DISSERTATIONES
KINESIOLOGIAE
UNIVERSITATIS
TARTUENSIS
58

MARIT SALUS

Effect of sprint interval training on body composition, cardiorespiratory fitness, blood biochemical markers and bone health in adolescent boys with obesity

DISSERTATIONES KINESIOLOGIAE UNIVERSITATIS TARTUENSIS
58

MARIT SALUS

Effect of sprint interval training on body composition, cardiorespiratory fitness, blood biochemical markers and bone health in adolescent boys with obesity

UNIVERSITY OF TARTU
Press
1632

Institute of Sport Sciences and Physiotherapy, Faculty of Medicine, University of Tartu, Estonia

Dissertation is accepted for the commencement of the Degree of Doctor of Philosophy in Exercise and Sport Sciences on October 13, 2023 by the Council of the Institute of Sport Sciences and Physiotherapy, University of Tartu, Estonia.

Supervisors: Professor Jaak Jürimäe, PhD, University of Tartu, Tartu, Estonia

Professor Vallo Tillmann, Dr, University of Tartu, Tartu, Estonia

Opponent: Professor Arvydas Stasiulis, PhD, Lithuanian Sports University, Kaunas, Lithuania

Commencement: Senate Room of the University of Tartu, Ülikooli St. 18, Tartu on November 17, 2023, at 3 p.m.

Publication of this dissertation were granted by the University of Tartu and Estonian Research Council grant PUT 1428 and PUT 1120.

ISSN 1406-1058 (print)
ISBN 978-9916-27-377-7 (print)
ISSN 2806-2361 (pdf)
ISBN 978-9916-27-378-4 (pdf)

University of Tartu Press
www.tyk.ee

CONTENTS

LIST OF ORIGINAL PUBLICATIONS

I Salus M, Tillmann V, Remmel L, Unt E, Mäestu E, Parm Ü, Mägi A, Tali M, Jürimäe J. Effect of supervised sprint interval training on cardiorespiratory fitness and body composition in adolescent boys with obesity. *Journal of Sports Sciences* 2022; 40: 2010–2017.

II Salus M, Tillmann V, Remmel L, Unt E, Mäestu E, Parm Ü, Mägi A, Tali M, Jürimäe J. Effect of supervised sprint interval training on cardiometabolic biomarkers and adipokine levels in adolescent boys with obesity. *International Journal of Environmental Research and Public Health* 2022; 19: 12672.

III Salus M, Tillmann V, Remmel L, Unt E, Mäestu E, Parm Ü, Mägi A, Tali M, Jürimäe J. Serum osteocalcin, sclerostin and lipocalin-2 levels in adolescent boys with obesity over 12-week sprint interval training. *Children* 2023; 10: 850.

In all papers, Marit Salus had primary responsibility for study protocol development, participants' enrollment, performing training intervention, data analysis, and writing the manuscripts.

ABBREVIATIONS

ANCOVA	analysis of covariance
BF %	body fat percentage
BP	blood pressure
BMC	bone mineral content
BMD	bone mineral density
BMI	body mass index
CRF	cardiorespiratory fitness
CVD	cardiovascular disease
DBP	diastolic blood pressure
ES	effect size
DXA	dual-energy x-ray absorptiometry
FM	fat mass
HDLc	high-density lipoprotein cholesterol
HIIT	high-intensity interval training
HOMA-IR	homeostasis model assessment of insulin resistance
HR_{max}	maximum heart rate
HR_{rest}	resting heart rate
IR	insulin resistance
LBM	lean body mass
LDLc	low-density lipoprotein cholesterol
LICT	low-intensity continuous training
MAP	mean arterial pressure
MetS	metabolic syndrome
MICT	moderate-intensity continuous training
MSCs	mesenchymal stem cells
MSSS	metabolic syndrome severity z-score
PA	physical activity
SBP	systolic blood pressure
SE	standard error
SIT	sprint interval training
TC	total cholesterol
TG	triglyceride
VO_2peak	peak oxygen consumption
WB	whole body
WC	waist circumference
WHO	World Health Organization

1. INTRODUCTION

Obesity, a common chronic health problem in childhood and adolescence, is a risk factor for cardiovascular disease (CVD) and type 2 diabetes later in life (Ayer et al., 2015; Hejazi & Ferrari, 2022). In addition, increased body mass index calculated as a person's body mass in kilograms divided by the square of their height in meters (BMI, $kg.m^{-2}$) is also a risk factor for different musculoskeletal disorders and psychological problems, including anxiety and depression (Kelly et al., 2013; Tremmel et al., 2017; Wang et al., 2022). High BMI or increased total body fat mass (FM) and body fat percentage (BF %) are associated with dyslipidemia, insulin resistance (IR), increased systolic (SBP) and diastolic (DBP) blood pressure and elevated levels of adipokines (Kelly et al., 2013). It is also reported that individuals with increased BMI are more prone to several cancers (breast, kidney, prostate, ovarian, liver) and respiratory dysfunction (WHO, 2021) expressed as sleep apnea syndrome or a somnolence during daytime (Kelly et al., 2013). Being overweight or obese is inversely associated with cardiorespiratory fitness (CRF) in childhood (Utsal et al., 2013). It is identified that CRF is a strong predictor of CVD and cardiometabolic disease outcomes in adolescents (Ortega et al., 2008). For instance, boys with low CRF may have nearly six times higher risk to have CVD in their lifetime (Ruiz et al., 2016). As CVD is the most common cause of premature death all over the world, including Estonia (Nichols et al., 2014), increasing CRF may diminish the detrimental effects of obesity-related risk factors for CVD (Dias et al., 2018). The latter may be particularly important during puberty.

Health-related behaviors during childhood and adolescence affect health in adulthood (WHO, 2014). The early detection of obesity-related health problems is essential because majority of them are preventable through changing the risk behaviors such as unhealthy dietary pattern and/or low levels of physical activity (PA) (WHO, 2021). The knowledge that the level of daily PA sharply decreases and the level of sedentary time increases during the pubertal maturation (Lätt et al., 2015), makes exercise training an indispensable strategy tool to improve CRF and other cardiometabolic parameters during this growth period. Exercise training can be largely divided into three groups: low-intensity continuous training (LICT), moderate-intensity continuous training (MICT) and high-intensity interval training (HIIT). To date, the most commonly used training programs to improve health-related aspects in adolescents with overweight and obesity are LICT or MICT programs (Sarvottam & Yadav, 2014). However, these LICT and MICT programs are rather time consuming and monotonous and may not suit to everybody. Moreover, one of the main reasons and barriers to achieve regular physical exercise in youth with overweight today is a lack of time (Zabinski et al., 2003). To overcome the time consuming and monotonous LICT and MICT programs for weight reduction purposes in young individuals, it is recommended to use interval training that consists of high-intensity exercise sets interspersed by recovery period between the sets (Corte

de Araujo et al., 2012). It has been suggested that interval training requires about 40% less training time than MICT, but achieves similar health outcomes as MICT (Viana et al., 2019; Wewege et al., 2017). In addition, interval training can also be more enjoyable for children as it is possible to manipulate with different training variables (e.g. work interval intensity and duration, between-series recovery intensity and duration, exercise modality, number of repetitions, number of series) and therefore, its recurrent short sprints reflect childlike behavior (Buchheit & Laursen, 2013). In recent years, more intense and even shorter form of HIIT – sprint interval training (SIT) – in which sets are performed in an all-out effort (Weston et al., 2014), has increased its popularity in training world. The time-efficient SIT training can be carried out by swimming (Kabasakalis et al., 2020), rope jumping (Nazari et al., 2020), stair climbing (Allison et al., 2017), and with the most frequently used training mode – by running (Gillen et al., 2016; Racil et al., 2013; Racil et al., 2016), which again, emphasizes the practical and highly accessible model of SIT.

According to World Health Organization report, more than 340 million children and adolescents at the age of 5–19 were overweight or obese in 2016, and it is still in upward trend (WHO, 2021). More importantly, it is shown that overweight adolescents have a 40–80% risk of being overweight or obese in adulthood (Hejazi & Ferrari, 2022, Kansra et al., 2021; Raj & Kumar, 2010). Therefore, treatment strategies to reduce overweight or obesity among young population must be quickly implemented, and interval training may be a good option for this. To date, there are relatively few complex intervention studies performed, which have investigated interval training effect on several different health parameters among adolescents with obesity (Dias et al., 2018). To our best of knowledge, no studies have investigated the effect of all-out bicycle SIT program on health parameters in a specific group of adolescent boys with obesity. Therefore, the general aim of the present thesis was to investigate the effect of 12-week SIT program on body composition, cardiorespiratory fitness, blood biochemical parameters and bone health in adolescent boys with obesity.

2. REVIEW OF THE LITERATURE

2.1. General overview of obesity

Obesity is one of the most concerning chronic health problems during the twenty-first century that is affecting individuals at all ages. World Health Organization reported in 2016 that more than 340 million children and adolescents aged 5–19 were overweight or obese. Unfortunately, the problem is visibly increasing, especially among young boys (Martin-Smith et al., 2020; Shah et al., 2020). By the conducted survey results (Metsoja et al., 2018; Spinelli et al., 2021), every forth first grader (seven to eight years old) in Estonia is overweight, one tenth is obese, and boys being more overweight and obese than girls (28.6% vs 23.3%, and 23.3% vs 11.4%, respectively). Similar trend was observed in a meta-analysis carried out among children aged 10–19 years from 188 different countries: in 112 countries the obesity was more common in boys compared to girls and the gender-difference was especially seen in high- and upper middle-income countries (Shah et al., 2020). The possible reasons for this gender-difference are differences in body composition, hormonal homeostasis (Shah et al., 2020) and sociocultural habits, such as sleeping hours, time spent on PA or behind the screen (Kavey et al., 2003). Additionally, girls and boys have different consumption of nutrients – boys prefer more meat and calorie-dense food, whereas girls like more vegetables or consume low calorie food (Shah et al., 2020). All these sex- and gender-based factors play an important role in the prevalence of overweight and obesity during adolescence.

Although obesity is a very complex disease with a mix of biological, genetic, metabolic, endocrine, environmental, behavioral and socio-cultural factors, it is simply defined as a condition of abnormal or excessive accumulation of body fat, even to the extent that the individuals' health is at hazard (Kansra et al., 2021; Raj & Kumar, 2010). The most commonly used characteristic to define obesity is BMI. As BMI is age dependent, no universal BMI absolute value can be used in childhood to define overweight or obesity, as BMI above 25 and above 30 respectively are used in adults. Therefore, age- and gender-specific BMI charts should be used. There are many BMI charts with different criteria to define overweight or obesity in children. Most widely used BMI charts are WHO growth charts where overweight is defined as BMI-for-age greater than 1 standard deviation, and obesity greater than 2 standard deviations above the median and, BMI charts by Cole et al. (2000). The latter uses specific centiles for overweight and obesity based on adults BMI values of 25 and 30 $kg.m^{-2}$ respectively (Cole at al., 2000). However, as there are big differences in body size between different countries, the country- (or national) specific growth charts should be used (Bonthius et al., 2012) to define overweight or obesity in concrete country. In Estonia, BMI equal to or exceeding the age-gender-specific 85^{th} percentile is defined as overweight, and those whose BMI is equal or exceeding the 95^{th} of Estonia BMI charts are defined as obese (Grünberg et al 1998).

