Received: 6 November 2023 | Revised: 1 May 2024 | Accepted: 6 May 2024
DOI: 10.1111/apa.17274

ACTA PÆDIATRICA
NURTURING THE CHILD
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ORIGINAL ARTICLE

Negative associations between step-up height and waist circumference in 8-year-old children and their parents

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Funding information
The Swedish Heart Lung Foundation, Grant/Award Number: 20150692 and 20170706; Skandia Mutual Life Insurance Company

Abstract

Aim: To study cross-sectional relationships between step-up height and waist circumference (WC), a potential proxy for sarcopenic obesity, in Swedish children and parents.

Methods: Participants were recruited from Swedish schools in disadvantaged areas in 2017. Height, body weight, WC and maximal step-up height were measured in 67 eight-year-old children and parents: 58 mothers, with a mean age of 38.5 and 32 fathers, with a mean age of 41.3. Sedentary time and physical activity were registered by an accelerometer. Associations between maximal step-up height and WC were analysed using Pearson's correlation and adjusted linear regression.

Results: Abdominal obesity, WC ≥ 66 centimetres (cm) in children, ≥88 cm in women and ≥102 cm in men, was observed in 13% and 35% of girls and boys, and in 53% and 34% among mothers and fathers, respectively. Negative associations between maximal step-up height and WC were found for children ($r = -0.37$, $p = 0.002$) and adults (mothers $r = -0.58$, $p < 0.001$, fathers $r = -0.48$, $p = 0.006$). The associations remained after adjustments for height, body mass index (BMI) and physical activity in adults. Reduced muscle strength clustered within families ($r = 0.54$, $p < 0.001$).

Conclusion: Associations between reduced muscle strength and abdominal obesity were observed in children and parents. Sarcopenic obesity may need more attention in children. Our findings support family interventions.

KEYWORDS
abdominal obesity, family, muscle strength, physical activity, Sarcopenic obesity

1 | INTRODUCTION

In Sweden, as well as in many other countries, children, adolescents and adults spend 9–10 h sedentary per day, and few children and adolescents meet the current physical activity guidelines.[1,2] Consequently, a steep decrease in fitness and reduced physical capacity in both adults and children have been reported from many countries. A study of 627 142 healthy young male conscripts, age 19.1 ± 0.4 years, entering the mandatory military service in Finland during the years 1975–2015 revealed a steep decrease in aerobic

Abbreviations: BMI, body mass index; cm, centimetre; kg, kilogram; WC, waist circumference.

capacity and, in addition, a decline in muscle fitness.[3] A study from Lithuania on secular trends in physical fitness in 16199 schoolchildren aged 11–18 years demonstrated loss of both cardiovascular fitness and muscle strength between 1992 and 2012.[4]

There are several different definitions of metabolic syndrome as well as different cut-off levels for WC in both children and adults, creating variations in the prevalence of metabolic syndrome and abdominal obesity in different studies. Obesity and, in particular, central obesity and metabolic syndrome are increasing in all age groups and in most societies.[5,6]

Extensive research has shown that metabolic syndrome is linked to an increased risk of the majority of our public health problems and, in particular, type 2 diabetes and cardiovascular disease.[7] Abdominal obesity is a central component in the pathogenesis of the metabolic syndrome.[8] The simultaneous occurrence of overweight or obesity and weak muscles or reduced muscle mass, sarcopenic obesity, has attracted attention as an important risk factor for common public diseases like type 2 diabetes and cardiovascular diseases. In a study in the United Kingdom of 490301 participants, with a median age of 70.0 years, 46% male, it was reported that sarcopenic obesity was associated with an increased risk of severe COVID-19. It was also concluded that sarcopenic obesity may increase the risk of severe COVID-19 over that of obesity alone.[9]

Previous studies on sarcopenic obesity have mainly focused on the adults and the elderly.[10] However, in a recent systematic review of studies on the definition, prevalence and adverse outcomes of sarcopenic obesity in children and adolescents, a total of 18 articles were included. There was heterogeneity in the methods used to define sarcopenic obesity, and different kinds of populations were studied, leading to a variation in prevalence between 6% and 70% in girls and between 7% and 81% in boys. In eight studies that evaluated outcomes related to sarcopenic obesity, a significant association with different cardiometabolic outcomes, non-alcoholic fatty liver disease, inflammation and mental health was noted.[11]

