INTRODUCTION

During the last three decades, obesity has become a global epidemic. Childhood obesity leads to an increased risk of morbidity and mortality later in life as well as large societal costs; obesity is therefore one of the greatest health challenges in the modern world. Independently of obesity, cardiorespiratory fitness (CRF) in children has been associated with multiple metabolic risk factors and future health and teenagers with a low CRF were more likely to develop hypertension in adulthood, even among participants with a normal body mass index (BMI). In adults, CRF has been shown to be a more powerful predictor for all-cause mortality than traditional risk factors for example, hypertension, smoking, sedentary

Abstract

Aim: To present specific reference values for cardiorespiratory fitness (CRF) in children with obesity and to analyse secular trends of CRF in the studied population.

Methods: Cardiorespiratory fitness, the maximal oxygen uptake (VO₂ max), was estimated with the Åstrand-Rhyming submaximal bicycle test, in 705 Swedish children (356 girls, 8-20 years) with obesity according to the International Obesity Task Force (IOTF). Data were collected from 1999 to 2013. Secular trends, analysed with multiple linear regression, were adjusted for age, height and body mass index standard deviation score (BMI SDS).

Results: All children had low CRF compared with normal weight standards but there was a marked variability of CRF in children with obesity, which was possible to quantify with the developed obesity specific CRF reference values. The mean value of absolute VO₂ max (L/min) increased with age and relative VO₂ max (mL/kg/min) decreased with age in both boys and girls. There was a negative secular trend in both sexes (P < .001).

Conclusion: These are the first obesity specific reference values of CRF in children enabling clinical evaluation in childhood obesity treatment. Cardiorespiratory fitness in children with obesity has declined the last decades, indicating that also within this vulnerable group physical activity has gone down.

KEYWORDS
cardiorespiratory fitness, child, obesity, reference values, secular trends
behaviour and obesity. This highlights the importance of incorporating an evaluation of CRF in children treated for obesity, as a complement to BMI.

Several studies have shown a negative trend with CRF in children declining from the 1980s up until today. Children with obesity have lower CRF than normal weight children but if CRF has declined over time also for children with obesity is to our knowledge still uncertain.

Reference values of CRF and other physical fitness components for healthy children and adolescents with normal weight have been developed and evaluated during the last decades. However, when assessing CRF in children and adolescents with obesity, using healthy children and adolescents as a reference group, relative maximal oxygen uptake (VO₂ max) is regularly categorised as one of ‘very low’ or ‘extremely low’, which severely limits the clinical value of the test evaluation. Specific reference values for CRF in children and adolescents with obesity would improve the interpretation of the test and enhance the possibility to assess to which extent cardiometabolic risk among children and adolescents with obesity is independently also affected by CRF. Therefore, the purpose of this study was to present age- and sex-specific reference values for cardiorespiratory fitness among children and adolescents with obesity. We also aimed to analyse the secular trends of CRF in the studied population.

2 | METHODS

2.1 | Study design

This was a cross-sectional study of a cohort of Swedish children and adolescents consecutively referred between the years of 1999 and 2013 to The National Childhood Obesity Center at Karolinska University Hospital, Stockholm. Anthropometric measures and CRF were obtained from all participants during their first visit to the clinic, as a part of the clinical evaluation before initiation of obesity treatment. The study was approved by the Ethics Committee of Stockholm (No. 2013/2273-32). Since data were previously collected, the need of informed consent was waived.

2.2 | Study population

The flowchart for subject inclusion is described in Figure 1. Seven hundred and five out of 1013 participants met the two inclusion criteria; a) being classified with obesity according to the International Obesity Task Force and b) completed a submaximal cycle ergometer test with a steady-state heart rate (HR) ≥120 bpm. Participants with a HR too high to estimate VO₂ max were excluded (Figure 1). Children were stratified on sex and categorised into age groups (8-11, 12-13, 14-15 and 16-20 years old) to reflect physical maturity.

2.3 | Anthropometric measurements

Weight was measured to the nearest 0.1 kg with participants dressed in light clothing (Vetek, Sweden, model T1 1200), and height was measured to the nearest 0.1 cm without shoes using a stadiometer (Ulmer). Body Mass Index was calculated as weight (kg) divided by height (m) squared (kg/m²). Body mass index standard deviation score (BMI SDS) was calculated according to Cole & Lobstein. Since exact date of the assessment was not available for all participants, BMI SDS was based on age in whole years.