Although BMI is the most widely and well-known used population-based screening method of obesity, the BMI value often does not provide the best overview of the body status while the height and body composition are continually changing during growth period (Sahoo et al., 2015). Therefore, combining BMI with the measure of waist circumference (WC) or skinfold thicknesses or body composition measured by dual energy x-ray absorptiometry (DXA) could give an extra information about the child's body composition and defining obesity (Kansra et al., 2021; Sahoo et al., 2015). A study by Sahoo et al. (2015) reported that children in the age-group of 5–18 years are classified as "fat" when the BF % is at least 25% for males and 30% for females. No matter how the state of overweight and obesity is measured, the consequences of both conditions have negative impact on individual's overall health.

2.2. Consequences of childhood obesity

2.2.1. Impact on cardiometabolic health

Adolescents with obesity are at risk of developing CVD and type 2 diabetes later in life (Bass & Eneli, 2015; Busnatu et al., 2022; Hejazi & Ferrari, 2022; Raj & Kumar, 2010). Several well-known biochemical markers for CVD have been established: serum glucose, insulin, total cholesterol (TC), triglyceride (TG), low- (LDLc) and high-density (HDLc) lipoprotein cholesterol concentrations in adolescents (Ruiz et al., 2016). Regarding to these biochemical markers for CVD, American Heart Associations have developed guidelines for the primary prevention of CVD (Kavey et al., 2003). The guidelines for cardiovascular risk reduction in children and adolescents with identified risk are as follows: LDLc < 4.14 mmol.L^{-1}, HDLc > 0.91 mmol.L^{-1}, fasting TG < 1.69 mmol.L^{-1}, SBP and DBP < 95^{th} percentile for age, sex and height, BMI < 95^{th} percentile for age and sex, fasting plasma glucose < 6.66 mmol.L^{-1}, and complete cessation of smoking (Kavey et al., 2003). As the number of cardiovascular risk factors increases, so does the pathological evidence for atherosclerosis in the aorta and coronary arteries beginning in early childhood. This all raises a big concern as unexpected death of children and young adults is positively correlated with those aforementioned risk factors (Kavey et al., 2003).

Obesity is a critical risk factor for the development of IR (Kurtoglu et al., 2010; Levy-Marchal et al., 2010; Tagi et al., 2019). IR is a pathological condition that refers to whole-body reduced glucose uptake in response to physiological insulin levels because of the β-cell dysfunction that occurs in obese children and adolescents with the consequence of impairment of glucose metabolism (Kostovski et al., 2018; Levy-Marchal et al., 2010, Tagi et al., 2019). Although IR can occur during normal physiological condition such as puberty when insulin sensitivity undergoes a decline of around 25–50% (Tagi et al., 2019), obesity during adolescence aggravates it (Kostovski et al., 2018). Kostovski et al. (2018) found that insulin resistant 4–17 years old children and

adolescents with obesity tend to have a worse metabolic profile compared to individuals without IR, making so IR a key component of the metabolic syndrome (Kostovski et al., 2018), and consequently ending with a higher CVD risk (Tagi et al., 2019). To define IR, a quite invasive and complex hyperinsulinemic euglycemic clamp test and modified minimal model are used as golden standards, but as these methods are costly, time-consuming and require intravenous infusions and frequent blood sampling, other surrogate measurement tools are also proposed (Kurtoglu et al., 2010; Levy-Marchal et al., 2010; Tagi et al., 2019). Fasting plasma insulin level or homeostasis model assessment for IR (HOMA-IR) are more cost-effective and more widely used methods in population screening and in clinical research, the latter being more accurate tool for assessing insulin sensitivity (Kurtoglu et al., 2010; Tagi et al., 2019). In children and adolescents with obesity aged between 5 and 18 years, the cut-off levels for HOMA-IR were calculated to be 2.67 in boys and 2.22 in girls in the prepubertal period, and for 5.22 for boys and 3.82 in girls in the pubertal period, and fasting insulin levels above 15 $\mu U.mL^{-1}$ in the prepubertal period and more than 30 $\mu U.mL^{-1}$ in the pubertal period showed IR (Kurtoglu et al., 2010). Calculating HOMA-IR for determining the IR rate, only fasting insulin and glucose values are needed, and the higher HOMA-IR value expresses a more severe IR (Tagi et al., 2019). The increase in insulin activation and secretion during puberty are thought to be related with the increase of growth hormone during somatic growth or due to the alterations in the pubertal fat distribution (Kurtoglu et al., 2010). Despite the reasons for these changes, as previously described – both obesity and puberty play an important role in the development of IR (Tagi et al., 2019). Therefore, the detection of increased IR, especially in children and adolescents with obesity, is of great importance.

Another significant CVD risk indicator for later life is the presence of metabolic syndrome (MetS) in childhood (Lee et al., 2016). MetS is a condition of the most dangerous clustered cardiovascular risk factors such as raised fasting plasma glucose, high cholesterol and blood pressure (BP), but the central obesity and IR is considered the most significant factors (IDF, 2005). MetS is defined based on central obesity (WC or increased BMI z-score in pediatrics) plus at least two of the aforementioned components, and the more components of MetS is evident, the higher is the cardiovascular mortality rate (IDF, 2005). Elevated MetS corresponds with higher levels of LDLc in adolescents (Lee et al., 2017a), and lower values of MetS score during puberty is strongly related to higher CRF values (Silva et al., 2013) in young adulthood (Mäestu et al., 2020). A sex- and racial/ethnicity-specific MetS severity z-score (MSSS) has been developed as a continuous score to assess the severity of metabolic derangement (Gurka et al., 2012), and the successful use of MSSS among youth has been seen in previous studies (DeBoer & Gurka, 2017; Lee et al., 2016; Lee et al., 2017a). For example, DeBoer et al. (2015a; 2015b) showed that raised MSSS in childhood is correlated with increased risk of CVD later in adult life. This knowledge gives a strong support to use MSSS as one important health marker among adolescents with obesity.

In addition, adipokines such as leptin and adiponectin, both secreted in adipose tissue, exert effects on energy homeostasis, and regulate lipid and insulin/glucose metabolism throughout autocrine, paracrine, and endocrine signalling (Galic et al., 2010; Kirk et al., 2020; Lelis et al., 2019; Mancuso, 2016). These adipokines are dependent on body FM gain, where the level of the leptin increases, and adiponectin diminishes, which in turn, is an increased risk for CVD (Argente et al., 1997; Galic et al., 2010). For example, visceral adipose tissue accumulation results in release of leptin, which contributes to chronic systemic low-grade proinflammatory state that, unfortunately, may be followed by the development of IR (Gonzalez-Gil & Elizondo-Montemayor, 2020; Kirk et al., 2020). Furthermore, adiponectin expression is inversely associated with adipose tissue mass – its levels are lower in adolescents with obesity than in non-obese peers (Kirk et al., 2020; Panagopoulou et al., 2008) and higher in individuals who are regularly involved in intense weight-bearing exercises (King et al., 2003). Additionally, adiponectin has an important role in IR – normal adiponectin concentration levels increase free fatty acids oxidation, decrease glucose levels by increasing its uptake and prevent lipid aggregation in the skeletal muscle (Hejazi & Ferrari, 2022; Kirk et al., 2020).

2.2.2. Impact on cardiorespiratory fitness

CRF, measured as peak oxygen consumption (VO_2peak), is an accurate objective physiological measure of the overall capacity of the cardiovascular and respiratory system to carry out rhythmic and dynamic exercises for a prolonged time that is affected by PA habits, genetics, and disease status in children and adolescents (Ortega et al., 2007; Raghuveer et al., 2020). VO_2peak is expressed as the volume of oxygen consumed per unit of time and is presented as in absolute value ($L.min^{-1}$) or in relation to body mass ($VO_2peak/_{kg}$; $mL.kg^{-1}.min^{-1}$) or lean body mass (LBM) ($VO_2peak/_{LBM}$; $mL.kg^{-1}.min^{-1}$) (Ortega et al., 2007) that is attained during a graded maximum exercise until voluntary exhaustion (Armstrong & Welsman, 2020; Ortega et al., 2008). This method is the gold standard of testing CRF and is the single best indicator of CRF (Cao et al., 2019; Mintjens et al., 2018; Ortega et al., 2008).

In children and adolescents with normal weight or with overweight aged 8–16 years VO_2peak increases steadily with age (Berndtsson et al., 2007), but is strongly influenced by body size (especially BF %) (Ortega et al., 2007), pubertal maturation status (Cooper et al., 1984) or by the way in which VO_2peak is expressed (Ortega et al., 2007). Nevertheless how the cardiorespiratory system ability is evaluated in youth – whether the cardiopulmonary exercise testing is done using an incremental exercise protocol with gas exchange measurements on treadmill or cycle ergometer (Blais et al., 2015), or assessed by the most known aerobic capacity battery tests such as with Cooper test or with 20 m shuttle run test (Cooper et a., 1984; Léger et al., 1988), interpreting CRF values in adolescents with overweight, additionally to gender and maturation (age and

pubertal stage), LBM should definitely be used to adjust for body size (Blais et al., 2015; Ortega et al., 2007).

In cardiopulmonary exercise testing among pediatric population, there is no "universal size" for all, because the are many individual's confounders (age, pubertal status, sex, physical fitness, exercise modality) that affect the results of exercise tests (Blais et al., 2015; Cooper et al., 1984; Ortega et al., 2007). Unfortunately, beyond doubt, youngsters with overweight and obesity have significantly lower CRF than normal weight peers (Berndtsson et al., 2007; Johansson et al., 2020; Rosa et al., 2011, Ruiz et al., 2016), and although the absolute VO_2peak may increase with age, the relative VO_2peak decreases with age in both boys and girls with obesity (Johansson et al., 2020). Individuals aged 8–19 years whose CRF is at or below 25th percentile of aerobic fitness battery test outcomes or VO_2peak is below 42.0 mL.kg^{-1}.min^{-1}, is classified as unfit (Ortega et al., 2018). These results should be identified as a "red flag", because in children and in adolescents, low CRF is associated with obesity, higher risk of CVD, decreased mental and skeletal health, and is a substantial risk factor for cancer in future adult life (Andersen et al., 2008; Johansson et al., 2020; Ortega et al., 2008; Ruiz et al., 2016; Vandoni et al., 2021). In addition, low CRF is associated with higher MetS (Lätt et al., 2018; Mäestu et al., 2020), and elevated MetS corresponds with higher levels of LDLc in adolescence (Lee et al., 2017a). CRF through adolescence to young adulthood is also inversely associated with TC, TG, glucose, insulin, IR and HDLc (Mäestu et al., 2020; Silva et al., 2013). In addition, Ortega et al., (2018) showed that individuals with low CRF have a higher risk of mortality eight years later. Therefore, low CRF is a strong predictor of cardiovascular and -metabolic disease outcomes in adolescents (Ortega et al., 2008), especially in late adolescent males (Lätt et al., 2018). Also, higher CRF during puberty is important in preventing higher HOMA-IR in later life (Lätt et al., 2016). Therefore, CRF is recognized as a good marker of cardiovascular and -metabolic health in youth (Silva et al., 2013), and this suggests that higher CRF induces reduction in other cardiometabolic risk factors and might change the metabolic impairment associated with obesity.