Low cardiorespiratory fitness was associated with a significantly higher burden of future disability in a Swedish study in 1079128 male adolescents aged 16–19 followed for 28 years.[12] During that period, 54304 men were granted a disability pension. It is also clear from prospective studies in adults that muscular strength is independently and negatively associated with increased risk of type 2 diabetes, cardiovascular mortality, cancer mortality and total mortality.[13,14] A negative association between muscle fitness in childhood or adolescence and overweight and obesity as well as other cardiometabolic parameters later in life has also been demonstrated in prospective studies.[15]

The primary aim of the present study was to investigate the associations between maximal step-up height as a measure of leg muscle strength and WC as a measure of abdominal obesity and metabolic risk in 8-year-old children and their parents. The secondary aim was to study whether there were associations for maximal step-up height or WC between children and parents within the same family.

Key notes

- Sarcopenic obesity is a known risk factor for common public diseases among adults, but better knowledge of this subject in children is needed.
- Independent negative associations were shown between maximal step-up height and waist circumference in children and parents, and clustering of reduced muscle strength was noted within families.
- Sarcopenic obesity poses a threat to children's future health, and more effective preventive measures focusing on whole families are needed.

2 | METHODS

2.1 | Study design, setting and participants

In this cross-sectional study, the participants took part in an evaluation of an ongoing national health promotion programme, which has been described elsewhere.[16] In brief, the programme aims to support families in a more physically active and healthier lifestyle and is running in collaboration with schools and local sports associations in municipalities. The area where the study was conducted, a municipality outside Stockholm, has a somewhat lower socioeconomic status compared to the national average in Sweden. Children in grade 2 (8–9 years) and their parents were invited and least one parent in each family should take part. In total, 67 children, 58 mothers and 32 fathers agreed to participate in the study. Before the intervention started from May to June 2017, children and their parents underwent a health check which included measurements of anthropometric variables, maximal step-up height and physical activity.

2.2 | Ethics statement

The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Regional Ethical Review Board in Stockholm, Sweden (Dnr 2016/447-31/2 and 2016/1254-32). Parents gave their informed written consent before the family was included in the study. The trial registration number is ISRCTN11660938.

2.3 | Data collection

2.3.1 | Anthropometry

Weight was measured according to standardised procedures using a calibrated scale to the nearest 0.1 kg and height with a stadiometer to the nearest centimetre. Body mass index (BMI) was calculated as weight (kg) divided by height (metres) squared. Overweight and obesity for children were defined according to the International Obesity Task Force recommendation.[17] WC was measured with the subjects in the standing position after a normal expiration at the midway point between the iliac crest and the lower rib margin. Abdominal obesity for children was defined according to a Norwegian study of 5725 healthy children, 51% boys, 4–18 years of age, as WC ≥ 66 cm in 8-year-old children corresponding to 95th percentile and for parents according to the American Heart Association; National Heart, Lung and Blood Institute; Diagnosis and Management of the Metabolic Syndrome as ≥88 cm in women and ≥102 cm in men.[18,19]

2.3.2 | Maximal step-up height

The standardised maximal step-up test assessing leg muscle strength and function as maximal step-up height with body weight as the loading has been described in detail elsewhere.[20] Instructions for the maximal step-up test provided to the participant are presented in Figure 1.

The participants were instructed to perform the step-up onto the box slowly to allow the tester to detect push-off with the foot on the floor. Imbalance in the whole body, excessive use of arms, or any reliance on handlebars on the box would render the step-up test not approved at the current level.

2.3.3 | Physical activity

The level of physical activity and time spent sedentary were assessed by accelerometry from Actigraph model GT3X+ (Actigraph, LCC, Pensacola, USA). The measurement of physical activity has been described in detail elsewhere.[16] In brief, the children and parents wore the accelerometers in an elastic belt at the right hip during all waking hours for 7 consecutive days and removed the monitors for activities involving water. The epoch length was set to 5 s for children and 60 s for parents. Children and parents with at least 500 min/600 min of activity registration per day for a minimum of 1 day were included in the analysis. Cut-off-points for children and parents for sedentary intensity were defined as all activity below 100 counts per minute/100 counts per minute, which corresponds to sedentary activities such as sitting and lying down with an energy expenditure below the metabolic equivalent of 1.5, and moderate to vigorous intensity was defined as all activity ≥2296 counts per minute/2020 counts per minute.

