Original Article

Cross-sectional association between physical fitness and cardiometabolic risk in Chilean schoolchildren: the fat but fit paradox

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Background: Previous studies have examined the "fat but fit" paradox, revealing that greater levels of physical fitness may diminish the harmful consequences of excess weight on cardiometabolic risk. Despite the above, specific information about the "fat but fit" paradox in prepuberal population is scarce. The aim of this study was to determine the relationship between cardiometabolic risk across (individual and combined) physical fitness and excess weight status and whether the "fat but fit" paradox is met in the sample of schoolchildren analyzed.

Methods: A cross-sectional study was conducted including 452 children (59.1% girls), aged 7–9 years from Santiago (Chile). Physical fitness was assessed as cardiorespiratory fitness and muscular fitness. Cardiorespiratory fitness was determined by the 6-minute-walk-test and muscle strength was assessed by the handgrip and standing long jump tests. Excess weight (overweight and obesity) was computed through body mass index (z-score). Cardiometabolic risk was established by summing the z-score of the serum glucose, triglycerides, high-density lipoprotein, insulin and waist-to-height ratio.

Results: Schoolchildren with high physical fitness (individual or combined) showed the lowest cardiometabolic risk mean scores (P for trend <0.001 for all physical fitness groups). Conversely, schoolchildren with low physical fitness (individual or combined) showed the highest cardiometabolic risk mean scores (P for trend <0.001 for all categories). Additionally, schoolchildren without excess weight and with high individual or combined physical fitness status exhibits lower cardiometabolic risk mean scores compared to schoolchildren with excess weight and low physical fitness status (individual or combined) (P for trend <0.001 for all physical fitness groups). A lower odd of having high cardiometabolic risk was found in schoolchildren without excess weight and with both high physical fitness (both cardiorespiratory fitness and muscular fitness) [odds ratio (OR) =0.08; 95% confidence interval (CI): 0.04 to 0.16] in comparison to those with excess weight and low physical fitness.

Conclusions: Our results suggest that improvements in both fatness and aerobic fitness could be associated with lower cardiometabolic risk.

Keywords: Cardiorespiratory fitness (CRF); muscular fitness (MF); metabolic syndrome; obesity; children

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Introduction

Excess weight (overweight and obesity) is a cardiovascular risk factor commonly found in childhood and adult. However, scientific evidence has recently pointed out that these risk factors can be also found in early years (1,2). Excess weight in Chilean children has tripled in recent decades, reaching 23.9% in 2017 (3). Obesity is linked with a high incidence fasting insulin levels (42.0% of all children with obesity have atypical values) and hypercholesterolemia (27.0%) (4,5). Childhood obesity is also related to a higher risk of cardiovascular disease in later in life (6).

Cardiometabolic risk (CMR) score (computed by summing several risk factors) is recognized as a suitable tool for establishing CMR in children (7). CMR is higher with clustering of risk factors such as abnormal cholesterol, hypertension, hypertriglyceridemia, abdominal obesity, in young people (8). This coexistence of these risk variables has been related to increased risk of cardiovascular disease and type 2 diabetes (known as metabolic syndrome) (9). Since CMR clustering in children is linked with higher odds of metabolic syndrome in adulthood (10), efforts are needed to define and quantify the risk of metabolic syndrome in children (11). In this sense, unhealthy dietary patterns and a lack of regular physical activity at moderate-to-vigorous (12) are essential contributors to the early onset of CMR. Sixty percent of the world's population does not engage regular physical activity as recommended to prevent noncommunicable diseases (13,14). More specifically, Chilean children are predominantly insufficiently active, given that only 1 out of 5 meets with the physical activity recommendations (15).

