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Longitudinal association between ideal cardiovascular health status and muscular fitness in adolescents: The LabMed Physical Activity Study

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Abstract *Background and aims:* Muscular fitness is an emerging predictor for cardiovascular disease mortality. The ideal cardiovascular health metrics has been inversely related to a subsequent cardiometabolic health in adulthood. However, evidence regarding muscular fitness and ideal cardiovascular health in adolescents is scarce. This study aimed to examine the longitudinal association between ideal cardiovascular health index and muscular fitness.
Methods and results: This study cohort consisted of 331 adolescents (183 girls) from the LabMed Physical Activity Study who were followed from 2011 to 2013. Ideal cardiovascular health, as defined by the American Heart Association, was determined as meeting ideal health factors (total cholesterol, blood pressure, and glucose) and behaviors (smoking status, body mass index, physical activity, and diet). Handgrip strength and standing long jump tests assessed muscular fitness and were transformed into standardized values according to age and sex. ANCOVA showed a significant association between the accumulation of ideal cardiovascular health metrics at baseline and muscular fitness indices at follow-up ($F_{(4, 322)} = 2.280$, $p = 0.04$). In addition, the higher the number of ideal cardiovascular health metrics accumulated, the higher the likelihood of having a high muscular fitness over a two-year period (p for trend $= 0.01$), after adjustments for age, sex, pubertal stage and socioeconomic status and muscular fitness at baseline.
Conclusion: The ideal cardiovascular health status during adolescence was associated with high muscular fitness levels over a two-year period.

Introduction

Low muscular fitness is an emerging predictor for mortality and premature death [1,2]. The age-related loss of muscle strength and power (dynapenia) and the reduction in muscle mass (sarcopenia) have been reported as a

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public health problem in adults [3,4]. In addition, the increase in the prevalence of unhealthy behaviors is likely to lower the age of onset and increase the incidence of dynapenia worldwide [5]. Indeed, muscular fitness and motor skills deficits may emerge at an even earlier age [5].

In youth, muscular fitness has been considered an important determinant of health [6–8] and global physical activity guidelines recommend muscular and bone strength activities at least three times per week. Despite these guidelines and the evidence of the health benefits of maintaining high levels of muscular fitness, a global secular decline in muscular fitness levels of children and youth has been reported worldwide [9–11] modern-day youth are getting weaker and slower [5].

In response to the increasing burden of cardiometabolic risk factors on CVD mortality, in 2010 the American Heart Association (AHA) established a set of seven cardiovascular health components to describe ideal cardiovascular health in both youth and adults [12,13]; four health behaviors (body mass index [BMI], smoking, physical activity, and diet) and three health factors (blood pressure, total cholesterol, and fasting blood glucose). Since then, some studies have examined the associations between the ideal cardiovascular health index and other outcomes [14,15]. For example, Laitinen and colleagues [14] in a sample of 856 subjects from the Cardiovascular Risk in Young Finns Study cohort showed that the presence of a number of ideal cardiovascular health components during childhood predicted subsequent cardiometabolic health in adulthood.

Recently, in a cross-sectional study involving 510 European adolescents, Ruiz et al. reported that a number of ideal cardiovascular health components were associated with higher levels of cardiorespiratory fitness and that cardiorespiratory fitness was significantly higher in adolescents meeting at least four ideal components [16]. Likewise, with 1199 Colombian youths, Ramírez-Vélez and colleagues [17] showed that the ideal cardiovascular health index was strongly associated with muscular fitness (assessed by the handgrip test). However, longitudinal evidence regarding the effect of the accumulation of ideal cardiovascular health metrics (health behaviors and health factors) on muscular fitness during adolescence is lacking. From a public health point of view, it seems important to identify the impact on muscular fitness phenotype of not meeting the metrics of the ideal cardiovascular index in youth. In fact, adolescence is characterized by prevalence of cardiometabolic risk factors, including increased body fat [18], blood pressure [19], altered lipid metabolism [20], and dietary and health habits alterations, such as, decreased physical activity and increased inactivity [21] and tobacco use [22]. This is due to associated physiological and behavior changes. Thus, particular attention should be given to this population, especially in connection with the implementation of preventive or treatment strategies of metabolic diseases. Therefore, the aim of this study was to examine the association between ideal cardiovascular health index (at baseline) and muscular fitness two years later.