2.4 | Statistics

Descriptive statistics are presented as means and standard deviations (±). Pearson's correlation was performed to analyse unadjusted associations between maximal step-up height on the right leg and WC. Similar results were found for maximal step-up test on the left leg and therefore only the maximal step-up test on the right leg was included in the analyses. Linear regression was conducted to explore associations between the dependent variable maximal step-up height and WC, in children, mothers and fathers, adjusted for height, BMI and minutes in moderate to vigorous physical activity. Pearson's correlation was used to analyse associations between maximal step-up height and WC in children and their mothers and their fathers. The level of statistical significance was set to $p < 0.05$. Data analyses were conducted using Statistica version 13.5 (Statsoft Inc., Oklahoma, USA).

3 | RESULTS

3.1 | The study population

In total, 67 families participated in the investigation, with a 26% response rate for families. Sixty-seven children, 30 girls aged 8.2 ± 0.29 years, 37 boys aged 8.2 ± 0.34 years, and 90 parents, 58 mothers aged 38.5 ± 6.2 years and 32 fathers aged 41.3 ± 6.2 years formed the study population. The characteristics of the study population are presented in Table 1.

- Place one foot on the step-up box at a height lower than expected.
- Stand tall and look straight ahead.
- Rise onto your toes as high as possible with the foot on the floor, while your body weight rests on the floor foot. Find your balance.
- Transfer all your body weight onto the foot on the box and regain balance.
- From there, perform the step-up slowly onto the box without using a push-off with the foot on the floor.
- Bring both feet together on the box to complete the maximal step-up test. The tester approves a correct test.
- Repeat the test on the other leg. The tester approves a correct maximal step-up test.
- The tester increases the height of the step-up box by 3 cm each time until you are unable to perform the test as described.

FIGURE 1 Instructions given to the participants for the maximal step-up test.

TABLE 1 Characteristics of participating children and parents (mean and standard deviation unless otherwise specified).

	Girls		Boys		Mothers		Fathers	
	n	Mean (±)	*n*	Mean (±)	*n*	Mean (±)	*n*	Mean (±)
Total		*n*=30		*n*=37		*n*=58		*n*=32
Age (years)	30	8.2 (0.29)	37	8.2 (0.34)	58	38.5 (6.2)	32	41.3 (6.2)
Height (cm)	30	129 (5.0)	35	132 (6.5)	58	163 (6.4)	32	176 (6.9)
Body weight (kg)	29	27.7 (6.1)	34	31.1 (7.9)	52	72.3 (16.1)	31	88.0 (19.8)
BMI	29	16.6 (3.0)	33	17.8 (3.2)	52	27.4 (6.1)	31	28.3 (6.5)
Waist circumference (cm)	30	60 (6.9)	37	64 (8.6)	56	91 (14.7)	32	100 (15.9)
Maximal step-up height left leg (cm)	30	30 (6.5)	37	28 (5.5)	55	34 (6.6)	32	39 (8.9)
Maximal step-up height right leg (cm)	30	30 (6.6)	37	28 (5.5)	55	34 (6.3)	32	39 (8.6)
Sedentary time, week (min)	26	441 (122)	28	442 (83)	48	475 (89)	25	533 (115)
Moderate-vigorous physical activity, week (min)	26	63 (16)	28	69 (26)	48	31 (14)	25	37 (21)
Overweight/obesity (%)[a]	29	27/4	33	24/12	52	35/25	31	48/19
Waist circumference at risk (%)[b]	30	33	37	51	55	73	32	63
Waist circumference obesity (%)[c]	30	13	37	35	55	53	32	34

[a]Overweight and obesity for boys and girls defined according to the International Obesity Task Force recommendations, for mothers and fathers defined as a BMI ≥25 and obesity ≥30.

[b]At risk defined as ≥61 cm for boys and girls, ≥80 cm for mothers and ≥94 cm for fathers.

[c]Abdominal obesity defined as ≥66 cm for boys and girls, ≥88 cm for mothers and ≥102 cm for fathers.

A quarter of the children and half of the fathers were overweight. Among mothers, the prevalence of overweight was somewhat lower compared to fathers, 35% versus 48%. On the other hand, data from the measurements of WC showed that abdominal obesity was more prevalent in mothers compared to fathers, 53% versus 34%. In children, abdominal obesity was more common in boys compared to girls, 35% versus 13%.