2.2.3. Impact on bone health

During lifetime, human skeleton undergoes several changes in shape and size. During childhood and adolescence, rapid and significant longitudinal bone growth, areal bone expansion, and bone mineral accrual takes place. The main bone mass accrual occurs during the first two decades of life, and 90% of the peak bone mass accrual is achieved in late teenage (Fintini et al., 2020). During this period, the amount of gathered bone mass predicts bone mineral density (BMD) in adulthood (Fintini et al., 2020). Exercise training (Julian et al., 2020), hormonal milieu during pubertal growth (Fintini et al., 2011) and even adipokines (Kirk et al., 2020) play an important role of BMD accrual, excessive body mass being a major player for bone accrual (Fintini et al., 2020; Klentrou &

Kouvelioti, 2020). Although the prevalence of obesity is increasing worldwide (WHO, 2021), there are still conflicting results whether obesity influences youths' bone health positively or negatively. Excessive body FM in childhood or in adolescence may affect bone health during its development time positively as increased body mass puts a greater mechanical load on bones (Fintini et al., 2020), but also negatively as adipokines negatively modulate bone turnover and BMD, finally leading to bone frailty, osteoporosis and fractures (Kirk et al., 2020). Kessler et al. (2013) found that 2–19 years old individuals with obesity had 50% increased risk of foot, knee and leg fractures. This is supported by Liu et al. (2011) findings, where BF % was negatively correlated with BMD, or by Fintini et al. (2011), where obesity had a negative effect on BMD in boys aged 12–16 years. On the other hand, it is suggested that individuals with obesity have higher bone mineral content (BMC) and BMD than normal-weight peers, indicating that adipose tissue owns a positive effect on bone quality and structure (Hou et al., 2020; Savvidis et al., 2018). For example, El Hage et al. (2010) found positive correlations of body FM with BMC and BMD values in adolescents. Still, these conflicting results are explained by a very simple pathway – both adipocytes and osteoblasts are derived from mesenchymal stem cells (MSCs) and obesity drives the differentiation of MSCs toward adipocytes at the expense of osteoblast differentiation (Fintini et al., 2020; Kirk et al., 2020). Nevertheless, individuals who achieve a higher peak bone mass during puberty might prevent or delay osteoporosis later in life (Bass et al., 1999).

2.3. Exercise training and obesity

One of the priority intervention strategies in tackling obesity is engaging in exercise training, especially during adolescence when the participation in PA declines precipitously (Dumith et al., 2011; Lätt et al., 2015). A great effort has been globally directed into the development of such exercise training interventions which attenuate the prevalence rate of obesity and increase physical fitness among adolescents. A systematic review of longitudinal studies (Mintjens et al., 2018) showed that higher PA, especially higher CRF, in youth is associated with lower BMI and body FM later in life. These findings suggest that CRF is an important factor and therefore increasing CRF might be a potential intervention strategy in the management of obesity among adolescents (Eddolls et al., 2017; Martin-Smith et al., 2020). MICT done at the intensities of 55–70% maximum heart rate (HR_{max}) or 40–60% VO_2peak and involving large training loads with a substantial time commitment from the participant has been the traditional exercise training method used in reducing total body FM, excessive visceral fat, and increasing CRF in adolescents with overweight and obesity (Arboleda Serna et al., 2016; Dias et al., 2018; Keating et al., 2017; Viana et al., 2019). In addition, MICT generates improvements in other cardiometabolic risk factors (glucose homeostasis, SBP and DBP, and blood lipid profile) in children and adolescents with obesity (Blüher et al., 2017; Ingul et al., 2010; Koubaa, 2013; Racil et al., 2013; Sarvottam & Yadav, 2014; Sgro et

al., 2009). Nevertheless, this type of exercise training may be less appealing for "time poor" adolescents as lack of time is one perceived barrier to exercise (Biddle et al., 2011; Zabinski et al., 2003). In a recent decade, HIIT as a novel exercise training has also been introduced as a weight management method among adolescents with overweight and obesity (Corte de Araujo et al., 2012; Costigan et al., 2015; Logan et al., 2014). HIIT programs, consisting of repeated short (45 s) to long (2–4 min) rather high-intensity exercise sets with almost "near maximal" efforts performed at the intensities of ≥ 80% HR_{max} or VO_2peak interspersed with active or passive interval rest periods between each set (Buchheit & Laursen, 2013; Gibala et al., 2012; Keating et al., 2017; Viana et al., 2019) with a total volume of ∼5–40 min training session, elicits similar, if not superior physiological adaptations compared with MICT (Gibala, 2018) in a wide range of individuals with different age and body composition values (Batacan et al., 2017; Corte de Araujo et al., 2012; Higgins et al., 2016). Furthermore, both running and cycling HIIT protocols have been reported to improve CRF in children and adolescents as little as after 4-week training period (Martin-Smith et al., 2020), but also improving many cardiometabolic health parameters such as body composition, resting heart rate (HR_{rest}), lipid profile, SBP and DBP (Eddolls et al., 2017; Thivel et al., 2019). Over the last years, in addition to HIIT, SIT with short (8–30 s) bursts with efforts performed at intensities equal or superior to the one that elicited a VO_2peak on an incremental test, defined as all-out sprints (Buchheit & Laursen, 2013; Gibala et al., 2014; Viana et al., 2019) has greatly increased its popularity and has also been recommended as a good strategy for weight loss among young individuals with obesity (Racil et al., 2013; Racil et al., 2016). The most classical SIT protocol consists typically of sets as few as 4–6 Wingate-like 30 s all-out sprints, separated by 4 min rest periods (Burgomaster et al., 2005), but such SIT protocols as 3 x 20 s all-out sprints followed by 2 min low-intensity cycling or 80 x 6 s all-out sprints with 9 s rest and 8–16 x 15 s all-out sprints with 15 s rest have been also used to enhance CRF among individuals with overweight and obesity (Gillen et al., 2016; Racil et al., 2016; Tong et al., 2018). Based on several meta-analyses (Cao et al., 2019; Costigan et al., 2015; García-Hermoso et al., 2016; Hejazi & Ferrari, 2022; Logan et al., 2014; Martin-Smith et al., 2020; Thivel et al., 2019; Wang et al., 2022; Yin et al., 2020) carried out on adolescents with overweight and obesity, both interval training forms show their efficacious impact on different health-related parameters, especially on adiposity indices. Results from a systematic review and meta-analysis show that the effect of interval training on the reduction of visceral fat is better than the effect of MICT, and the effect is more significant in adolescent males than that in females (Wang et al., 2022). Primary outcomes of both interval training forms (with the attendance rate to training at least 80%) on body composition among adolescents with obesity (12–19 years of age range) are demonstrated in Table 1.

Table 1. Characteristics included in different exercise training interventions among adolescents with overweight and obesity.

Author	Subject characteristics	Sample size	Exercise protocol	Intervention duration, frequency, mean adherence rate in HIIT group	Main outcome in HIIT group
Tjonna et al., 2009	14.0 ± 0.3 yrs; F + M; BMI ≥ 95th percentile	HIIT: n=22; MICT: n=20	HIIT: 4 x 4 min 90–95% HR_{max} treadmill walk and run followed by 3 min rest at 70% HR_{max}; MICT: NR exercise + P/NC	12 weeks; 2 sessions in a week; ≥ 80%	**BMI, BF % and WC ↓,** NS change in BM
Ingul et al., 2010	14.8 ± 1.2 yrs; M + F; BMI ≥ 30 kg.m^{-2}	HIIT: n=10; CONT: n=10	HIIT: 4 x 4 min 90% HR_{max} treadmill walk and run followed by 3 min rest at 70% HR_{max}	13 weeks, 2 sessions in a week; ≥ 80%	**WC ↓;** NS change in BM and BMI
Koubaa et al., 2013	13.0 ± 0.8 yrs; M; BMI ≥ 97th percentile	HIIT: n=14; MICT: n=15	HIIT: NR x 2 min 80–90% VO_2max run followed by 1 min passive rest; MICT: 30 min 60–70% VO_2max run	12 weeks; 3 sessions in a week; ≥ 80%	**BMI, BM, BF % and WC ↓**
Racil et al., 2013	15.9 ± 0.3 yrs; F; BMI ≥ 97th percentile	HIIT: n=11; MIIT: n=11; CONT: n=12	HIIT: 2 series of 6–8 x 30 s 100% MAS run followed by 30 s rest at 50% MAS run; 4 min passive rest between series; MIIT: 2 series of 6–8 x 30 s 70% MAS run followed by 30 s rest at 50% MAS run; 4 min passive rest between series	12 weeks; 3 sessions in a week; NR	**BMI z-score, BM, BF % and WC ↓**
Starkoff et al., 2014	14.7 ± 1.5 yrs; F + M; BMI ≥ 36 kg.m^{-2}	HIIT: n=14; MICT: n=13	HIIT: 10 x 2 min 90–95% HR_{max} cycling followed by 1 min rest at 55% HR_{max}; MICT: 30 min 65–70% HR_{max} cycling	6 weeks; 3 sessions in a week; ≥ 80%	NS change in BMI, BM, BF % or WC
Murphy et al., 2015	12 -18 yrs; F + M; BMI ≥ 95th percentile	HIIT: n=7; MICT: n=6	HIIT: 10 x 1 min 80–90% HR_{max} cycling followed by 2 min rest at 60% HR_{max}; MICT: MICT: 50 min 65% HR_{max} aerobic exercise	12 weeks; 3 sessions in a week; ≥ 95%	NS change in BM, BMI, BF % or WC
Racil et al., 2016	14.2 ± 1.2 yrs; F; BMI ≥ 97th percentile	HIIT: n=17; MIIT: n=16; CONT: n=14	HIIT: 8–16 x 15 s 100% MAS run followed by 15 s rest at 50% MAS run; MIIT: 8–16 x 15 s 80% MAS run followed by 15 s rest at 50% MAS run;	12 weeks; 3 sessions in a week; NR	**BM, BMI Z-score, BM, BF % and WC ↓**