Methods

Study design and sample

The current study is part of the "Longitudinal Analysis of Biomarkers and Environmental Determinants of Physical Activity (LabMed Physical Activity Study)", a school-based cohort carried out in the North of Portugal. Detailed description of sampling and recruitment approaches, procedures and protocols have been described elsewhere [23,24]. In short, baseline data was collected in 2011 for 1229 adolescents aged 12 to-18 years 1011 and 789 subjects were reevaluated one and two years later, respectively. Of those, 331 adolescents aged 12 to-18 years on baseline (183 girls) had complete data on the variables of interest for the present study at baseline and 2nd follow-up.

The study was conducted according to the World Medical Association's Helsinki Declaration for Human Studies. The Portuguese Data Protection Authority (#1112434/2011), the Portuguese Ministry of Science and Education (0246200001/2011) and Faculty of Sport, University of Porto, approved the study. All participants in this study were informed of the study's aims, and written informed consent was obtained from participating adolescents and their parents or guardians.

Measures

Ideal cardiovascular health metrics

The AHA released the ideal cardiovascular health index in 2010 [12] with the cut-off values for adolescents. Four health behaviors (BMI, smoking behavior, physical activity and diet) and three health factors (blood pressure, total cholesterol, and fasting blood glucose) were considered.

Health factors

Blood samples were obtained from each subject early in the morning, following a 10-h overnight fast by venipuncture from the antecubital vein. The samples were stored in sterile blood collection tubes in refrigerated conditions (4°–8 °C) for no longer than 4 h during the morning of collection and then sent to an analytical laboratory for testing according to standardized procedures, as follows: Fasting serum glucose concentrations were analyzed enzymatically, Hexokinase method (Siemens Advia 1600/1800 Erlangen, Germany). Total cholesterol CHOD-POD enzymatic method (Siemens Advia 1600/1800). All assays were performed in duplicate according to the manufacturers' instructions and none of the study youths were on any drug treatments.

Ideal total cholesterol have been defined as "ideal" $<$ 4.40 mmol/L ($<$170 mg/dL), or "non-ideal" $\geq$ 4.40 mmol/L ($\geq$170 mg/dL) [12]. Ideal fasting blood glucose concentrations were classified as ideal $<$5.6 mmol/L ($<$100 mg/dL), or non-ideal $\geq$ 5.6 mmol/L ($\geq$100 mg/dL) [12].

Resting blood pressure was measured using a Dynamap vital signs monitors (model BP 8800, Critikon, Inc., Tampa, Florida). Trained nurses took measurements, and all adolescents were required to sit and rest for at least 5 min prior to the first blood pressure measurement. Participants were in a seated, relaxed position with their feet resting flat on the ground. Two measurements in the non-dominant arm were taken, after five and 10 min of rest. The mean of these two measurements was considered. If the two measurements differed by 10 mmHg or more, a third measure was taken [25]. Blood pressure was defined as ideal (mean diastolic blood pressure or mean systolic blood pressure <90th percentile), or non-ideal (mean diastolic blood pressure or mean systolic blood pressure ≥ 90th percentile) [12].

Health behaviors

Body Mass Index: Body height and weight were measured according to standard procedures with the participants lightly dressed and in bare feet with a portable stadiometer (Seca213, Hamburg, Germany) a portable electronic weight scale (Tanita Inner Scan BC532, Tokyo, Japan) [26], respectively. Body mass index (BMI) was calculated from the ratio body weight (kg)/body height (m^2). Participants who had a BMI <85th percentile were categorized as meeting the ideal cardiovascular health criteria for BMI [12].

Dietary Assessment: Dietary intake and food consumption was assessed by the Kidmed questionnaire (Mediterranean Diet Quality Index for children and adolescents) [27], an index ranging from 0 to 12 points. Participants were classified as having an ideal healthy diet (≥8 points), whereas children and adolescents with <7 points were classified as having a non-ideal healthy diet, as already published elsewhere [17].