Physical fitness is considered a powerful marker of health (16), and its evaluations are feasible measures that can contribute to improved follow-up on pediatric health management (17). The independent biological influence of cardiorespiratory fitness (CRF) and muscular fitness (MF) on CMR has been verified in children and adolescents (18,19). Similarly, a meta-analysis by Ruiz *et al.* (20) found a robust association between CRF and CMR factors in young people, providing cut-points that more accurately define cardiovascular disease risk. The combined effect of both CRF and MF and its interdependence has been less studied. For example, Artero *et al.* (21) found that MF was negatively associated with CMR, irrespective of CRF. Furthermore, these same authors found an inverse association between CRF clustered metabolic risk, regardless of MF. Moreover, Steene-Johannessen *et al.* (22) reported that in 2,818 children aged 9–15 years, MF was negatively associated with clustered CMR, regardless of CRF. Despite these benefits, a recent systematic review by Fühner *et al.* (23) found negative secular trends for physical fitness (e.g., CRF, MF), independently of sex (from 1972 to 2015).

The "fat but fit" paradox refers to those individuals whom in spite of having obesity show a relatively high physical fitness level (24). This paradigm suggests that individuals with both obesity and moderate-to-high CRF do not have a significantly greater risk of mortality from cardiovascular disease than normal weight with low CRF (in adults) (25). In young population, evidence with regards to this paradox is not consistent (25-28). Previous studies have examined the "fat but fit" paradox, revealing that greater levels of physical fitness may diminish the harmful consequences of excess weight on CMR risk (28-30). Despite the above, specific data about the "fat but fit" paradox in prepuberal population is rare (25). However, scientific evidence has indicated that having moderate-to-high CRF levels may mitigate the detrimental metabolic consequences associated with excessive adiposity (both total and central) (31,32). Similarly, physical fitness data (e.g., CRF) has been required from children in low-income and middle- income countries (e.g., Chile) to determine if temporal trends are similar to those found in high-income and upper middle-income countries (33).

Based on the above, the aim of this study was to determine the relationship between CMR across (individual and combined) physical fitness and excess weight status and whether the "fat but fit" paradox is met in schoolchildren from Santiago (Chile). We present the following article in accordance with the STROBE reporting checklist (available at https://tp.amegroups.com/article/view/10.21037/tp-22-25/rc).

Methods

Design and participants

This is a cross-sectional study including children of the "Growth and Obesity Chilean Cohort Study", which assessed the association of early growth and development with adiposity and metabolic risk (34). To perform this study, 452 healthy Chilean children (185 boys and 267 girls) aged 7 to 9 years were randomly selected from original study. The inclusion criteria of the study were as follows: (I) children attending Chilean National Nursery School Council Program nursery schools from the south

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area of Santiago (Chile); (II) singletons; (III) birth weight ≥2,500 grams (data retrieved from medical archives); (IV) gestational age 37–42 weeks; (V) no psychological or physical conditions that may severely influence on growth; and (VI) blood data available.

The final sample size included 452 schoolchildren (59.1% girls) aged 7–9 years. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the Institute of Nutrition and Food Technology Ethics Committee for research in human subjects institutional and/or national research (Act No. 19, 2009). Parents or legal guardians of all participants signed an informed consent form before participation.

Procedures

Anthropometric measurements and pubertal status

Weight was measured in underclothing with an electronic scale (0.1 kg of accuracy) by a body composition analyzer (TANITA BC-418, Tokyo, Japan). Height was measured with a portable stadiometer (SECA 222®), with a 1-mm precision using the Frankfurt standard (35). Body mass index (BMI) was determined by dividing body weight (in kg) by height (in meters squared). Subsequently, the World Health Organization criteria for BMI were used to compute BMI z-score and the prevalence of excess weight (overweight and obesity) was calculated (36). Thus, schoolchildren were divided into: participants with excess weight (high BMI) and participants without excess weight (low BMI). Waist circumference (WC) was measured with a flexible tape (SECA®) (37). All variables were measured twice for each child. The measurements agreed within 0.5 cm for height and WC and 20 g for weight. In addition, waist-to-height ratio (WHtR) was computed by dividing WC by height.

Pubertal status was assessed using the method described by Tanner and Whitehouse (38).