Author	Subject characteristics	Sample size	Exercise protocol	Intervention duration, frequency, mean adherence rate in HIIT group	Main outcome in HIIT group
Lazzer et al., 2017	15 – 17 yrs; M; BMI = 37.5 kg.m^{-2}	HIIT: n=10; MICT: n=20	HIIT: 6 x 40 s 100% VO_2max run followed by 5 min rest at 40% VO_2max walk + P/NC; MICT: 40 min 70% VO_2max run + P/NC	3 weeks; 3 sessions in a week; ≥ 95%	**BM, FM ↓;**
Blüher et al., 2017	15.5 ± 1.4 yrs; F + M; BMI ≥ 90th percentile	HIIT: n=20	NR x 80–95% HR_{max} running followed by NR min active rest at 50–60% HR_{max}	6 months; 2 sessions in a week; NR	**BM, BMI, WC, BF % ↓**
Lee et al., 2017b	14.9 ± 1.5 yrs; F + M; BMI = 34 kg.m^{-2}	HIIT: n=12	HIIT: 10 x 10 s 80–90% HR_{max} cycling followed by 90 s rest at 40–50% $HR_{max;}$	4 weeks; 3 sessions in a week; ≥ 92%	NS change in BM and FM
Morrissey et al., 2018	12–16 yrs; F + M; BMI ≥ 34 kg.m^{-2}	HIIT: n=16; MICT: n=13 CONT: n=16	HIIT: 2 series of 4–6 120 s 90–95% HR_{max} training circuit and boxing exercises followed by 90 s 55% HR_{max} rest + P/NC; MICT: 40–60 min 60–70% HR_{max} boxing and Nordic Walking + P/NC	12 weeks; 3 sessions in a week; NR	**BM, BMI, BMI z-score, FM (total, abdominal, gluteal) ↓**
Cvetkovic et al., 2018	11 – 13 yrs; M; BMI ≥ 25 kg.m^{-2}	HIIT: n=11; FOOTBALL: n=10; CONT: n=14	HIIT: 3 series of 5–10 x 10–20 s 100% MAS run followed by 10–20 s slow-walk rest; 3 min passive rest between series; FOOTBALL: 4 x 8 min football play followed by 2 min passive rest	12 weeks; 3 sessions in a week; NR	NS change in BMI, BM, BF %
Meng et al., 2022	11 – 13 yrs; M; BMI ≥ 95th percentile	HIIT: n=12; MICT: n=11; CONT: n=13	HIIT: 2 series of 8 x 15 s 80–90% HR_{max} run followed by 15 s 40–60% HR_{max} run, and 3 min rest between series; MICT: 30 min 60–70% MAS run	12 weeks; 3 sessions in a week; ≥ 85%	**BMI, FM, BF %, VAT ↓**

Abbreviations: HIIT, high-intensity interval training; CONT, non-exercising control group; MICT, moderate-intensity continuous training; MIIT, moderate-intensity interval training; F, females; M, males; BMI, body mass index; HR_{max}, maximum heart rate; VO_2max, maximal oxygen uptake; NR, not reported; P/NC; physiological and/or nutritional consultations throughout the intervention period; NS, nonsignificant; BF %, body fat percentage; N; nutrition group; BM, total body mass; FM, fat mass; WC, waist circumference; VAT; visceral adipose tissue; VT, ventilatory threshold; MAS, maximal aerobic speed.

Main barriers achieving regular recommended dose of exercise training in obese youth are lack of time and enjoyment and limited access to sport facilities (Biddle et al., 2011; Zabinski et al., 2003). As both interval training methods allow the manipulation of at least nine training variables, including work interval intensity and duration, rest interval intensity and duration, number of sets, number of series, between-series rest intensity and duration and exercise modality (Buchheit & Laursen, 2013), then these aforementioned training variables make start-stop nature like SIT a time-efficient, enjoyable and satisfaction providing training modality for adolescent population with obesity (Ingul et al., 2018; Lee et al., 2017b; Murphy et al., 2015; Starkoff et al., 2014; Thum et al., 2017). Also, these non-boring less monotonous training routines which imitate childlike movement patterns, and inexpensive training equipment used in interval training protocols, increase the feasibility and adherence to exercise training among young population with obesity (Vella et al., 2017). Therefore, exercise training done at high-intensity interval mode is a good obesity reducing strategy as it achieves equal or even superior cardiometabolic goals in a much shorter time period compared to MICT (Costigan et al., 2015; Dias et al., 2018; Eddolls et al., 2017; Starkoff et al., 2014; Thivel et al., 2019). Nevertheless, as shown in Table 1, based on several meta-analysis of interval training effect on adiposity indices in adolescents with obesity aged of 12–19 years (Cao et al., 2019; Costigan et al., 2015; García-Hermoso et al., 2016; Hejazi & Ferrari, 2022; Logan et al., 2014; Martin-Smith et al., 2020; Thivel et al., 2019; Wang et al., 2022; Yin et al., 2020), sprint running is a favored method, whereas only three of the studies used cycling protocols (Lee et al., 2017b; Murphy et al., 2015; Starkoff et al., 2014). Additionally, out of those latter three studies, none of them was carried out only in male cohort. Five studies (Cvetković et al., 2018; Lee et al., 2017b; Meng et al., 2022; Racil et al., 2013; Racil et al., 2016) out of nine included in meta-analysis described in Table 1, used SIT-specific short sprint bouts (≤ 30 s), but none of them was carried out as an all-out cycling SIT protocol. Taken together, all this gives a good reason for evaluating the effectiveness of this specific SIT protocol methodology among adolescent boys with obesity.

2.3.1. Impact of exercise training on cardiometabolic risk factors and adipokines

Exercise training with different modalities and intensities is a very important particle in improving cardiovascular health in individuals with obesity by having positive effect on different cardiometabolic markers (Hejazi & Ferrari, 2022). It is reported that higher CRF is inversely associated with healthier cardiometabolic profile in children and adolescents (Lätt et al., 2018; Ruiz et al., 2007), and that there might be potential interactions between CRF and adiposity in relation to CVD risk (Ortega et al., 2008). Studies have shown that individuals with obesity who intend moderate-to-vigorous group-supervised exercise training, which last at least 45 to 60 min each for three times per week,

have improved such CVD biomarkers as HOMA-IR, insulin, LDLc, HDLc, SBP and adiponectin (Corte de Araujo et al., 2012; Koubaa, 2013; Racil et al., 2013). Regarding young individuals, it is reported that time-efficient interval training delivers similar or even superior benefits to the cardiometabolic profile compared to MICT (Costigan et al., 2015; Logan et al., 2014). These findings are inconsistent with another meta-analysis of randomized controlled trials (Yin et al., 2020), where interval training showed no significant effect on body mass, BMI, WC, SBP and DBP, glycemia, insulinemia, TC, HDL and LDLc, TG, HOMA-IR, and leptinemia when compared to MICT. Nevertheless, based on meta-analysis (Martin-Smith et al., 2020), the summary effect of interval training for BMI and BF % is significant with a moderate effect size (ES) for BMI and BF %, and the ES of interval training for WC was small without any significance. Logan et al. (2014) report in their meta-analysis that investigating the effects of 2 x 30 s bouts of all-out cycling sprint interval training on post-exercise substrate utilization, the results revealed that total of only 60 s of exercise training time was needed to enhance fat oxidation 30–60 min post-exercise to induce metabolic changes in adolescents. According to Thivel et al. (2019) meta-analysis, interval training significantly reduces such cardiometabolic parameters in addition to body mass and BF % as SBP, DBP in adolescents with overweight and obesity. Exercise training in high-intensity form generates greater reduction in SBP in youth with obesity compared with such exercise forms as MICT or LICT (Racil et al., 2016; Tjønna et al., 2009). Possible positive effect of interval training on BP may be evoked by the reduction of sympathetic nervous system activity, which in turn, induces increase in nitric oxide-mediated vasodilatation, endothelial function and therefore, possesses greater vascular benefits (Farah et al., 2014; Logan et al., 2014; Ramos et al., 2015).

Interval training done either in HIIT or in SIT format is an effective strategy for evoking improvements in such CVD biomarkers outcome measures in youngsters as blood glucose, fasting insulin, HOMA-IR, TR, TC, HDLc, leptin, and adiponectin levels with an ES indicating moderate-to-large clinically important difference compared to MICT or control groups (Morrissey et al., 2018; Racil et al., 2013; Tjønna et al., 2009). 12-weeks running HIIT protocol (4 x 4 min 90–95% HR_{max} followed by 3 min active rest) in female and male adolescents with overweight and obesity improved HDLc, reduced fasting glucose levels and improved insulin sensitivity (measured by HOMA-IR method) from their baseline measures (Tjønna et al., 2009). Improved insulin sensitivity effect caused from exercise training is based on a direct effect on blood glucose usage, reduction of plasma insulin and therefore, better overall regulation of lipid metabolism (Logan et al., 2014). Another 12-week study (Racil et al., 2013) among adolescents with obesity showed that SIT training (6 x 30 s all-out run sprints with 30 s active recovery between sets) three times per week caused significant improvements in plasma LDLc, TC and insulin sensitivity (measured by HOMA-IR), providing again, a beneficial effect of interval training on such cardiometabolic marker as insulin sensitivity. Improved insulin sensitivity increases the availability of fat for utilization as an energy substrate and there-

fore, causing body fat reduction even during high-intensity interval trainings (Alahmadi, 2014). Exercise training decreases fasting glucose, insulin and HOMA-IR by several pathways – improving glucose uptake, increasing glucose transport in muscle, and increasing glycogen storage capacity (Boutcher, 2011). As muscle mass is the main site of normal glucose uptake, then, possible increase in muscle mass after exercise training might be another explanation of improved insulin sensitivity (Hejazi & Ferrari, 2022). Accordingly, exercise training done as HIIT or SIT may change intramuscular fat volume by increasing fat utilization, which in turn contributes to better insulin sensitivity (Hejazi & Ferrari, 2022).

A systematic review done in children and adolescent cohort reports that running-based interval training sessions at an intensity of > 90% HR_{max} or 100–130% maximal aerobic capacity at least 2–3 times a week with a minimum intervention duration of 7 weeks improves CVD biomarkers the greatest (Eddolls et al., 2017). However, to date, no systematic reviews have investigated the effects of cycling-based all-out SIT protocol on metabolic biomarkers in adolescent boys with obesity.

2.3.2. Impact of exercise training on cardiorespiratory fitness

The fact that CRF is a strong predictor of cardiovascular and -metabolic disease outcomes in adolescents (Ortega et al., 2008), any kind of exercise training is required for improving and maintaining CRF during childhood, especially during adolescence, because individuals with low CRF own a higher risk of mortality eight years later (Ortega et al., 2018) and higher risk on becoming obese in adulthood (Ruiz et al., 2016). In addition, low CRF is associated with cardiometabolic risk independently of abdominal adiposity in late adolescent males (Lätt et al., 2018). Although it is known that MICT improves CRF expressed in VO_2peak in children and adolescents with obesity, several meta-analyses have shown that interval training approach is also effective in increasing CRF in adolescents with obesity (Costigan et al., 2015; Martin-Smith et al., 2020), and even a superior improvement in VO_2peak in youth with obesity is seen with interval training than with MICT (Cao et al., 2019; García-Hermoso et al., 2016). Based on meta-analyses (Cao et al., 2019; Martin-Smith et al., 2020), the summary effect of interval training for CRF is statistically significant with a large ES, especially in adolescents with the mean age of ≥ 12 years (Yin et al., 2020). Implementing interval exercise training induces physiological adaptations, and cardiorespiratory response is typically first to take in place (Buchheit & Laursen, 2013; Gist et al., 2014). Both interval training forms, HIIT and SIT, yield similar training results such as an increase in mitochondrial enzyme activity, muscle oxidative capacity, and muscle glycogen content as traditional MICT trainings and all achieved is from reduced training volume and with an increase in exercise intensity (Astorino et al., 2012; Gist et al., 2014; Kaspar et al., 2016). From the prospective of increased VO_2peak, findings report that interval training interventions elicit more favorable adapta-

tions in the central cardiorespiratory (including increase in stroke volume and maximal cardiac output, total blood plasma volume and hemoglobin) and peripheral skeletal muscle (increased skeletal muscle glycogen content and skeletal muscle buffering capacity that improves the ability to extract and use available oxygen) system than any other form of exercise training (Astorino et al., 2012; Burgomaster et al., 2008; Gist et al., 2014; Sloth et al., 2013). In adults, a 3.5 $mL.kg^{-1}.min^{-1}$ increase in VO_2peak, equivalent to 1 metabolic equivalent, is associated with a 10–25% improvement in survival (Ross et al., 2016), and improvement of VO_2peak by 1 $mL.kg^{-1}.min^{-1}$, reduces the risk for development overweight or obesity by 10% in the following six years (Cao et al., 2019). This knowledge emphasizes the benefits of increased CRF achieved from interval exercise training.