Physical Activity Level: Physical activity was assessed with accelerometers GT1M (ActiGraph, Pensacola, Florida, USA). Participants were instructed to use the accelerometer attached on the right side of hip, with the notch faced upwards, over five consecutive days (three weekdays, two weekend days) during waking hours, and remove it during water-based activities. The epoch length was set to 2 s to allow a more detailed estimate of physical activity intensity. Accelerometer data were analyzed by an automated data reduction program (ActivLive software v. 6.12, ActiGraph, Pensacola, Florida, USA). Periods with 60 min of consecutive zeros were detected and flagged as non-wear time. The cut-points proposed by Evenson, Catellier et al. [28] were used to determine physical activity intensities. Adolescents who, on average, performed more than 60 min of moderate-to-vigorous physical activity per day were classified as having an ideal physical activity level [12,13].

Smoking Habits: Data on smoking were self-reported questionnaires. Never smokers were classified as having an ideal smoking behavior [12].

Muscular fitness

Handgrip strength: Upper body isometric strength (handgrip strength test) was assessed using a handgrip dynamometer, (T.K.K. 5001, Grip-A, Takei, Japan), adjusted by sex and hand size for each adolescent. The participants were instructed to stand with their arms completely extended, squeezing gradually and continuously the handgrip up to the maximum of their strength, for at least 2 s. The adolescents were standing during the entire test, with the arm straight down at the side and performed the test twice for each hand, alternating between both hands. A period rest was given between trials. The best score for each hand was recorded in kilograms [29]. The handgrip score (kg) was calculated as the average of the left and right and then expressed per kilogram of body weight [30,31].

Standing long jump test: Lower body explosive strength (standing long jump test) was performed in an indoor wood floor gymnasium and the adolescents were instructed to jump from the starting line and to push off vigorously and jump as far forward as possible landing on both feet and staying upright. The test was done twice, and the best attempt was recorded. The standing jump score was determined by the distance between the last heel-mark and the take-off line [29].

Muscular fitness score: The results of the handgrip strength and long jump tests were transformed into standardized values (Z-scores) by age and sex. Then the sum of the Z-scores of the two tests was used to create the muscular fitness score. For muscular fitness score, participants below the 20th percentile were classified as having a low muscular fitness and those above this percentile value as having a high muscular fitness [30].

Pubertal stage

Participants self-assessed their pubertal stage of secondary sex characteristics (breast and pubic hair development in girls and genital and pubic hair development in boys) ranging from stage I to V, according to the criteria of Tanner and Whitehouse [32].

Socioeconomic status

Adolescents' socio-economic status was assessed with the Family Affluence Scale [33]. The scale is based on a 6-questions and the results varied between 0 and 13 points. 13 points indicated the highest socioeconomic status. The answers were summed and a continuum variable was computed to perform the statistical analyses.

Statistics analysis

Descriptive data are shown as means and standard deviations. Numbers (n) and percentage (%) are presented for categorical variables. Independent Two-tailed *t*-Tests for continuous variables, and Chi-square for categorical variables were used to examine sex differences.

Analysis of covariance (ANCOVA) to study the differences on muscular fitness score by ideal cardiovascular health metrics at baseline were conducted. Muscular fitness at follow-up (two years later) were entered as dependent variable, the ideal cardiovascular metrics at baseline as independent variable and age, sex, pubertal status, socioeconomic status at follow-up and muscular fitness baseline as covariates.

Finally, binary logistic regression was constructed to verify the odds ratios (OR) of accumulated metrics numbers of ideal cardiovascular health index to predict a high muscular fitness over 2 years, adjusted for age, sex, pubertal status, socioeconomic status at follow-up and muscular fitness baseline. We used three ideal metrics as reference because none of the participants had 1 or 2 metrics at baseline.

Results

Baseline characteristics of the participants are presented in Table 1. Boys showed higher levels of muscular fitness and moderate-to-vigorous physical activity than girls ($p < 0.05$ for all). Girls presented higher levels of total cholesterol ($p < 0.05$ for all). Only 36% of the total sample complied with physical activity guidelines.