Blood extractions

Blood samples were collected from 08:30 to 10:30 after an 8-h overnight fast. Glucose, insulin and blood lipids were calculated after 8 h of fasting. Ten milliliters of venous blood were gathered, and serum glucose was determined using a commercial kit by the GOD-PAP (Glucose GOD/PAP, Roche Diagnostics, Basel, Switzerland) enzymatic colorimetric method. Insulin was measured by RIA (RIA DCP Diagnostic Products Corporation, LA, USA). Glucose impaired was defined by a fasting glucose ≥100 mg/dL (39). Basal insulin sensitivity was estimated by homeostatic model assessment for insulin resistance (HOMA-IR) [fasting insulin (mIU/dL) * fasting glucose (mmol/L)/22.5] (40). Hyperinsulinemia was defined as baseline insulin ≥10 mIU/dL in children with Tanner I or II (41). Insulin resistance was diagnosed if HOMA-IR ≥2.1, which corresponds to >75th percentile of the observed quartile in Chilean children (42). Cholesterol, high-density lipoprotein (HDL) and triglycerides were determined by dry analytical methodology (Johnson & Johnson Clinical Diagnostics, Inc., NY, USA) using the USA population as a reference (non-HDL cholesterol >145 mg/dL; HDL <40 mg/dL; and triglycerides >130 mg/dL) (43).

The CMR score was defined by the sum of the blood related variables z-scores and WHtR, using the following equation (44): [glycaemia (z-score) + insulin (z-score) + triglycerides (z-score) – HDL (z-score)]/5. These variables were chosen because they are frequently used in adults as criteria to establish metabolic syndrome (7). In addition, scores above the 75th percentile were considered to indicate high risk of CMR (26,45).

Physical fitness

CRF was determined by a sub-maximal test, the 6-minute walk test (6MWT) (46,47). This test included a walking course of 30-m in length. The turnaround points were marked with a cone. The starting line, marked on the floor by brightly colored tape, indicated the beginning and end of each 60-m lap. The result obtained in the 6MWT was divided by height (48), because leg length was not evaluated (49). The values obtained were standardized into z-scores.

MF was assessed using both handgrip strength test and standing long jump test. Handgrip strength was measured using an adjustable handgrip digital dynamometer (Baseline 12-0286®; 100 g accuracy), and the results were expressed in kg. Each child performed handgrip twice by squeezing the dynamometer as hard as possible for at least two seconds. One minute of recovery between squeezes was measured (interchanging the left and right hands). Thus, the best result of two attempts was registered and, therefore, handgrip strength was normalized by body weight (kg) to consider body size differences (50). The values obtained were also converted into z-scores. The standing long jump test was carried out by starting in a flexed semi-squat position before initiating the upward phase and jump. This test was conducted on a 2-m long non-slippery surface, free of obstacles. A starting line was made to identify the initial position from the child must jump. The longest

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distance in cm was recorded (51) and, therefore, it was also transformed into z-score. MF score was determined as follows: handgrip strength/body weight (z-score) + standing long jump (z-score). Conversely, physical fitness (z-score) was computed as follows: 6MWT/body height (z-score) + handgrip/body weight (z-score) + standing long jump (z-score).

Physical fitness values (i.e., individual and combined CRF and MF z-scores) were categorized into two groups using a median split of the different results obtained in the physical tests as follows: high physical fitness (z-score) ($>50^{th}$ percentile) and low physical fitness (z-score) ($\leq 50^{th}$ percentile) (26).

Statistical analysis

Continuous variables are shown as frequencies and percentages for categorical variables and means and standard deviation for continuous variables. All model assumptions were checked (i.e., homoscedasticity, normality). Due to the non-normal distribution of some variables (i.e., handgrip strength, handgrip strength/body weight, triglycerides, insulin, HOMA-IR and BMI), the assumptions for executing an analysis of covariance (ANCOVA) were not met. Because of this, bootstrapping as a reliable technique to determine robust estimations of standard errors and confidence intervals (CIs) was performed. Thus, a robust bootstrapping ANCOVA with similar level of significance ($P<0.05$) was performed to control for confounding variables. Preliminary analyses showed no significant interactions between sex and CRF ($P=0.115$), MF ($P=0.075$), physical fitness ($P=0.075$), and BMI status ($P=0.115$) in relation to CMR; therefore, all the analyses were carried out with boys and girls together to increase the statistical power. Four different groups were established related to physical fitness and BMI: (I) low physical fitness/high BMI; (II) low physical fitness/low BMI; (III) high physical fitness/high BMI; and (IV) high physical fitness/low BMI. These groups were also created in relation to individual physical fitness components (i.e., CRF and MF). ANCOVAs were performed to determine mean differences of CMR related to combination of CRF, MF or physical fitness and BMI groups. Similarly, mean differences between groups were assessed by *post-hoc* analyses with adjustment of the CIs by Bonferroni test and adjusting by age, sex, and maturation stage. Lastly, we examined the odds of having high CMR in relation to the different physical fitness/BMI established groups through binary logistic regression analyses, after adjusting for age, sex, and pubertal status. All analyses were conducted using SPSS software, version 25.0. A two-sided $P<0.05$ indicates statistical significance.