2.3.3. Impact of exercise training on bone health

Being physically inactive is associated with detrimental effects on bone health by lowering BMD and increasing risk of bone fractures (Klentrou & Kouvelioti, 2020; Sahrir & Ooi 2018). The best approach to prevent the loss of bone is doing exercise training (Sahrir & Ooi 2018). Mechanical loading activity during childhoods' growth period imposes mechanical strain on the bones and therefore stimulate the process of bone metabolism by increasing bone formation and increasing bone mass (Sahrir & Ooi 2018; Seeman, 2003). The mechanical strain on bones depends on the type, intensity and load or duration of the exercise, and it is found that participation in vigorous intensity PA, but not in moderate or light intensity PA, may have a long-term benefits for bone health (Klentrou & Kouvelioti, 2020; Lazcano-Ponce et al., 2003; Noll, et al., 2021; Sahrir & Ooi 2018; Sayers et al., 2011).

The importance of tissue crosstalk has been highlighted by previous studies examining the role of different muscle-derived factors in regulating several adipose tissue adaptations to exercise training (Kirk et al., 2020). However, less is known about the bone-derived factors in regulating adipose tissue in response to exercise training (Jürimäe et al., 2021; Kurgan et al., 2022). It has been suggested that bone can also work as an endocrine organ and secrete several systemic humoral factors like osteocalcin, sclerostin and lipocalin-2, that are involved in regulating energy metabolism and adiposity in humans (Kirk et al., 2020; Takashi & Kawanami, 2022; Xu et al., 2018).

Osteocalcin is secreted solely by active osteoblasts and in the circulation is present in carboxylated and undercarboxylated forms, playing a role in the body's metabolic regulation (Kirk et al., 2020). It acts as a hormone by regulating systemic glucose metabolism, increasing insulin secretion, sensitivity and energy expenditure (Xu et al., 2018). It also participates in bone formation and therefore is used as a bone formation biomarker (Kirk et al., 2020). In children with overweight, serum osteocalcin levels are lower compared to non-overweight peers, and are inversely correlated with BMI and insulin (Oh et al., 2019). For example, a body fat reduction as a result of a 8-week supervised

MICT period increased osteocalcin levels in young males with obesity (Kim et al., 2015). In contrast, a recent study demonstrated that a 12-week diet and exercise training intervention (a concurrent training consisting of aerobic and resistance exercises three times a week) caused decreases in circulating osteocalcin levels without changes in body mass in adolescent girls with overweight and obesity (Josse et al., 2020). However, studies investigating the effect of SIT on circulating osteocalcin levels in adolescent boys with obesity have not yet been performed.

Sclerostin is a glycoprotein secreted mainly by mature osteocytes within the mineralized bone matrix that negatively regulates bone formation by the inhibition of the Wnt/β-catenin signaling pathway (Takashi & Kawanami, 2022). It has also been proposed that sclerostin is involved in a negative regulation of glucose metabolism by upregulating adiposity (Kirk et al., 2020; Takashi & Kawanami, 2022). Circulating sclerostin concentration is positively associated with body FM in children (Jürimäe et al., 2021) and adults (Amrein et al., 2012). Interestingly, sclerostin decreases in response to exercise training with various exercise training intensities in normal-weight untrained adults with different ages (Ardawi et al., 2012; Hinton et al., 2017; Sansoni et al., 2018). Although Kurgan et al. (2020) and Luziani et al. (2022) suggested a role of sclerostin in response to training also among individuals with obesity, no studies have included the SIT training modality among adolescent boys with obesity.

Lipocalin-2, first recognized as an adipokine, is expressed by osteoblasts with at least tenfold higher expression levels in bone than in adipose tissue (Kirk et al., 2020; Mosialou et al., 2017). Lipocalin-2 has been implicated in regulating appetite and energy metabolism (Mosialou et al., 2017). Circulating lipocalin-2 levels are increased in individuals with obesity and positively related to the development of obesity-related metabolic disorders (Takashi & Kawanami, 2022; Xu et al., 2018; Zaki et al., 2015). In addition, serum lipocalin-2 levels are associated with total body FM and visceral fat area in middle-aged individuals (Xu et al., 2018) or with BF % in children with obesity (Zaki et al., 2015). However, it has also been reported that serum lipocalin-2 expression remains stable after 12-week MICT period despite weight loss in adults with overweight and obesity (Choi et al., 2009; Nakai et al., 2021). Recently, Atashak et al. (2022) found that a 12-week interval training period lowered circulating lipocalin-2 levels together with decreased body fat values in young men with obesity, and suggested that lipocalin-2 can be used as a predictive biomarker of CVD. Although, it has been found that a 12-week cycling interval training (5 x 2 min at 85–95% HR_{max} with 1 min passive rest) period lowered circulating lipocalin-2 levels together with decreased body fat values in young men with obesity (Atashak et al., 2022), such findings among adolescent boys with obesity still needs to be clarified.

From previous findings, it can be concluded that the response of the skeleton (including osteokines and bone mineral characteristics) to exercise training in individuals with obesity is very complex process and still needs thoroughly investigation how all different factors such as different body mass, different

exercise training mode and training intensity, gender, age, or secreted osteokines regulate bone health. Nevertheless, a systematic review by Noll et al. (2021) concluded that there is still a lack of clarity on the influence of interval training on adolescents' bone health outcomes. This emphasizes the need for further interventional studies among adolescents.

2.4. Summary of the literature

Adolescence is an important period of human life as during this time various lifestyle and behavior patterns are established for later life. It has been reported that PA during adolescent years may decrease almost up to 65%. In addition, obesity developed in childhood or adolescence is very often continuing through adulthood with so many different adverse health consequences. Moreover, a prevalence of childhood obesity is still an upward trend and therefore, there is an urgent need to develop effective training strategies to reduce obesity in adolescence.

Previous evidence has demonstrated that health improvements including different cardiovascular and -metabolic parameters can be achieved with MICT, but as it is too monotonous and time-consuming exercise method, the attendance to trainings will not be continued for a prolonged time. Therefore, more time-efficient and enjoyable exercise training method – interval training modalities with either long (up to several min) or short (equal or even fewer than 30 s) work durations have been developed as possible training strategy to reduce adiposity among young populations with obesity. It has been found that interval training with short sub- or supramaximal (defined as all-out) exercise bouts are used to reduce body mass, FM and BF % and to enhance VO_2peak, but also to regulate blood glucose and insulin levels and lipid profile, and therefore, potentially modify the risk factors of developing CVD and type 2 diabetes.

There is a lack of studies in adolescent boys with obesity that show the effects of specific 4–6 x 30 s all-out SIT intervention training programs on different health characteristics. In addition, to our best of knowledge, based on several meta-analyses, there are no complex intervention studies, which have investigated the effects of short-term SIT program on body composition, CRF, different blood biomarkers and bone health in adolescent boys with obesity.

There is a growing interest on the effects of different interval training protocols in young individuals with obesity. Therefore, it is very important to identify suitable and even less time-consuming SIT programs to improve body composition, CRF, blood biochemical markers and bone health in adolescents with obesity, especially among young growing and maturing boys.

3. AIM AND PURPOSES OF THE STUDY

The general aim of the current thesis was to investigate the effect of 12-week supervised all-out sprint interval training on body composition, cardiorespiratory fitness, blood biochemical markers and bone health in adolescent boys with obesity.

According to the general aim, the specific purposes of the present study were to:

1. examine the effect of sprint interval training on body composition and cardiorespiratory fitness in adolescent boys with obesity (Study I);
2. examine the effect of sprint interval training on cardiometabolic risk factors and adipokine levels in adolescent boys with obesity (Study II);
3. examine the effect of sprint interval training on osteokine levels and bone mineral parameters in adolescent boys with obesity (Study III).

4. METHODS

4.1. Participants and study design

A total of fifty-nine 12–16-year-old adolescent boys with obesity from Tartu City or Tartu County who had been diagnosed simple obesity (E66.0 by ICD-10) at the Tartu University Children's Clinic since 1. January 2016 were approached before going through inclusion criteria. To be included, participants had to: a) have BMI at or above 95th percentile on the Estonian BMI chart (Grünberg et al., 1998), b) have no participation in any regular exercise training program (except obligatory physical education lessons twice per week at school), c) have no use of medications (except vitamins) known to affect body composition or metabolism, and d) have no endocrine disorders or other chronic diseases, which may limit testing and the study progress. After a full medical screening upon enrollment by a certified endocrinologist, thirty-seven participants met inclusion criteria and were then randomly divided into sprint interval training (SIT) or non-exercising control (CONT) groups (Figure 1). Both SIT and CONT groups (Table 2) underwent pre- and post-intervention testing one week before and one week after 12-week study period. All testing at both times were completed during the two visits to the study site – blood sampling, body composition and bone mineral assessment performed at first visit and CRF assessment at the second visit. During the 12-week SIT period no injuries were reported, but three participants were excluded as their adherence rate to the trainings was below 80%. All excluded participants' data have been excluded from the analyses. Although the drop-out rate was substantial (24%), the drop-out subjects were similar according to their body composition to the subjects who completed the intervention (data not shown).

Each participant and participants' legal guardian provided written informed consent and were thoroughly informed about the purposes and procedures of the study. The study protocol was performed in accordance with the ethical standards of the Helsinki Declaration and reviewed and approved by the Medical Ethics Committee of the University of Tartu, Estonia (#282/T-5, 21 May 2018).