The mean maximal step-up height (right leg) was 30 ± 6.5 cm, in girls, 28 ± 5.5 cm in boys, 34 ± 6.6 cm in mothers and 39 ± 8.6 cm in fathers. In total, 42% of the women and 38% of the men had a lower maximal step-up height than 32 and 35 cm, indicating low muscle strength.[21]

Children spent more than 7 hours per day in sedentary activities, girls 441 ± 122 minutes per day and boys 442 ± 83 minutes per day. Mothers and fathers spent 8–9 hours per day sedentary, 475 ± 89 minutes per day and 533 ± 115 minutes per day, respectively. Time spent in moderate to vigorous physical activity was approximately 1 hour per day in children and half an hour in parents, girls 63 ± 6 min and boys 69 ± 26 min, mothers 31 ± 14 min and fathers 37 ± 21 min.

3.2 | Associations between maximal step-up height and waist circumference

The associations between maximal step-up height and WC in children and parents are presented in Figure 2A–C. A linear negative association between maximal step-up height and WC was noted for both children and parents. Significant associations between maximal step-up height and WC were found in children ($r = -0.37$, $p = 0.002$). In a sub-group of 16 children with abdominal obesity, WC ≥ 66 cm, the association between maximal step-up height and WC was stronger ($r = -0.69$, $p = 0.002$) compared to children without abdominal obesity ($r = -0.23$, $p = 0.12$). Significant associations between maximal step-up height and WC were also found in mothers ($r = -0.58$, $p < 0.001$) and in fathers ($r = -0.48$, $p = 0.006$). In a linear regression model with maximal step-up height as the dependent variable, the association with WC was still significant for mothers ($b = -0.29$, $p = 0.04$) and fathers ($b = -0.62$, $p = 0.02$) but not for children ($b = -0.50$, $p = 0.12$) when adjusting for height, BMI and a weekly average of moderate to vigorous physical activity.

3.3 | Correlation maximal step-up height and high waist circumference within families

The correlation between parents and children was strong and significant for maximal step-up height, for mothers and children ($r = 0.54$, $p < 0.001$), and for children and fathers ($r = 0.65$, $p < 0.001$). However, the correlation was not significant between parents and children for WC.

4 | DISCUSSION

The main finding of this study in 8-year-old children and their parents was the linear negative association between maximal step-up height and WC. The higher the maximal step-up height, the lower the WC. The association persisted when a weekly average of moderate to vigorous physical activity, BMI and body height were adjusted