Results

Table 1 shows the characteristics of the study participants. The age mean was 7.8±0.5 years old. The proportion of excess weight participants was 48.9%.

Figure 1 shows the mean differences in CMR score in relation to different physical fitness categories and excess weight status. Schoolchildren with high physical fitness (individual or combined) showed the lowest CMR mean scores (P for trend <0.001 for CRF, MF, and physical fitness groups). Conversely, schoolchildren with low physical fitness (individual or combined) showed the highest CMR mean scores (P for trend <0.001 for all categories). Additionally, schoolchildren without excess weight and high individual or combined physical fitness status exhibits lower CMR mean scores compared to schoolchildren with excess weight and low physical fitness status (individual or combined) (P for trend <0.001 for CRF, MF, and physical fitness groups). Differences in mean values of CMR in schoolchildren across different physical fitness and BMI groups established is found in Table S1. Moreover, a visual representation of the moderation of CRF, MF and physical fitness in the relationship between BMI groups and CMR can be found in Figure S1.

The odds of having CMR in schoolchildren across different physical fitness and BMI groups established are shown in *Figure 2*. A lower odd of having high CMR was found in schoolchildren without excess weight and with both high physical fitness (both CRF and MF) [odds ratio (OR) =0.08; 95% CI: 0.04 to 0.16], schoolchildren without excess weight schoolchildren and with high physical fitness (OR =0.11; 95% CI: 0.05 to 0.25), and excess weight schoolchildren with high physical fitness (OR =0.43; 95% CI: 0.23 to 0.78), in comparison with those excess weight schoolchildren with both low physical fitness. These lower odds were also found when examined physical fitness individually in both cases.

Discussion

In general, our results indicate that both high CRF and MF are inversely related to CMR score, which suggests that improvements in both BMI and physical fitness could be important for having a low CMR among young Chilean

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Table 1 Description of anthropometric and cardiometabolic risk variables of the analyzed sample

Variables	Total (n=452)
Age (years)	7.8±0.5
Weight (kg)	28.0±8.1
Height (cm)	126.9±5.7
BMI (kg/m^2)	17.9±2.7
BMI (z-score)	0.98±1.16
Excess weight[a]	221 (48.9)
WHtR	0.48±0.05
Body fat (%)	29.8±7.6
Glycaemia (mg/dL)	89.3±6.4
Triglyceride (mg/dL)	95.9±40.9
High-density lipoprotein (mg/dL)	49.8±13.3
Insulin (µU/dL)	5.4±1.3
HOMA-IR	1.2±0.5
Standing long jump (cm)	108.0±16.3
Handgrip strength (kg)	11.5±2.3
Handgrip strength/weight	0.40±0.1
6MWT (m)	625.2±53.7
6MWT/height	503.6±49.8
Muscular fitness (z-score)	1.14±2.1
6MWT/height (z-score)	0.43±1.2

Data expressed as mean ± SD or n (%). [a], excess weight determined as the sum of overweight and obesity following the World Health Organization criteria (36). 6MWT, 6-minute walk test; BMI, body mass index; HOMA-IR, homeostatic model assessment for insulin resistance; WHtR, waist-to-height ratio.