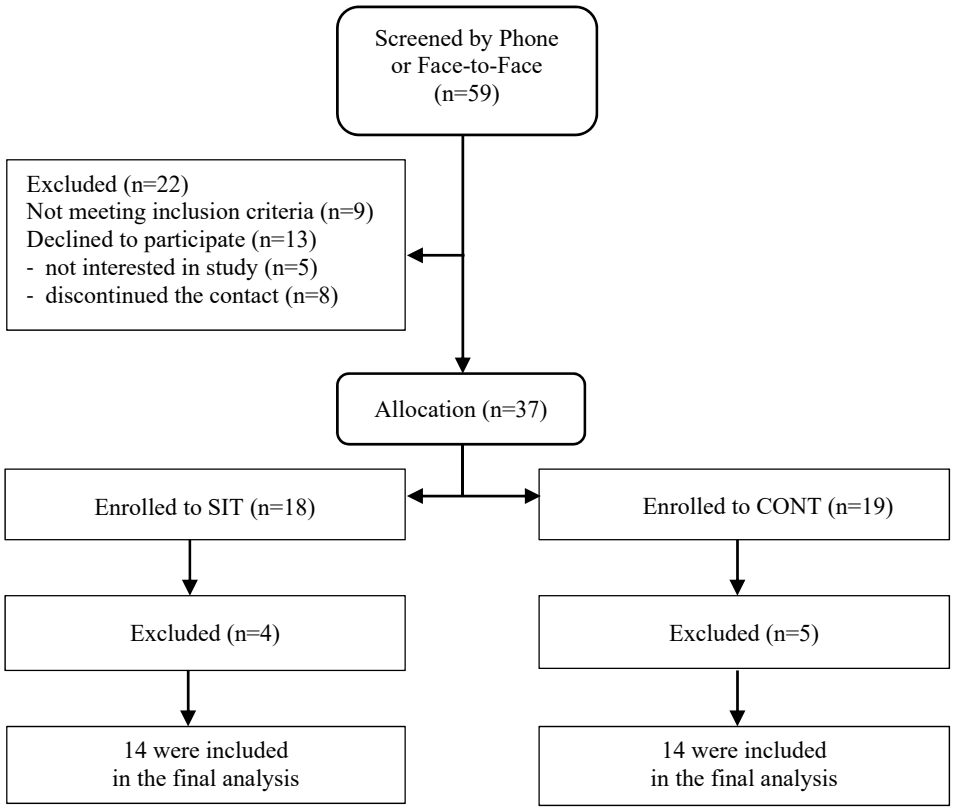

Figure 1. Flow-chart of study design, participant enrollment process, randomized group allocation, and analysis in sprint interval training (SIT) and control (CONT) groups.

Table 2. Mean (±SE) baseline characteristics in sprint interval training (SIT) and control (CONT) groups.

	SIT (n = 14)	CONT (n = 14)
Age (years)	13.1 ± 0.3	13.7 ± 0.4
Pubertal stages I/II/III/IV/V (n)	0/3/3/7/1	0/2/2/5/5
Height (cm)	170.6 ± 2.7	173.5 ± 2.9
Body mass (kg)	89.1 ± 4.3	99.3 ± 6.4
Body mass index ($kg.m^{-2}$)	30.3 ± 0.9	32.6 ± 1.6
$VO_2peak/_{kg}$ ($mL.kg^{-1}.min^{-1}$)	29.7 ± 1.4	27.6 ± 1.6
Daily energy intake (kcal)	1825.7 ± 143.2	2139.9 ± 130.2
Carbohydrates (%)	46.2 ± 1.6	42.6 ± 2.3
Fat (%)	37.2 ± 1.2	39.0 ± 1.6
Protein (%)	16.6 ± 0.8	18.4 0.8
Total PA ($count.min^{-1}$)	408.5 ± 30.2	343.9 ± 28.8

SE, standard error; VO_2peak, peak oxygen consumption; PA, physical activity.

4.2. Sprint interval training protocol

Supervised SIT training program was performed for 12 consecutive weeks (3 sessions a week on Monday, Wednesday and Friday) (Wyckelsma et al., 2020) on an electronically-braked cycle ergometer (Wattbike Pro/Trainer, Vermont House, Wilford Ind Est, Nottingham, England) with a continuous power recording to quantify the amount of work performed during each SIT session. All training sessions consisted of a warm-up period of 10 min and an active cool-down period of 5 min cycling at a low cadence (< 50 rpm) against a light resistance (< 50 W), and with the 4–6 repetitions of 30 s all-out cycling bouts with 4 min active recovery (light cycling at 30 W) between each bout. Designed SIT warm-up and cool-down periods are in accordance with previous studies in adolescents with obesity (Dias et al., 2018; Morrissey et al., 2018; Murphy et al., 2015). Before the first training session, participants were familiarized with the SIT protocol. Verbal encouragement to pedal as fast as possible for 30 s was provided during each all-out cycling bout (Wyckelsma et al., 2020). To avoid poor pacing during sprint phase, participants were instructed to target a cycling cadence above 90 pedaling rate (Boroujerdi et al., 2009), and a 4 min recovery period between work intervals was chosen to delay premature fatigue and therefore help to achieve higher work intensities in each of the following work interval (Schoenmakers & Reed, 2019). To maintain the desired exercise intensity, the number of work interval repetitions were increased over time (Ouerghi et al., 2017). Training load and intensity during and immediately following completion of the 30 s cycling bout were reported via mean and peak power output, fatigue index [(peak power – mean power) / peak power)] (Fehr et al., 2022) and % of maximum HR measured by Polar H7 (Polar Electro OY, Kempele, Finland).

4.3. Anthropometric measurements

Body height was measured using a Martin metal anthropometer (GPM Anthropological Instruments, Zurich; Switzerland) to the nearest 0.1 cm according to the standard technique, and body mass was measured with minimal clothing to the nearest 0.05 kg with a medical electronic scale (A&D Instruments Ltd., Abingdon, UK). Body mass index (BMI; $kg.m^{-2}$) was calculated as body mass (kg) divided by square of body height (m^2). Waist circumference (WC; cm) was also measured with a metal anthropometric tape at midway between the lowest rib and the iliac crest at the end of a gentle expiration. All anthropometric measurements were performed by a well-trained specialist.

4.4. Pubertal maturation

Pubertal maturation of the participants was assessed at the beginning and at the end of the study by self-assessment method according to Tanner's pubertal stages (1962) efficiently used in boys in previous studies (Dias et al., 2018; Gutin et al., 2005; Lätt et al., 2016; Mengel et al., 2017). The participants were given photographs, figures and descriptions of genitals and pubic hair development stages, and asked to choose the one that most accurately reflected their appearance.

4.5. Body composition and bone mineral parameters

Body composition was measured by dual-energy x-ray absorptiometry (DXA; Hologic Discovery QDR Series, Waltham, MA, USA). The following characteristics were used in the analyses: total body fat mass in kilograms (FM), total body fat percentage (BF %), lean body mass in kilograms (LBM), whole body (WB) and lower limbs region (LL) bone mineral density (BMD) in $g.cm^{-2}$ and bone mineral content for the whole body (WB BMC) in grams. Participants were scanned in light clothing while lying flat on their backs with arms on their sides and kept still during the measurement. To reduce errors, all DXA measurements and results were evaluated by the same trained examiner. Coefficient of variations (CVs) for body composition measurements were less than 2%.

4.6. Cardiorespiratory fitness

Stepwise incremental exercise test until volitional exhaustion was performed on an electrically braked bicycle ergometer (Lode Corival V3, Groningen, Netherlands) to determine CRF. The initial work rate was 50 W and the stage increment was 25 W after every 2 min until maximal volitional exhaustion was reached (Lätt et al., 2016). Pedaling frequency was set to 60–70 rpm. Subjects were verbally encouraged to produce maximal effort. Heart rate was recorded continuously throughout the test using a Polar H7 monitor (Polar Vantage, Polar Electro OY, Kempele, Finland). Respiratory gas exchange variables were measured directly throughout the test using breath-by-breath mode with data being recorded in 10 s intervals for the measurement of oxygen consumption (VO_2) using a gas analyzer (SpiroPro SensorMedics, GE, USA). The analyzer was calibrated with gases of known concentration before the test according to the manufacturer`s guidelines. Peak oxygen consumption (VO_2peak; $L.min^{-1}$) was considered as the highest VO_2 rate achieved within 30 s at the end of the exercise test (Davis, 2006). The criteria for maximal exercise test were the following: (1) respiratory exchange ratio equaled at least 1.1; (2) HR_{max} > 90% of the age-predicted maximum calculated according to the formula 220 – age (Davis, 2006). CRF was defined either by VO_2peak per kg of body mass

($VO_2peak/_{kg}$; $mL.kg^{-1}.min^{-1}$) or by more relevant morphological variable VO_2peak per kg of LBM ($VO_2peak/_{LBM}$; $mL.kg^{-1}.min^{-1}$) as used before (Lätt et al., 2016) and stated by Armstrong & Welsman (2020).

4.7. Cardiometabolic risk factors

For assessing biochemical cardiometabolic risk factors, a 10-ml venous blood sample from antecubital vein were drawn in both timepoints between 8:00 and 9:00 AM after an overnight fast with the participant sitting in the upright position. Serum was separated and then frozen at -80° until further analysis. Total cholesterol (TC; $mmol.L^{-1}$), triglycerides (TG; $mmol.L^{-1}$), high- (HDLc; $mmol.L^{-1}$) and low-density (LDLc; $mmol.L^{-1}$) lipoprotein cholesterol levels were measured by conventional methods. Insulin ($\mu U.mL^{-1}$) was analyzed using Immulite® 2000 (Diagnostic Products Corporation, Los Angeles, CA), while concentrations of glucose ($mmol.L^{-1}$) was measured with a commercial kit (Boehringer, Mannheim, Germany). Insulin resistance (IR) was evaluated using an IR index calculated by the homeostasis model assessment (HOMA-IR): fasting serum insulin × fasting serum glucose / 22.5 (Matthews et al., 1985). To define IR in pubertal boys, a HOMA-IR index above 5.22 was used and which have shown to have sensitivity of 56% and specificity of 93.3% (Kurtoglu et al., 2010).

In addition to different biochemical cardiometabolic risk factors, a metabolic syndrome severity risk score (MSSS), expressed in z-score, was calculated by multiplying each participant's clinically measured value (height, body mass, WC, SBP, HDLc, TG, fasting glucose) by a subgroup-specific coefficient. For calculating MSSS, the Pediatric MSSS online calculator was used (http://mets.health-outcomes-policy.ufl.edu/calculator/) (Gurka, et al., 2012). The lower MSSS indicates a healthier overall risk profile. After relaxation in a seated position for approximately over 5 min, resting systolic and diastolic blood pressure (SBP and DBP; mmHg) was measured from the non-dominant arm as a mean of 3 consecutive measurements at 5 min intervals using a validated auscultatory method with an appropriately sized cut (Hillrom Welch Allyn Durashock Aneroid Blood Pressure BP Monitor – DS44, Welch Allyn, USA). The mean of the two closest BP readings was used in further analysis. Mean arterial pressure (MAP; mmHg) was calculated as [(SBP-DBP) / 3] + DBP. Resting heart rate (HR_{rest}; $beats.min^{-1}$) was taken from standard ECG analysis in a lying position.

4.8. Serum adipokines and osteokines

Serum leptin ($ng.mL^{-1}$) was determined by radioimmunoassay (RIA, Mediagnost GmbH, Reutlingen, Germany) with the least detection limit of 0.01 $ng.mL^{-1}$, and the intra- and inter-assay CVs less than 5%, while adiponectin ($\mu g.mL^{-1}$) was also determined by commercially available RIA kit (Linco Research, St.