ANCOVA showed significant association between ideal cardiovascular metrics at baseline and muscular fitness score at follow-up ($F_{(4,322)} = 2.280$, $p = 0.04$), after adjustment for age, sex, pubertal status and socioeconomic status at follow-up and muscular fitness at baseline (Fig. 1).

Fig. 2 shows the odds for high muscular fitness at follow-up by accumulated metrics of ideal cardiovascular health at baseline. The odds ratios for having high muscular fitness at follow-up were 11.12 for 7 metrics (95% confidence interval [CI], 4.3–19.5) (p = 0.002), 7.1 for 6 metrics (95% CI, 3.15–12.05 p = 0.001), for 5 metrics 3.3 (95% CI, 2.3–7.8 p = 0.009) and for 4 metrics (95% CI, 0.5–5.1 p = 0.117) when compared to those with 3 or less accumulated metrics of ideal cardiovascular health, after adjustments for potential confounders.

Discussion

In this study, ideal cardiovascular health status at baseline was positively associated with muscular fitness two years later. We also observed that the accumulation of ideal cardiovascular health metrics at baseline was associated with an increased muscular fitness at follow-up. In addition, we found a significant trend showing that the more ideal cardiovascular health metrics adolescents accumulated, the greater the likelihood of having high muscular fitness at follow-up.

To the best of our knowledge, the present report is the first longitudinal study to report the application of the concept of ideal cardiovascular health to a cohort of adolescents, and to investigate its relationship with muscular fitness across adolescence. Our findings underscore the potential effect of the ideal child cardiovascular health index, generated from the individual cardiovascular components (health behaviors and health factors) on muscular fitness phenotype over adolescence. These results have public health and clinical implications, since adolescence has been reported as the period of life where changes in physical activity, fitness, adiposity, and metabolic status, are likely to occur [34].

Evidence has suggested that optimal cardiovascular health index during adolescence may be critical in preventing the development of future cardiovascular disease [14]. One of the primary focuses of the AHA strategy is the maintenance of ideal cardiovascular health from birth through childhood to young adulthood and beyond [13]. Recently, several studies in the youth population have analyzed cross-sectional relationships between

Table 1 Participants' characteristics at baseline.

Characteristics	Total (331)	Boys (148)	Girls (183)
Age (year)	13.9 (±1.6)	14.02 (±1.6)	13.8 (±1.6)
Body mass index (kg/m^2)	20.9 (±3.7)	20.6 (±3.7)	21.2 (±3.9)
Pubertal status A: ≤III/IV/V (%)	43.4/44.8/11.8	56.3/32.8/10.9	32.3/55.2/12.6
Pubertal status B: ≤III/IV/V (%)	31.3/48.9/19.8	38.5/50/11.5	25.1/48/26.9
Handgrip (kg)	25.3 (±6.6)	27.7 (±8.7)	23.2 (±4.6)*
Standing long Jump (cm)	157.1 (±28.3)	170.3 (±30.7)	146.1 (±23.3)*
Systolic blood pressure (mmHg)	118.3 (±12.7)	118.5 (±11.1)	118.1 (±11.8)
Diastolic blood pressure (mmHg)	63.3 (±7.8)	62.75 (±7.8)	64.1 (±7.5)
Glucose (mg/dL)	88.8 (±7.1)	90.1 (±6.3)	87.7 (±7.45)
Total cholesterol (mg/dL)	153.6 (±25.6)	148.3 (±26.5)	157.9 (±26.6)*
Moderate-to-vigorous physical activity (min/day)	54.9 (±18.5)	61.2 (±20.2)	49.9 (±16.2)*
Socioeconomic Status	6.5 (±1.6)	6.5 (±1.5)	6.4 (±1.7)
Ideal health behaviors			
Non smokers n (%)	309 (93.4)	135 (91.2)	174 (95.1)
Non overweight n (%)	290 (87.6)	130 (87.8)	160 (87.4)
Physically active n (%)	119 (36)	73 (49.3)	46 (25.1)*
Healthy diet n (%)	158 (47.7)	68 (45.9)	90 (49.2)
Ideal health factors			
Normal cholesterol n (%)	253 (76.4)	120 (81.1)	133 (72.7)*
Normal blood pressure n (%)	301 (90.9)	166 (90.7)	135 (91.2)
Normal plasma glucose n (%)	315 (95.2)	141 (95.3)	174 (95.1)

*Significantly different from girls ($p < 0.05$).