2.4 | Cardiorespiratory fitness

Cardiorespiratory fitness was assessed by a submaximal bicycle ergometer (Monark, 864, Varberg) test. According to Åstrand-Rhyming, the test is based on the ‘Relationship between pulse rate during work and actual oxygen intake in % of subject’s aerobic capacity’. Heart Rate was registered every minute by a chest-worn heart rate monitor (Polar, Polar Oy. Kempele, Finland or Polar Tempo, Polar Sverige AB, Bromma). Absolute VO₂ max, expressed as litres per minute (L/min), was estimated from the measured HR and workload (minimum 50 watt/300 kmp). Since oxygen uptake differs in male and female, and maximal HR varies with age, absolute VO₂ max was adjusted for age and sex based on Åstrand-Rhyming, with a factor of 1.1 for participants under the age of 15 years. Relative VO₂ max, expressed as millilitres per kilogram and minute (mL/kg/min), was calculated by dividing absolute VO₂ max (converted to mL/min) by body weight in kg.

2.5 | Incomplete data

All included subjects had data on estimated absolute (L/min) and relative (mL/kg/min) VO₂ max. However, the background data on workload and HR, used for the documented estimation of VO₂ max, were missing in 329 participants. Of these subjects, 87.2% were tested between the years of 1999 and 2004, in the beginning of the National Childhood
Obesity Center’s history. Missing data analysis showed that they had a significantly higher absolute VO₂ max (L/min) compared to subjects with complete data in the following age groups; girls 14-15 years (P = .001), boys 12-13 years (P = .002) and boys 16-19 years (P = .001). Regarding relative VO₂ max (mL/kg/min), only boys 12-13 years differed (P = .038) with higher values in the group with incomplete data. Further analysis revealed that boys 16-19 years with incomplete data had a higher BMI SDS than their peers (P = .027), but no differences in BMI SDS were detected in the other age groups. Incomplete data were associated with the year when the children were tested; the Åstrand-Rhyming test protocol has remained unchanged, while documentation has become more detailed in later years. Therefore, the percentiles for CRF are presented for all included subjects and are based on the documented estimations of VO₂ max.

2.6 Statistical analysis

IBM SPSS version 25 (IBM SPSS) was used for all statistical analyses. Continuous data are presented with mean and standard deviation (SD). Results are presented stratified for sex and age groups, as mean, 95% confidence interval (CI), standard deviation (SD) and percentile values featured with the 5th, 25th, 50th, 75th and 95th percentiles (the 50th with 95%CI). Group differences were compared by student’s t test. Secular trend of VO₂ max was analysed with multiple linear regression, stratified by sex, and adjusted for age, height and BMI SDS. A time trend for BMI SDS was also assessed. A P-value of <.05 was considered statistically significant.

3 RESULTS

Body Mass Index and BMI SDS stratified on sex and age are presented in (Table 1). Percentiles for estimated absolute and relative VO₂ max are presented in Figure 2A-D. The mean value of absolute VO₂ max (L/min) increased with age in both sexes (Tables 2 and 3). Girls with low CRF (within/below the 5th percentile) had

| Table 1 | Body mass index (BMI) and BMI SDS for Swedish girls and boys with obesity |
|---------|-------------------------------------------------|
| Age (y) | N     | Mean  | SD    | Min-Max |
| Girls  |       |       |       |        |
| BMI     |       |       |       |        |
| 8-11    | 49    | 30.8  | 3.7   | 24.1-40.3 |
| 12-13   | 80    | 35.0  | 5.1   | 26.8-52.7 |
| 14-15   | 112   | 37.1  | 5.4   | 27.8-58.3 |
| 16-20   | 115   | 38.8  | 5.9   | 28.9-67.7 |
| BMI SDS<sup>a</sup> |       |       |       |        |
| 8-11    | 49    | 3.1   | 0.3   | 2.5-3.9   |
| 12-13   | 80    | 3.1   | 0.4   | 2.3-4.0   |
| 14-15   | 112   | 3.2   | 0.4   | 2.3-4.2   |
| 16-20   | 115   | 3.3   | 0.4   | 2.3-4.5   |
| Boys   |       |       |       |        |
| BMI     |       |       |       |        |
| 8-11    | 57    | 31.7  | 4.8   | 24.6-47.6 |
| 12-13   | 83    | 33.4  | 4.2   | 26.6-47.2 |
| 14-15   | 109   | 36.1  | 4.9   | 29.0-53.6 |
| 16-19   | 100   | 39.0  | 5.8   | 29.6-56.1 |
| BMI SDS<sup>a</sup> |       |       |       |        |
| 8-11    | 57    | 3.1   | 0.4   | 2.2-4.0   |
| 12-13   | 83    | 2.9   | 0.4   | 2.0-3.8   |
| 14-15   | 109   | 2.9   | 0.4   | 2.2-3.9   |
| 16-19   | 100   | 3.1   | 0.5   | 2.2-4.2   |