Charles, MO) with the least detection limit of 1 $\mu g.mL^{-1}$, and the intra- and inter-assay CVs less than 7% (Mengel et al., 2017). Serum osteocalcin ($ng.mL^{-1}$) was analyzed using Immulite 2000 (DPC, Los Angeles, CA, USA). The intra- and inter-assay CVs for osteocalcin was less than 7%. Lipocalin-2 ($ng.mL^{-1}$) was assessed by a commercially available enzyme-linked immunosorbent assay (ELISA) kit (R&D Systems Inc., Minneapolis, MN, USA). This assay had intra- and inter-assay CVs 3.1% and 6.1%, respectively, and the least detection limit was 0.4 $ng.mL^{-1}$. Sclerostin ($pg.mL^{-1}$) was determined using ELISA kit (R&D Systems Inc., Minneapolis, MN, USA) with a minimum detectable level of 1.7 $pg.mL^{-1}$, and an intra-assay CVs 1.9% and an inter-assay CVs 9.5%.

4.9. Energy intake

Energy intake data were collected over a 3-day period including 2 weekdays and 1 weekend day, and are reported as average values. A 3-day food record represents a person's habitual energy intake better than a 24-h recall (Dias et al., 2018; Hills et al., 2007). The nutrition data were entered into Nutridata System for Research (www.nutridata.ee; National Institute for Health Development, Tallinn, Estonia) and were analyzed for total daily energy ($kcal.day^{-1}$), and fat, protein and carbohydrate intake in % of total energy intake. During the 12-week intervention period, no restrictions were placed on dietary intake and all participants were instructed to maintain their habitual eating habits.

4.10. Physical activity

Daily physical activity (PA) was monitored using an ActiGraph accelerometer (model GT3x ActiGraph; Pensacola, FL, USA) for seven consecutive days as a best sensible practical recommendation for children and adolescents (Ward et al., 2005). The accelerometer was programmed to record activity counts in 15-s epochs. For the analyses of accelerometer data, all night activity (24:00–6:00 hours) and all sequences of 20 min or more of consecutive zero counts were excluded from each participant`s recording. PA was suitable for further analyses when the subject had accumulated a minimum of 10 hours of activity data per day for three weekdays and one weekend. Total PA ($counts.min^{-1}$) was considered as an indicator of daily PA (Lätt et al., 2015). All participants were asked to continue with their usual PA habits.

4.11. Statistical analysis

Based on the primary outcome of VO_2peak resulting from sprint interval training on aerobic capacity in the parent study, a priori power analysis based on a systematic review of the literature and meta-analysis (Gist et al., 2014)

showed that the estimated sample size was at least 12 for SIT group and also stated in previous studies with similar research questions (Kong, et al., 2016a; Sun et al., 2019; Trilk al., 2011). Standard preliminary procedures were used to test the violations of assumptions. The normality of raw data and residuals from one-way analysis of covariance (ANCOVA) was assessed with the Shapiro-Wilk test or through visual examination of histograms and normal quantile-quantile plots, and the homogeneity of variance by Levene's test. To limit the influence of outliers, raw scores in the data set were first winsorized as used before (Sink et al., 2015). The aforementioned value modification method replaces extreme values with the second largest or second smallest value in the cohort without discarding outliers (Kwak & Kim, 2017). Differences between groups at baseline were analyzed using a *t* test for independent samples, and a Fischer's exact test was used to compare dependent proportions (pubertal maturation). A *t* test for paired samples were used as a validity check to confirm possible changes in CRF and blood biochemical markers between the pre- and post-intervention independently for both groups. In addition, paired *t* test was used to evaluate changes in work performed by SIT across 12 weeks of training. The primary analysis to evaluate main and intervention effects, ANCOVA with groups (SIT, CONT) as between-subject comparator, post − pre intervention changes as the dependent variable and baseline values of the variables as a covariate to better control for between-group differences, was used. In addition to baseline values, age, body FM and Tanner stage were also included in the ANCOVA model as covariates, but as there was observed only a slight difference in the effects of interest between the analysis models including/not including age, FM or pubertal stage, it is not considered in the final ANCOVA model. To characterize the magnitude of the difference between two groups, effect size (ES) eta squared (η^2) was reported and considered small if $\eta^2 < 0.06$ and large if $\eta^2 > 0.14$ (Kirk, 1996). Cohen's *d* ES was also calculated to determine the magnitude of the change in main outcome variables within groups, and the values were interpreted as following: > 0.8, large effect; 0.5, medium effect; < 0.2, small effect (Hopkins et al., 2009). Changes were calculated by subtracting the final value at 12 weeks from the corresponding initial value at baseline. To assess associations between changes of osteokines and clinical variables such as body mass and BMI, in the course of 12-week SIT training period, Pearson (*r*) correlation was used. Analyses were performed with the SPSS software (version 21.0; SPSS Inc, Chicago, IL, USA). All data were expressed as means and standard errors (±SE), unless otherwise stated. The level of significance was set at $p < 0.05$ for all analyses.

5. RESULTS

5.1. Efficacy of 12-week sprint interval training protocol

Table 3 shows the protocol of sprint interval training during 12 consecutive weeks. Progressive increase was observed in peak and in mean power output, which demonstrates the efficacy of the used SIT protocol in adolescent boys with obesity.

Table 3. Mean (±SE) characteristics of sprint interval training (SIT, n = 14) protocol.

Variable	Week 1–4	Week 5–8	Week 9–12
SIT	4 x 30 s	5 x 30 s	6 x 30 s
	4 min rest	4 min rest	4 min rest
HR_{max} (%)	81.7 ± 1.5	82.5 ± 1.5	79.8 ± 1.2
Peak power ($W.kg^{-1}$)	5.8 ± 0.4	6.5 ± 0.6$^{\#}$	7.0 ± 0.6$^{\#}$*
Mean power ($W.kg^{-1}$)	3.6 ± 0.3	3.8 ± 0.3$^{\#}$	3.6 ± 0.3
Fatigue index (%)	38.2	40.1	46.9
Attendance rate (%)	89.0	81.0	80.0
Training time per session (min)	29.0	33.5	38.0
Workload time per session (min)	2.0	2.5	3.0
Weekly training time (min)	87.0	100.5	114.0

HR_{max}, maximum heart rate; $^{\#}$ Significantly different ($p < 0.05$) from the corresponding values of Week 1–4; * Significantly different ($p < 0.05$) from the corresponding values of Week 5–8.

5.2. Body composition and cardiorespiratory fitness in response to 12-week intervention period

Mean body composition variables and CRF measured before and after the 12-week study period in SIT and CONT groups are presented in Table 4. At baseline, groups were similar ($p > 0.05$) by in all measured clinical parameters. After the intervention period boys increased body mass 1.2 ± 0.7 kg ($p > 0.05$) in the SIT group and 2.8 ± 0.7 kg ($p = 0.002$) in the CONT group, and height 2.0 ± 0.3 cm ($p < 0.001$) in the SIT group and 1.5 ± 0.3 cm ($p < 0.001$) in the CONT group. The post-intervention measurements revealed a significant reduction in BF % by 1.2 ± 0.6% ($p = 0.006$) in the SIT group and an increment by 0.5 ± 0.6% ($p > 0.05$) in the CONT group, and a significant increase in LBM for both SIT and CONT (both groups by 2.3 ± 0.5 kg, $p < 0.001$) groups. Although there was no between-group difference in any body composition parameter after adjusting for baseline values, the magnitude of the decrement for BF % was almost large [$F(1,25)= 3.67$, $p = 0.067$, $\eta^2= 0.13$)] (Table 4). Other two measured body composition parameters, WC and FM, were not

different ($p > 0.05$) between the two studied groups. After the 12-week study period, significant increase in $VO_2peak/_{kg}$ and $VO_2peak/_{LBM}$ were observed only in SIT group ($p < 0.001$ and $p = 0.035$, respectively) (Table 4). For the primary analysis, ANCOVA model comparing post – pre intervention differences between two groups revealed a significant difference in $VO_2peak/_{kg}$ and $VO_2peak/_{LBM}$ with SIT exhibiting a significant increase, when controlling for baseline values [$F(1,25)= 10.02$, $p = 0.004$, and $F(1,25)= 23.08$, $p < 0.001$, respectively]. Inspecting differences within groups over time, HR_{rest} showed a decrease by 11.2 ± 2.5 beats.min^{-1} ($p = 0.003$) in SIT group and an increase by 3.3 ± 2.5 beats.min^{-1} ($p = 0.043$) in CONT group. After adjusting for baseline values in ANCOVA analysis, significant difference between groups was also seen in mean HR_{rest} [$F(1,25)= 16.64$, $p < 0.001$] (Table 4).

Table 4. Mean (±SE) body composition and cardiorespiratory fitness characteristics before (Pre) and after (Post) 12 weeks in sprint interval training (SIT) and control (CONT) groups.

Variable	SIT (n = 14)		CONT (n = 14)		Difference (95% CI)[a]		
	Pre	Post	Pre	Post	SIT	CONT	η^2
Height (cm)	170.6 ± 2.7	172.7 ± 2.6[#]	173.5 ± 2.9	174.8 ± 2.8[#]	2.0 ± 0.3 (1.4, 2.5)	1.5 ± 0.3 (1.0, 2.1)	0.06
Body mass (kg)	89.1 ± 4.3	90.3 ± 4.1	99.3 ± 6.4	102.0 ± 6.5[#]	1.2 ± 0.7 (-0.3, 2.7)	2.8 ± 0.7 (1.3, 4.3)	0.09
WC (cm)	96.2 ± 2.4	96.3 ± 2.4	100.8 ± 4.3	103.9 ± 4.8	-0.01 ± 1.7 (-3.6, 3.6)	3.1 ± 1.7 (-0.5, 6.7)	0.06
FM (kg)	35.9 ± 2.1	34.7 ± 2.2	38.6 ± 3.4	39.1 ± 3.5	-1.2 ± 0.7 (-2.5, 0.2)	0.5 ± 0.7 (-0.9, 1.8)	0.11
BF (%)	41.1 ± 1.3	39.2 ± 1.5[#]	39.6 ± 1.9	38.9 ± 1.9	-1.2 ± 0.6 (-2.6, 0.1)	0.5 ± 0.6 (-0.8, 1.9)	0.13
LBM (kg)	49.3 ± 2.6	51.5 ± 2.6[#]	55.7 ± 3.4	58.1 ± 3.6[#]	2.3 ± 0.5 (1.3, 3.2)	2.3 ± 0.5 (1.3, 3.2)	0.01
$VO_2peak/_{kg}$ ($mL.kg^{-1}.min^{-1}$)	29.7 ± 1.4	33.0 ± 1.2[#]	27.6 ± 1.6	28.0 ± 1.3	3.7 ± 0.8 (2.0, 5.3)*	0.1 ± 0.8 (-1.6, 1.7)	0.29
$VO_2peak/_{LBM}$ ($mL.kg^{-1}.min^{-1}$)	53.9 ± 2.1	57.5 ± 1.3[#]	48.8 ± 1.8	48.1 ± 1.1	5.2 ± 1.1 (3.0, 7.3)*	-2.1 ± 1.1 (-4.4, -0.04)	0.48
HR_{rest} ($beats.min^{-1}$)	84.9 ± 3.0	73.1 ± 3.4[#]	81.6 ± 2.4	85.5 ± 2.4[#]	-11.2 ± 2.5 (-16.3, -6.1)*	3.3 ± 2.5 (-1.9, 8.4)	0.40
HR_{max} ($beats.min^{-1}$)	190.6 ± 2.4	194.4 ± 2.6	186.5 ± 2.0	191.4 ± 3.1	4.1 ± 2.3 (-0.6, 8.9)	4.6 ± 2.3 (-0.1, 9.3)	0.01

CI, confidence interval; η^2, eta squared for effect size; WC, waist circumference; FM, fat mass; BF, body fat; LBM, lean body mass; VO_2peak, peak oxygen consumption; HR_{rest}, resting heart rate; HR_{max}, maximum heart rate; [a] Group differences (Post – Pre) examined by ANCOVA; [#] Significant change from the Pre ($p < 0.05$); * Significant change from the CONT ($p < 0.05$).