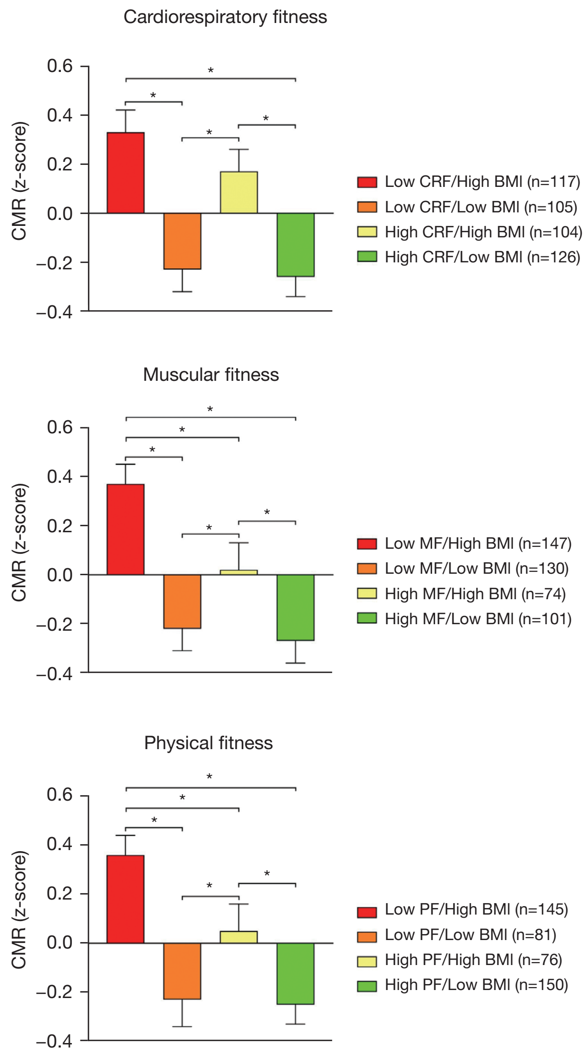

Figure 1 Differences in mean values of cardiometabolic risk score in schoolchildren across different physical fitness and body mass index groups established. Data expressed as mean (bars) and standard error (lines). *, P<0.05. BMI, body mass index; CMR, cardiometabolic risk; CRF, cardiorespiratory fitness; MF, muscular fitness; PF, physical fitness (both cardiorespiratory fitness and muscular fitness).

children.

We found no statistically significant differences in CMR score in relation to physical fitness in schoolchildren without excess weight. Thus, we failed to prove the "fat but fit" paradox in our study. Schoolchildren without excess weight and low physical fitness status showed lower CMR mean score than their counterparts with excess weight and high physical fitness status. This is in line with previous studies (26,28,52). For instance, Nyström *et al.* (28) pointed out that the "fat but fit paradox" was not confirmed by their results since CRF showed a beneficial effect on the metabolic profile only in children with obesity but not in their counterparts with normal weight. Sasayama *et al.* (26) did not find significant differences for CMR between high BMI/high CRF group and low BMI/low CRF group (in both sexes) in their study among Japanese children. This finding was also in line with a previous study among Australian children by Eisenmann *et al.* (52). One possible explanation justifying this finding is the mediator role of obesity in the associations of CRF (27) and MF (53) with CMR in schoolchildren, which could explain this finding.

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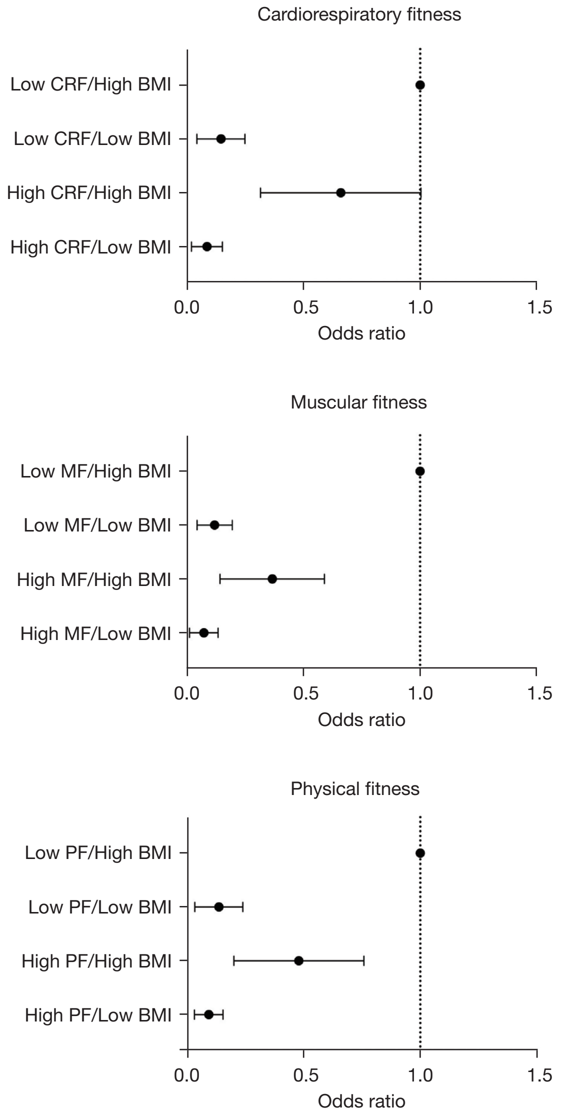