<sup>a</sup>BMI SDS IOTF.
Similar values of absolute VO$_2$ max (L/min) regardless of age group. Relative VO$_2$ max (mL/kg/min) decreased with age in all percentiles for both male and female. There was a statistically significant negative time trend (Figure 3A-B) for CRF in both sexes (P < .001). Absolute VO$_2$ max (L/min) decreased with −0.024 L/min (95% CI −0.037 to −0.012) in girls and with −0.044 L/min (95% CI −0.058 to −0.030) in boys per year. Relative VO$_2$ max (mL/kg/min) decreased with −0.29 mL/kg/min (95% CI −0.42 to −0.15) in girls and with −0.43 mL/kg/min (95% CI −0.57 to −0.29) in boys per year. There was a negative time trend for BMI SDS, −0.016 (−0.023 to −0.009). Sensitivity post hoc analysis showed a higher BMI SDS in the year 1999, but the differences in BMI SDS were non-significant between all other years.

### DISCUSSION

These are, to the best of our knowledge, the first obesity specific reference values of CRF in children and adolescents. There are multiple studies showing that low CRF in children is associated with metabolic risk factors such as hypertension, hyperinsulinaemia, elevated triglycerides and low insulin sensitivity.\(^4\,^5\,^18\) Low CRF is traditionally
defined as the lowest quartile or quintile of a population, and some studies also define low CRF as results below the median split.\(^\text{19}\) All children had equal or higher values of absolute VO\(_2\) max compared with a general paediatric population. However, none of the children in the present study with a relative VO\(_2\) max around the 95th percentile exceeded the 25th percentile in a normal population\(^\text{14}\) which means that all study subjects had what is commonly defined as low CRF.

Absolute VO\(_2\) max (L/min) in children is known to increase with body size, physical maturation and physical activity, but also decrease in relative VO\(_2\) max (mL/kg/min) with age is found.\(^\text{10,14,20,21}\) In the present study, we found a modest increase in absolute VO\(_2\) max during adolescence and a marked decline in relative VO\(_2\) max. Since absolute VO\(_2\) max was normal, the decrease in relative VO\(_2\) max is directly related to the excessive body weight. Children with obesity spend less time in physical activity, have poorer physical functioning and experience more pain compared to children with normal weight, which also affect CRF.\(^\text{22}\) We have previously shown that adolescents with obesity improve their absolute VO\(_2\) max (L/min) after Roux-en-Y gastric bypass, indicating that severe obesity might impair not only relative but also absolute VO\(_2\) max.\(^\text{23}\) Thus, the marked decrease in relative VO\(_2\) max may be explained by a negative effect of obesity on VO\(_2\) max.

The submaximal bicycle test was originally developed for adults\(^\text{16}\) and does not allow values below a certain level. In the present study, seventy-two subjects, a majority between 8 and 11 years, were excluded based on a HR too high for estimation and experience more pain compared to children with normal weight, which also affect CRF.\(^\text{22}\) However, for a clinical use FFM is of minor interest as such measurements are too expensive (dual-energy X-ray absorptiometry), and the accuracy has been questioned of the more affordable assessments (bioelectrical impedance) in children with obesity.\(^\text{30,31}\) The Åstrand-Rhyming test has been validated in general paediatric populations,\(^\text{26,32}\) but not explicitly in children with obesity. The main limitation of this study, also common in previous research, is the cross-sectional design. To have the ability to detect natural changes of CRF in growing children further research using longitudinal design is required.
4.1 | Clinical implications

Ortega et al.\textsuperscript{11} developed reference values of physical fitness for children in a normal population and have suggested that their normative values could be used for classification of an individual level of physical fitness ranging from very poor to very good. Our results show that all children in this cohort had a poor cardiorespiratory fitness; therefore, this type of classification should be avoided. Instead, the reported reference values could be used on an individual level to detect progress in CRF for example following an exercise programme. The ability to evaluate even minor changes in CRF can work as a motivational factor for the patient but also as an indicator for the healthcare professional whether or not the prescribed exercise is vigorous enough. It is likely but not yet proven that variations in CRF within the low range all children with obesity are in are associated with cardiometabolic risk.

5 | CONCLUSIONS

Most children with obesity have a low or very low CRF. To discriminate CRF within these children, we have developed reference values of CRF for children with obesity, which will be useful in the clinical evaluation and follow-up of children with obesity. In accordance with normal weight children, CRF in children with obesity has declined over the last 20 years. To reduce the risk of future cardiovascular disease in this group of children, it might be more important than ever to strive to enhance the level of physical activity and to improve their cardiorespiratory fitness.

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CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

DATA AVAILABILITY STATEMENT

The datasets used during the current study are available from the corresponding author on reasonable request.

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