the sample, which was randomly drawn from a population register. The sample of participating children was representative of their age group, considering the distribution of healthy-weight, overweight, and obese children (Vuorela, 2011). This study also had limitations. One limitation was that causal inferences could not be made due to the cross-sectional design of the study. In addition, the use of field tests to determine MF may not be ideal. Excessive body fat is an extra load that may adversely affect MF performance, especially when MF performance is measured with weight-bearing tests. However, field tests seem to provide results comparable to laboratory-based data in the assessment of overall MF in children, including those with obesity (Thivel et al., 2016). In the present study, MF was assessed with three test items of the FitnessGram, which is a valid and reliable, practical field test battery that has been widely used test to assess health-related fitness in children and youth (Kolimechkov, 2017; Plowman, 2013). These three test items mainly assess middle and upper body strength and endurance; thus, these items may be more suitable for children with excessive weight compared to test items that measure weight-bearing lower body strength.

The prevention of childhood obesity and the improvement of health-related fitness both have great impacts on public health (Chaput et al., 2020). Thus, the results of the present study of significant inverse associations between MF and DXA-measured total and abdominal adiposity in eight-year-old children, are important. Longitudinal studies have shown that childhood obesity often tracks into adulthood, and obesity is often difficult to treat (Di Cesare et al., 2019). In addition, studies have shown that youth with low MF are at an increased risk of maintaining low MF level into adulthood (Fraser et al., 2017). The persistence of weight status, the known health risks of obesity, and the low efficacy of obesity management, highlight the importance of health-related fitness. In particular, it would be important to inform kindergarten and lower grade school teachers about the importance of MF for health and for regularly include age-appropriate motivational MF enhancing activities.

Conclusion

The results of this population-based cross-sectional study revealed significant inverse associations between MF and DXA-measured total and abdominal adiposity in eight-year-old children. Within the same BMI category, total and abdominal adiposity were lower in children with moderate or high MF than in children with low MF. After adjusting for CRF, children with moderate or high MF had lower total adiposity compared to children with low MF. More studies utilizing accurate measures of body composition are needed to determine whether higher MF could attenuate the negative health consequences of obesity in children.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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