Figure 2 Odds ratio of having cardiometabolic risk in schoolchildren across different physical fitness and BMI groups established. Adjusted by sex, age, and pubertal status. Data expressed as odds ratio (dots) and 95% confident intervals (bars). Schoolchildren with low physical fitness (individual or combined) and high BMI selected as reference group. BMI, body mass index; CRF, cardiorespiratory fitness; MF, muscular fitness; PF, physical fitness (both cardiorespiratory fitness and muscular fitness).

Despite the above, caution is required to interpret this finding. As previous studies, we used a non-standardized cut-off points to determine physical fitness groups, which could influence on the results obtained (28,31). Although Tomkinson *et al.* (54) established sex- and age-specific centiles for CRF from the 20-m Shuttle Run test including over 1 million children and adolescents from 50 countries, most of the data is from high-income and upper middle-income countries. Thus, these same authors have pointed out the need of data from children in low-income and middle-income countries. Similarly, the different methodology applied to determine CRF (6MWT instead of 20-m Shuttle Run test) could also influence on the results obtained. Additionally, we used World Health Organization cut-off points to establish excess weight. In this sense, further studies using more accurate cut-off points for adiposity, as well as studies involving only children with obesity in the high adiposity group are required (28).

On the other hand, it seems that a high MF plays a relevant role in CMR, since the lowest values of CMR mean score and the lowest odds of having high CMR were found when we analyzed MF individually. In this sense, a high MF is related to more adequate skeletal muscle function, which directly influences on the metabolic function (55) and could explain the lower CMR in our analyzed. Furthermore, it is remarkable that we normalized handgrip strength by body weight instead of including absolute handgrip strength, as previously suggested (56,57). This choice could have influenced on the results obtained. In this sense, Castro-Piñero *et al.* (58) compared the discriminatory ability of handgrip strength in relation to body weight and of absolute handgrip strength and showing that relative handgrip strength had significantly greater discriminatory ability to detect CMR. Our finding suggests that MF in schoolchildren may confer additional benefits to cardiometabolic health. Supporting this notion, most excess weight children are reluctant to participate in aerobic activities; therefore, the promotion of MF through muscle-strengthening activities could be more attractive and easier for excess weight children (59).

Another interesting finding is that we found that children without excess weight and high physical fitness showed lower odds of having high CMR. This finding is in line with other previous studies (26,28-30,52). For instance, Nyström *et al.* (28) found that CRF decreased the CMR score, with the highest differences in the most Spanish children with obesity analyzed. Likewise, Brouwer *et al.* (30) showed that a high physical fitness attenuates the association between fatness and CMR (and HOMA-IR) (in adolescent boys). This finding was also supported by Stoner *et al.* (29), which found that high CRF may moderate the relationship between fatness and CMR in New Zealand children. One possible explanation is that a high CRF, understood as the

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ability of the respiratory and circulatory systems to provide fuel during maintained physical activity, entails more stable physiological features (i.e., increased capillary density, greater resting energy expenditure) (60). These features triggered by high CRF could also influence on CMR (61), and might be more pronounced in schoolchildren with high physical fitness. In parallel, as previously mentioned, a high MF is related to low CMR (through improvements in skeletal muscle function) (55). Thus, the combination of these two physical fitness components could attenuate the CMR among excess weight schoolchildren. Supporting this notion, a meta-analysis by García-Hermoso *et al.* (62) found that concurrent aerobic plus strength exercise improves metabolic profiles, body composition and inflammatory state in obese young population.