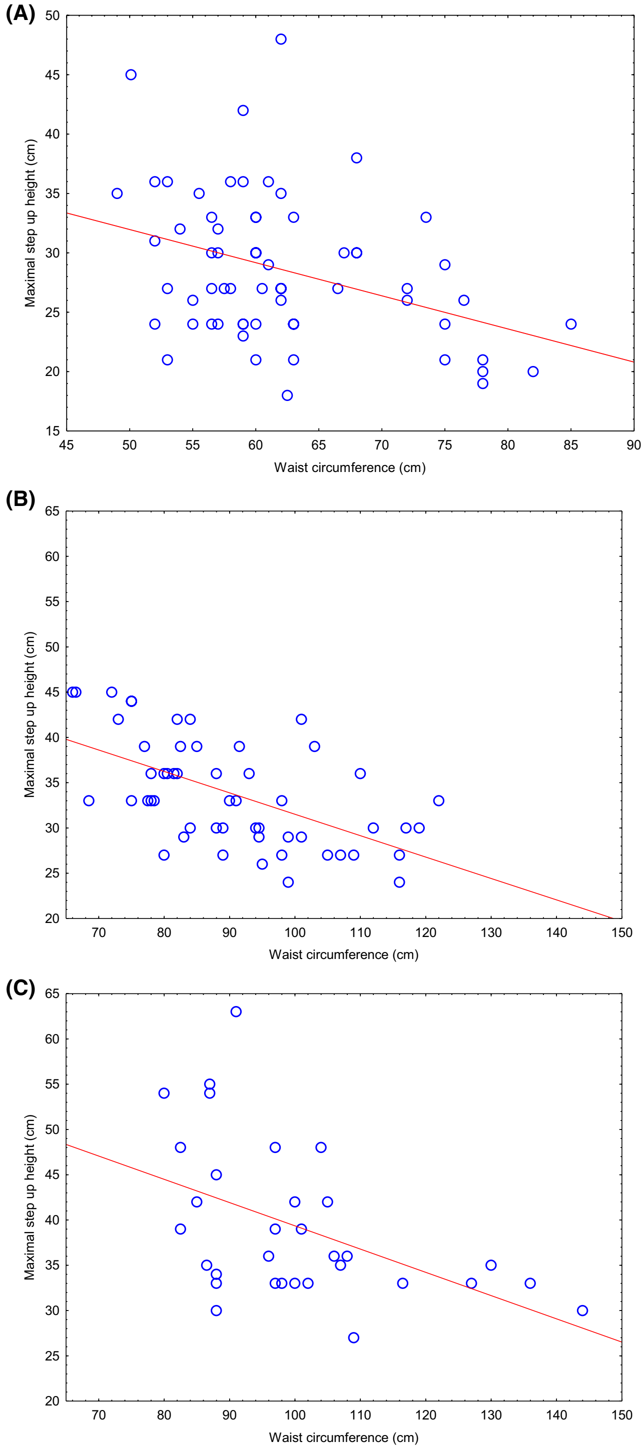

FIGURE 2 (A) Association between waist circumference and maximal step-up height in children ($r=-0.37$, $p=0.002$, $r^2=0.13$). (b) Association between waist circumference and maximal step-up height in mothers ($r=-0.58$, $p<0.001$, $r^2=0.33$). (c) Association between waist circumference and maximal step-up height in fathers ($r=-0.48$, $p=0.006$, $r^2=0.23$).

for. The results indicated an association between reduced muscle strength in the legs and abdominal obesity not only in adults but also in children. Furthermore, we noted clustering of reduced muscle strength within families.

Our results of an association between muscle strength and abdominal obesity agree with results from some previous studies. Poor handgrip strength and cardiorespiratory fitness were associated with a worse metabolic profile in Colombian school children, with a mean age of 11.52 ± 1.13 years.[22] Both handgrip and fitness were inversely associated with blood pressure and homeostasis model assessment of insulin resistance as well as triglycerides and C-reactive protein. The associations between handgrip strength and risk factors were only marginally weaker after adjusting for cardiorespiratory fitness. In our study, the association between maximal step-up height and WC persisted after adjustment for moderate to vigorous physical activity. In a cross-sectional study from Portugal of adolescents aged 12–18 years, higher levels of muscular fitness, standing long-jump and handgrip strength were associated with lower levels of inflammatory markers like C-reactive protein, fibrinogen and leptin as well as homeostasis model assessment of insulin resistance index.[23,24] In an Australian prospective study, muscular power, standing long-jump distance and cardiorespiratory fitness as well as WC was measured at age 9, 12 and 15 years and again 20 years later. Maintaining persistently high muscular power between childhood and adulthood was associated with healthier adult glucose homeostasis.[25]

The prevalence of overweight and obesity was high among our study participants but still lower than in many other countries.[26] We found that 7% of the girls and 12% of the boys were classified as having obesity, and 25% of the mothers and 19% of the fathers. Furthermore, abdominal obesity was prevalent in both parents and children. WC ≥ 88 cm was found in 53% of the mothers, and a WC ≥ 102 cm was found in 34% of the fathers. In children, abdominal obesity, WC ≥ 66 cm, was found in 13% of the girls and 35% of the boys. These results are worrying because studies in adults have established that abdominal obesity has been associated with a wide range of metabolic disorders and an increased risk of non-communicable diseases like type 2 diabetes and cardiovascular diseases.[7] Today, there is also a smaller, but growing number of studies, that have shown an association between abdominal obesity and metabolic syndrome as well as the separate components of the metabolic syndrome, for example, atherogenic dyslipidemia, insulin resistance, and elevated blood pressure, in children and young adults.[6,27]

Furthermore, muscular strength has, during the last decades, been recognised in the prevention of non-communicable diseases. A systematic review of 39 studies with 39 852 adult patients published in 2019 concluded that muscular strength was inversely associated with mortality risk in various acute and chronic conditions.[13]

The mean values for maximal step-up height among the parents in our study can be considered normal. However, an observation is that 42% of the women and 38% of the men had a lower maximal step-up height than 32 and 35 cm, respectively, which, based on Swedish studies, has been reported as a limit value for normal maximal step-up height.[21] There are still no cut-off values for normal maximal step-up height in children of different ages.