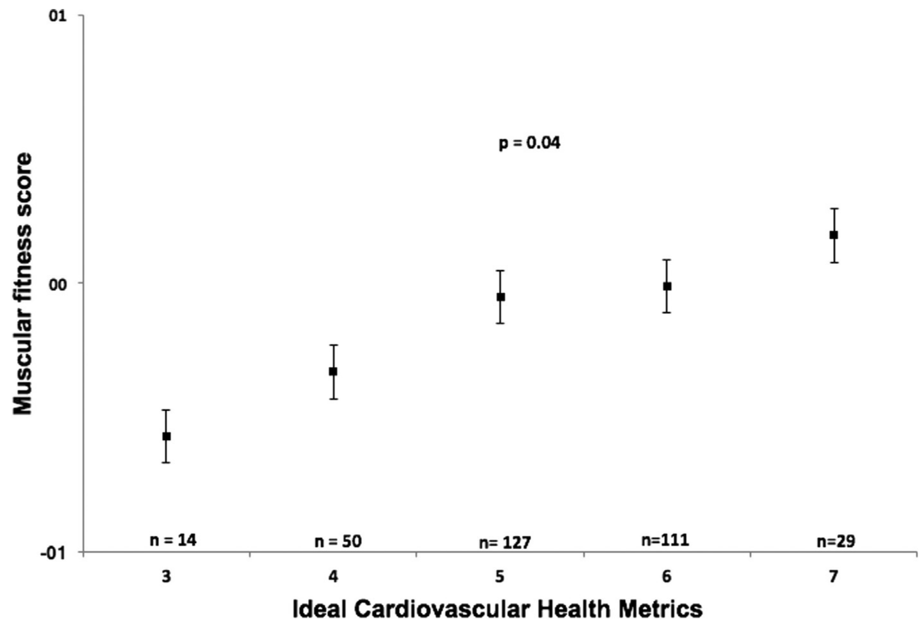

Figure 1 Associations of ideal cardiovascular health metrics at baseline by muscular fitness score at follow-up, adjustment for age, sex, pubertal status and socioeconomic status at follow-up and muscular fitness at baseline.

ideal cardiovascular health status and various health outcomes, such as inflammation [15], liver enzymes [35], and cardiorespiratory [16] and muscular fitness [17]. They all reported that a better ideal cardiovascular health status was associated with a healthier profile. However, in the previous studies, none of the adolescents met the seven components of the ideal cardiovascular health metrics [15,17], and in our sample only 8.76% of the participants met all the components of the ideal cardiovascular health index. One possible