Methodological considerations

Our results should be interpreted with certain caution because of the presence of some limitations in this study. Firstly, due to the cross-sectional design of this study, it is not possible to determine cause-and-effect relationships. Secondly, the present lack of consensus in young people in relation to the definition of CMR might limit our results. Thirdly, the 6MWT is a submaximal test to evaluate CRF, and it is not comparable with another aerobic field-tests (e.g., 20-m Shuttle Run test). However, the physical tests that we have used are simple to apply and well accepted among young children. Finally, we did not adjust our analysis by important confounders such as socio-economic status and dietary behavior. Conversely, there are some strengths that must be declared. For instance, we contribute to the scientific literature by adding information about physical fitness from schoolchildren in a low- to middle-income country (i.e., Chile). Similarly, we used a narrow age range of schoolchildren and standardized methods to collect the data.

Conclusions

This study suggests that improvements in both BMI and physical fitness could be important for having a low CMR among young Chilean children. Additional studies with different designs (e.g., longitudinal) are necessary to a further assessment of the independent and combined effects of CRF, MF and BMI in the prevention of CMR among schoolchildren.

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Footnote

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Data Sharing Statement: Available at https://tp.amegroups.com/article/view/10.21037/tp-22-25/dss

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://tp.amegroups.com/article/view/10.21037/tp-22-25/coif). AGH serves as an unpaid editorial board member of *Translational Pediatrics* from August 2021 to July 2023.The other authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the Institute of Nutrition and Food Technology Ethics Committee for research in human subjects institutional and/or national research (Act No. 19, 2009). Parents or legal guardians of all participants signed an informed consent form before participation.

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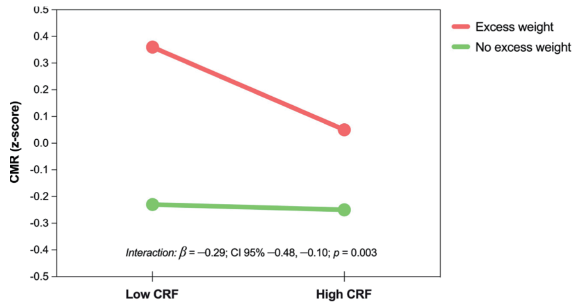

Figure S1 A visual representation of the moderation of cardiorespiratory fitness, muscular fitness and physical fitness in the relationship between body mass index groups and cardiometabolic risk among Chilean children. Adjusted by sex, age, and pubertal status. CI, confidence interval; CMR, cardiometabolic risk; PF, physical fitness (both cardiorespiratory fitness and muscular fitness).

Table S1 Differences in mean values of cardiometabolic risk score in schoolchildren across different physical fitness and body mass index groups established

Groups	CMR (z-score), M (SE)	P for trend
CRF		<0.001
Low CRF/high BMI	0.33 (0.05)	
Low CRF/low BMI	–0.23 (0.05)[a]	
High CRF/high BMI	0.17 (0.05)[b]	
High CRF/low BMI	–0.26 (0.04)[a,b,c]	
MF		<0.001
Low MF/high BMI	0.37 (0.04)	
Low MF/low BMI	–0.22 (0.04)[a]	
High MF/high BMI	0.02 (0.06)[a,b]	
High MF/low BMI	–0.27 (0.05)[a,c]	
PF		<0.001
Low PF/high BMI	0.36 (0.04)	
Low PF/low BMI	–0.23 (0.06)[a]	
High PF/high BMI	0.05 (0.06)[a,b]	
High PF/low BMI	–0.25 (0.04)[a,c]	

[a], significant differences from low MF/high BMI (P<0.05); [b], significant differences from low MF/low BMI (P<0.05). [c], significant differences from high MF/high BMI (P<0.05). BMI, body mass index; CMR, cardiometabolic risk score; CRF, cardiorespiratory fitness; MF, muscular fitness; PF, physical fitness; M, mean; SE, standard error.

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