There has been a decrease in fitness and reduced physical capacity, as well as an increase in the prevalence of obesity and metabolic syndrome in both adults and children in many societies. Therefore, it is important to pay attention to sarcopenic obesity and overweight or abdominal obesity not only in adults and the elderly but also in children.[6,9] There is an urgent need for deepened knowledge about sarcopenic obesity in children as it might threaten the health of future generations.

The methods used to measure muscle strength can be important. Handgrip is a common way to measure muscle strength. However, the larger muscle groups in the legs and buttocks might have a greater significance for metabolism, and therefore, it could be that measuring leg strength may be more relevant in clinical practice.[13] The standardised maximal step-up test is considered a reliable leg function test for clinical practice in adults.[20,21] The maximal step-up height is related to knee extension strength and self-reported physical function. Previous Swedish studies in adults have demonstrated that a maximal step-up height cut-off value of >32 cm for women and > 35 cm for men identified a perceived limitation of physical function.[21] Furthermore, maximal step-up height was negatively correlated to age, waist circumference (WC) and body weight and positively correlated to maximal oxygen consumption, self-reported physical function and height. Maximal step-up height correlated to training intensity at a follow-up after a 3-month group training intervention programme. Variations in changes in maximal step-up height were significantly explained by changes in WC and physical function, regardless of age and changes in maximal oxygen consumption.[20]

The method has not previously been used in children, but our study thus reveals, in agreement with the previous studies in adults, that maximal step-up height is inversely linked to WC in children as well as in parents in our study.[20,21]

Sarcopenic obesity has been suggested to be defined as a combination of low muscle strength, low muscle mass and obesity.[28] Since there are no validated cut-off values for reduced muscle mass and low muscle strength in children, we were not able to provide a diagnosis of sarcopenic obesity in children. Still, we think it is important to discuss the concept of sarcopenic obesity in relation to our study and our results.

We find our results worrying and worth noting regarding a high prevalence of abdominal obesity in both children and parents, together with the observed strong negative associations between maximal step-up height as a measure of leg muscle strength and WC as a measure of abdominal obesity and metabolic risk, in both children and their parents.

The prevalence of overweight and obesity has reached epidemic proportions worldwide due to a sedentary lifestyle with reduced energy consumption together with an unhealthy diet and several other obesogenic lifestyle changes. However, sarcopenia in overweight and obese children also needs to be paid attention to. The term “sarcopenic obesity” has been proposed to identify overweight or obesity combined with low skeletal muscle function and mass, but its utilisation is still largely limited to the ageing patient population.[9] Recently, the need for the development of a consensus regarding the definition and standardised evaluation methods for sarcopenic obesity in children and adolescents was highlighted.[11]

There is emerging evidence indicating that low muscle mass in overweight or obese individuals increases the risk of increased morbidity and mortality. Newly updated guidelines on physical activity also make it clear that physical activity needs to be varied, including strength training, and not just focus on fitness-promoting activities.[29]

However, awareness of the importance of good muscle function and muscle mass in health care and society is still low, especially regarding children and adolescents.

4.1 | Strengths and limitations

One strength of the study is that we have had the opportunity to examine children and adults in families at the same time. Another strength of the study is that our results add to the sparse knowledge of sarcopenic obesity in children. There are several limitations to be considered. The method of measuring maximal step-up height with a step-up box has thus not previously been used in children and has not been validated in children. However, we find it interesting and worth reporting that we notice the same negative relationship between maximal step-up height and WC in children as in parents. We cannot claim causal relationships because the study is cross-sectional. The fact that there are several different definitions of metabolic syndrome as well as different cut-off levels for WC in both children and adults create variations in the prevalence of metabolic syndrome and abdominal obesity in different epidemiological studies and jeopardise comparisons.[30]

5 | CONCLUSIONS

Our results from 8-year-old children and their parents demonstrated a high prevalence of abdominal obesity in both children and parents. The negative association between maximal step-up height, a measure of leg muscle strength, and WC, a measure of abdominal obesity and metabolic risk, indicate that sarcopenic obesity should be given attention in children and not only in adults and the elderly. Sarcopenic obesity most likely poses a great threat to children's future health. Our findings of clustering of low muscle strength within families provide support for family intervention.