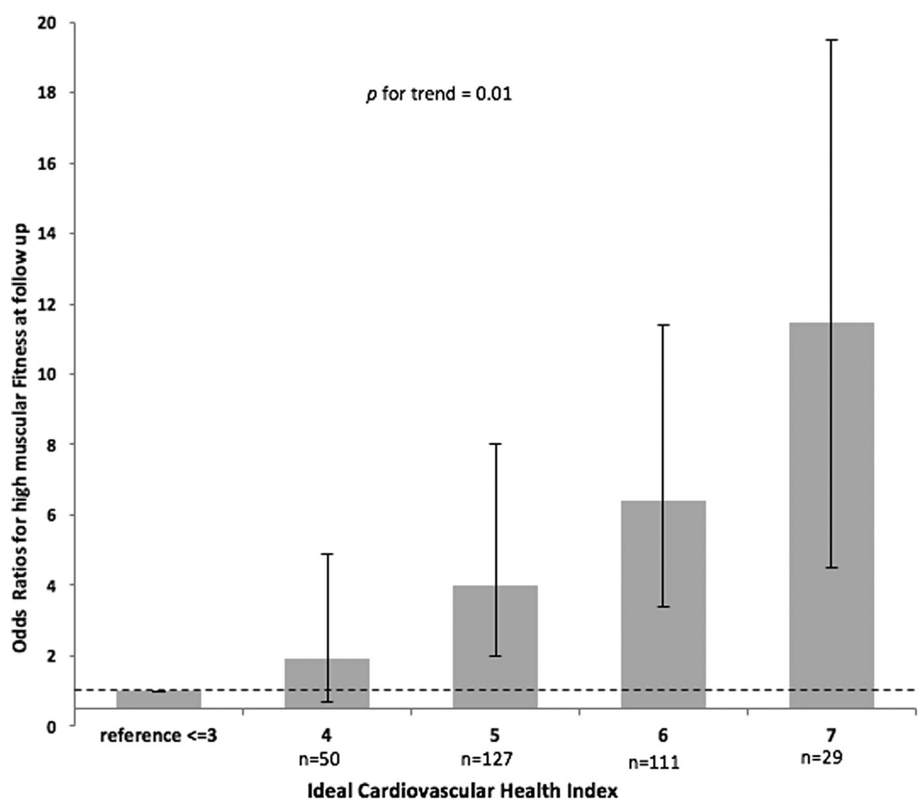

Figure 2 Odds ratios of ideal cardiovascular health metrics (95% confidence interval) for high muscular fitness at follow-up adjusted for age, sex, pubertal status and socioeconomic status at follow-up and muscular fitness at baseline.

explanation could be that most of these studies showed low scores on the ideal diet score component, which contrasts with 42.6% of our participants meeting this criterion. Indeed, it has been reported that the Mediterranean diet is prevalent in Portugal [36].

Regarding muscular fitness, our findings are partially in agreement with Ramírez-Vélez and colleagues who reported that muscular fitness (assessed by the handgrip test) was associated with the ideal cardiovascular health index in a cross-sectional study of Colombian children and adolescents [17]. We have expanded those results by involving a longitudinal cohort. Furthermore, we used two tests to composite a muscular fitness score (upper body isometric strength and lower body explosive strength) which allowed a more comprehensive and complete measure of muscular fitness, rather than relying on a single test [29].

The effect of how each ideal cardiovascular health component may affect muscular fitness is not well established. Therefore, low prevalence of ideal diet and physical activity are of special importance since they seem to represent two key health behaviors [37]. In addition, both diet and physical activity have been associated with muscular strength [38]. Conversely, studies also have reported the negative effect of tobacco [39], fatness [40], hyperglycemia [41] and cholesterol [42] on skeletal muscle health.

Our findings also showed that the new AHA definition of cardiovascular health in adolescents is appropriate, as it was able to reflect well the subsequent prevention of low muscular fitness. Indeed, phenotypes of childhood muscular fitness could be used to predict adult metabolic syndrome [43]. Previous work from our research group and others have shown cross-sectional associations between low muscular fitness and unhealthy cardiometabolic profile in adolescents [7,17,38,44]. However, to the best of our knowledge, no studies have been conducted considering the AHA's definition of ideal cardiovascular health and its associations with physical fitness levels using a longitudinal design. In a cross-sectional study, Ruiz and colleagues [16] showed that high cardiorespiratory fitness thresholds were associated with the presence of more ideal cardiovascular health components.

The strengths of this study include its longitudinal design and the objectively assessment of physical activity with accelerometers, as these devices do not rely on subjects' recall and may capture the entire daily pattern of physical activity. In addition, adolescence is a period of natural changes in several metabolic systems such as body composition and sex hormones, which may confound the results [34]. However, in our study the muscular fitness scores were standardized by age and sex [30], and all analyses were controlled for pubertal stage. The muscular fitness tests used in our study have demonstrated good criterion-related validity in youth [7,45,46]. Another strength of the study was the use of health-related, valid, and reliable field tests recommended for fitness assessment in European youth [47].

Limitations of the current study include the fact that our sample is not nationally representative, and therefore, these results cannot be extended to the entire population of Portuguese adolescents. Also, we do not evaluate all the ideal cardiovascular health metrics at follow-up; hence longitudinal research in adolescents is needed to confirm or rule out our findings.

In conclusion, the ideal cardiovascular health index during adolescence was associated with high muscular fitness levels over a two-year period. These results provide a further insight into our understanding of the association between health behaviors and health factors with muscular fitness in youth population.

Conflict of interest

The authors declare that they have no conflicts of interest.

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