AUTHOR CONTRIBUTIONS

Mai-Lis Hellénius: Conceptualization; investigation; funding acquisition; writing – original draft; methodology; formal analysis; resources; writing – review and editing; supervision; project administration. **Susanne Andermo:** Software; data curation; formal analysis; writing – review and editing. **Anja Nordenfelt:** Investigation; resources; writing – review and editing. **Matthias Lidin:** Investigation;

writing – review and editing. **Lillemor Nyberg:** Conceptualization; methodology; investigation; resources; writing – review and editing. **Gisela Nyberg:** Investigation; project administration; software; data curation; formal analysis; resources; writing – review and editing; funding acquisition.

ACKNOWLEDGEMENTS

We thank the families that participated, the research assistants from Karolinska Institutet and The Healthy Generation, Haninge municipality and statistician Jan Kowalski. Late Professor Steven Blair and MSc Jane Blair for support and advice in the planning phase of the study. The Royal Opera Carpentry Department for producing and providing step-up boxes. We thank HRH Prince Daniel, Honorary Doctor at Karolinska Institutet, for being the initiator and protector of the programme A Healthy Generation and The Swedish Crown Princess Couple's Foundation for support.

FUNDING INFORMATION

This work was supported by grants from The Swedish Heart Lung Foundation (Grant 20150692 and 20170706) and Skandia Mutual Life Insurance Company.

CONFLICT OF INTEREST STATEMENT

All authors declare no conflict of interest.

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REFERENCES

1. Ekblom-Bak E, Borjesson M, Bergman F, et al. Accelerometer derived physical activity patterns in 27.890 middle-aged adults: the SCAPIS cohort study. Scand J Med Sci Sports. 2022;32(5):866-80.
2. Guthold R, Stevens GA, Riley LM, Bull FC. Global trends in insufficient physical activity among adolescents: a pooled analysis of 298 population-based surveys with 1.6 million participants. Lancet Child Adolesc Health. 2020;4(1):23-35.
3. Santtila M, Pihlainen K, Koski H, Vasankari T, Kyrolainen H. Physical fitness in young men between 1975 and 2015 with a focus on the years 2005-2015. Med Sci Sports Exerc. 2018;50(2):292-8.
4. Venckunas T, Emeljanovas A, Mieziene B, Volbekiene V. Secular trends in physical fitness and body size in Lithuanian children and adolescents between 1992 and 2012. J Epidemiol Community Health. 2017;71(2):181-7.
5. Saklayen MG. The global epidemic of the metabolic syndrome. Curr Hypertens Rep. 2018;20(2):12.
6. Nolan PB, Carrick-Ranson G, Stinear JW, Reading SA, Dalleck LC. Prevalence of metabolic syndrome and metabolic syndrome components in young adults: a pooled analysis. Prev Med Rep. 2017;7:211-5.
7. Lemieux I, Despres JP. Metabolic syndrome: past, present and future. Nutrients. 2020;12(11):3501.
8. Despres JP, Lemieux I. Abdominal obesity and metabolic syndrome. Nature. 2006;444(7121):881-7.
9. Wilkinson TJ, Yates T, Baker LA, Zaccardi F, Smith AC. Sarcopenic obesity and the risk of hospitalization or death from coronavirus disease 2019: findings from UK biobank. JCSM Rapid Commun. 2022;5(1):3-9.
10. Barazzoni R, Bischoff S, Boirie Y, et al. Sarcopenic obesity: time to meet the challenge. Obes Facts. 2018;11(4):294-305.
11. Zembura M, Matusik P. Sarcopenic obesity in children and adolescents: a systematic review. Front Endocrinol (Lausanne). 2022;13:914740.
12. Henriksson P, Shiroma EJ, Henriksson H, et al. Fit for life? Low cardiorespiratory fitness in adolescence is associated with a higher burden of future disability. Br J Sports Med. 2021;55(3):128-9.
13. Jochem C, Leitzmann M, Volaklis K, Aune D, Strasser B. Association between muscular strength and mortality in clinical populations: a systematic review and meta-analysis. J Am Med Dir Assoc. 2019;20(10):1213-23.
14. Garcia-Hermoso A, Cavero-Redondo I, Ramirez-Velez R, et al. Muscular strength as a predictor of all-cause mortality in an apparently healthy population: a systematic review and meta-analysis of data from approximately 2 million men and women. Arch Phys Med Rehabil. 2018;99(10):2100-13.e2105.
15. Garcia-Hermoso A, Ramirez-Campillo R, Izquierdo M. Is muscular fitness associated with future health benefits in children and adolescents? A systematic review and meta-analysis of longitudinal studies. Sports Med. 2019;49(7):1079-94.
16. Nyberg G, Andermo S, Nordenfelt A, Lidin M, Hellenius ML. Effectiveness of a family intervention to increase physical activity in disadvantaged areas-a healthy generation, a controlled pilot study. Int J Environ Res Public Health. 2020;17(11):3794.
17. Cole TJ, Lobstein T. Extended international (IOTF) body mass index cut-offs for thinness, overweight and obesity. Pediatr Obes. 2012;7(4):284-94.
18. Brannsether B, Roelants M, Bjerknes R, Juliusson PB. Waist circumference and waist-to-height ratio in Norwegian children 4-18 years of age: reference values and cut-off levels. Acta Paediatr. 2011;100(12):1576-82.
19. Grundy SM, Cleeman JI, Daniels SR, et al. Diagnosis and management of the metabolic syndrome: an American Heart Association/National Heart, Lung, and Blood Institute scientific statement. Circulation. 2005;112(17):2735-52.
20. Nyberg LA, Hellenius ML, Wandell P, Kowalski J, Sundberg CJ. Maximal step-up height as a simple and relevant health indicator: a study of leg muscle strength and the associations to age, anthropometric variables, aerobic fitness and physical function. Br J Sports Med. 2013;47(15):992-7.
21. Nyberg LA, Hellenius ML, Kowalski J, Wandell P, Andersson P, Sundberg CJ. Repeatability and validity of a standardised maximal step-up test for leg function–a diagnostic accuracy study. BMC Musculoskelet Disord. 2011;12:191.
22. Cohen DD, Gomez-Arbelaez D, Camacho PA, et al. Low muscle strength is associated with metabolic risk factors in Colombian children: the ACFIES study. PLoS One. 2014;9(4):e93150.
23. Agostinis-Sobrinho CA, Ramirez-Velez R, Garcia-Hermoso A, et al. Low-grade inflammation and muscular fitness on insulin resistance in adolescents: results from LabMed physical activity study. Pediatr Diabetes. 2018;19(3):429-35.
24. Agostinis-Sobrinho C, Garcia-Hermoso A, Ramirez-Velez R, et al. Longitudinal association between ideal cardiovascular health status and muscular fitness in adolescents: The LabMed Physical Activity Study. Nutr Metab Cardiovasc Dis. 2018;28(9):892-9.
25. Fraser BJ, Blizzard L, Schmidt MD, Dwyer T, Venn AJ, Magnussen CG. The association between muscular power from childhood to adulthood and adult measures of glucose homeostasis. Scand J Med Sci Sports. 2019;29(12):1909-16.
26. Collaboration NCDRF. Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: a pooled analysis of 2416 population-based measurement studies in 128.9 million children, adolescents, and adults. Lancet. 2017;390(10113):2627-42.
27. Kjellberg E, Roswall J, Bergman S, Almqvist-Tangen G, Alm B, Dahlgren J. Longitudinal birth cohort study found that a significant proportion of children had abnormal metabolic profiles and insulin resistance at 6 years of age. Acta Paediatr. 2019;108(3):486-92.

28. Donini LM, Busetto L, Bischoff SC, et al. Definition and diagnostic criteria for sarcopenic obesity: ESPEN and EASO consensus statement. Clin Nutr. 2022;41(4):990-1000.
29. World Health Organization. WHO guidelines on physical activity and sedentary behaviour. 2020 https://www.who.int/publications/i/item/9789240015128
30. Reisinger C, Nkeh-Chungag BN, Fredriksen PM, Goswami N. The prevalence of pediatric metabolic syndrome-a critical look on the discrepancies between definitions and its clinical importance. Int J Obes (Lond). 2021;45(1):12-24.

How to cite this article: Hellénius M-L, Andermo S, Nordenfelt A, Lidin M, Nyberg L, Nyberg G. Negative associations between step-up height and waist circumference in 8-year-old children and their parents. Acta Paediatr. 2024;00:1–8. https://doi.org/10.1111/apa.17274