5.3. Cardiometabolic risk factors and adipokine levels in response to 12-week intervention period

Mean values of cardiometabolic risk factors and adipokine levels before and after 12-week intervention in SIT and CONT groups are reported in Table 5. At baseline, two groups had similar ($p > 0.05$) values in MAP, SBP and DBP, glucose, HDLc, adiponectin, leptin and MSSS, but exhibited differences in such biomarkers as insulin, HOMA-IR, TC, LDLc, and TG ($p = 0.020$, $p = 0.024$, $p = 0.005$, $p = 0.014$, and $p = 0.005$, respectively). Compared to baseline values, HDLc and adiponectin showed a significant decrease in both the SIT and CONT groups after the study period ($p = 0.028$, and $p = 0.040$, respectively; and $p = 0.003$, and $p = 0.006$, respectively), while MSSS showed a significant decrease over time in the SIT group ($p < 0.050$). In ANCOVA analyses, adjusted for baseline values of the studied outcome, after 12-week period, there were no changes between the two groups in two adipokine levels or in any other cardiometabolic risk factors, except for LDLc, which was reduced in the SIT compared to the CONT group [$F(1,25)= 5.71$, $p = 0.025$].

Table 5. Mean (±SE) clinical and biochemistry characteristics before (Pre) and after (Post) 12 weeks in sprint interval training (SIT) and control (CONT) groups.

Variable	SIT (n = 14)		CONT (n = 14)		Difference (95% CI)[a]		
	Pre	Post	Pre	Post	SIT	CONT	η^2
MAP (mmHg)	91.7 ± 3.1	89.5 ± 2.9	93.4 ± 3.7	92.5 ± 2.9	-2.6 ± 2.2 (-7.2, 2.0)	-0.5 ± 2.2 (-5.1 ± 4.2)	0.02
SBP (mmHg)	123.9 ± 3.1	125.9 ± 2.4	124.7 ± 4.4	120.7 ± 4.4	1.8 ± 2.9 (-4.1, 7.7)	-3.8 ± 2.9 (-9.7, 2.1)	0.07
DBP (mmHg)	75.6 ± 3.3	71.3 ± 3.5	77.7 ± 3.5	78.4 ± 2.3	-4.8 ± 2.5 (-9.9, 0.3)	1.3 ± 2.5 (-3.9, 6.4)	0.11
Glucose (mmol.L^{-1})	5.18 ± 0.1	5.11 ± 0.1	5.24 ± 0.1	5.19 ± 0.1	-0.09 ± 0.1 (-0.21, 0.03)	-0.04 ± 0.1 (-0.16, 0.03)	0.01
Insulin (µU.mL^{-1})	20.91 ± 1.7	20.64 ± 1.8	34.41 ± 5.0[§]	31.80 ± 6.6	0.69 ± 2.6 (-4.58, 5.96)	-3.58 ± 2.5 (-8.85, 1.69)	0.05
HOMA-IR	4.85 ± 0.4	4.72 ± 0.4	8.11 ± 1.2[§]	7.45 ± 1.6	0.06 ± 0.6 (-1.20, 1.33)	-0.86 ± 0.6 (-2.12, 0.40)	0.04
TC (mmol.L^{-1})	3.90 ± 0.1	3.99 ± 0.1	4.67 ± 0.2[§]	4.64 ± 0.2	-0.04 ± 0.1 (-0.22, 0.14)	0.11 ± 0.1 (-0.07, 0.29)	0.05
HDLc (mmol.L^{-1})	1.16 ± 0.06	1.07 ± 0.05[#]	1.03 ± 0.04	0.96 ± 0.03[#]	-0.06 ± 0.3 (-0.12, -0.003)	-0.09 ± 0.03 (-0.15, -0.04)	0.02
LDLc (mmol.L^{-1})	1.99 ± 0.1	2.05 ± 0.1	2.53 ± 0.2[§]	2.60 ± 0.1	-0.06 ± 0.1 (-0.21, 0.08)*	0.19 ± 0.1 (0.05, 0.34)	0.19
TG (mmol.L^{-1})	1.12 ± 0.1	1.20 ± 0.1	1.89 ± 0.2[§]	1.69 ± 0.2	0.03 ± 0.1 (-0.22, 0.27)	-0.14 ± 0.1 (-0.38, 0.10)	0.03
Adiponectin (µg.mL^{-1})	4.11 ± 0.3	3.49 ± 0.3[#]	3.59 ± 0.3	3.15 ± 0.2[#]	-0.55 ± 0.1 (-0.83, -0.27)	-0.52 ± 0.1 (-0.79, -0.24)	0.001
Leptin (ng.mL^{-1})	26.49 ± 2.2	26.69 ± 1.2	28.61 ± 1.6	25.12 ± 2.2	-0.23 ± 1.4 (-3.05, 2.59)	-3.06 ± 1.2 (-5.88, -0.24)	0.08
MSSS (z-score)	2.16 ± 0.1	2.09 ± 0.1[#]	2.27 ± 0.1	2.27 ± 0.1	-0.06 ± 0.03 (-0.11, 0.003)	-0.01 ± 0.03 (-0.06, 0.03)	0.06

CI, confidence interval; η^2, eta squared for effect size; MAP, mean arterial pressure; SBP, systolic blood pressure; DBP, diastolic blood pressure; HOMA-IR, homeostasis model assessment of insulin resistance; TC, total cholesterol; HDLc, high-density lipoprotein cholesterol; LDLc, low-density lipoprotein cholesterol; TG, triglycerides; MSSS, metabolic syndrome severity risk score; [a] Group differences (Post – Pre) examined by ANCOVA; [#] Significantly different from the Pre ($p < 0.05$); [§] Significantly different from the SIT ($p < 0.05$); * Significantly different from the CONT ($p < 0.05$).

5.4. Bone mineral characteristics and osteokine levels in response to 12-week intervention period

Bone mineral characteristics and serum osteokines levels are presented in Table 6. Compared to baseline, WB BMC increased after 12-week period in both the SIT and CONT groups (p = 0.005 for both groups), while in the SIT group a significant increase with almost a large practical effect was seen in LL BMD (p = 0.029, ES = 0.75). After 12-week period, ANCOVA results showed no differences ($p > 0.05$) in any bone mineral parameters (including WB BMD, LL BMD, and WB BMC) between two groups. Although the mean change in osteocalcin showed a smaller reduction in the SIT compared to the CONT group (−1.22 ± 2.6 vs −3.95 ± 2.6, respectively), and the mean change in lipocalin-2 showed a bigger reduction in the SIT group that than the CONT group (−3.77 ± 1.6 vs −2.09 ± 1.6), none of the mean changes in all osteokines (osteocalcin, sclerostin, lipocalin-2) were significant within or between the groups after 12-week study period. As differences (Post − Pre) in all bone mineral and biochemical characteristics after 12-week study period between two groups represented a small ES ($\eta^2 < 0.06$) in ANCOVA analyses, then these values are not shown in Table 6. After the 12-week SIT period, the change in osteocalcin correlated negatively and the change in lipocalin-2 correlated positively with the change in BMI (r = -0.57, p = 0.034, and r = 0.57, p = 0.035, respectively). All other relationships between changes in BMI with sclerostin and measured bone mineral content and density variables were not significant ($p > 0.05$).

Table 6. Mean (±SE) bone mineral characteristics and serum osteokine levels before (Pre) and after (Post) 12 weeks in sprint interval training (SIT) and control (CONT) groups.

Variable	SIT (n = 14)			CONT (n = 14)			Difference (95% CI)[a]	
	Before	After	ES	Before	After	ES	SIT	CONT
WB BMD ($g.cm^{-2}$)	1.05 ± 0.03	1.06 ± 0.03	0.33	1.15 ± 0.05	1.13 ± 0.04	0.13	−0.01 ± 0.02 (−0.06, 0.04)	0.003 ± 0.02 (−0.05, 0.05)
LL BMD ($g.cm^{-2}$)	1.16 ± 0.04	1.19 ± 0.03[#]	0.75	1.29 ± 0.05	1.28 ± 0.05	0.13	0.009 ± 0.03 (−0.05, 0.07)	0.002 ± 0.03 (−0.06, 0.06)
WB BMC (g)	2247.98 ± 123.0	2325.05 ± 123.0[#]	0.89	2478.63 ± 160.2	2560.89 ± 170.6[#]	0.90	80.10 ± 24.4 (29.83, 130.4)	79.23 ± 24.4 (28.96, 129.5)
Osteocalcin ($ng.mL^{-1}$)	26.31 ± 4.9	24.66 ± 3.6	0.12	24.34 ± 4.3	20.84 ± 3.6	0.31	−1.22 ± 2.6 (−6.63, 4.20)	−3.95 ± 2.6 (−9.36, 1.46)
Sclerostin ($pg.mL^{-1}$)	275.18 ± 30.5	284.97 ± 27.6	0.24	284.49 ± 24.4	287.33 ± 26.8	0.05	9.17 ± 13.3 (−18.14, 36.48)	3.46 ± 13.3 (−23.85, 30.77)
Lipocalin-2 ($ng.mL^{-1}$)	33.07 ± 1.9	31.00 ± 1.7	0.32	37.46 ± 3.2	33.67 ± 1.6	0.32	−3.77 ± 1.6 (−7.05, −0.48)	−2.09 ± 1.6 (−5.38, 1.20)

CI, confidence interval; ES, effect size; WB, whole body; BMD, bone mineral density; LL, lower limb; BMC, bone mineral content; [a] Group differences (Post – Pre) examined by ANCOVA; [#] Significantly different from the Pre ($p < 0.05$).

6. DISCUSSION

6.1. Body composition and cardiorespiratory fitness after 12-week sprint interval training in adolescent boys with obesity

To the best of our knowledge, this is the first study to describe the effects of 4–6 x 30 s all-out SIT on body composition and CRF in adolescent boys with obesity. The SIT program resulted in a reduction in BF % and HR_{rest} values and an improvement in CRF. Although no favorable changes occurred in body mass, BMI, FM and WC indices, the findings of this study indicate that the used SIT protocol can elicit rapid improvement at least in one body composition parameter and an increase in aerobic fitness in adolescent boys with obesity.

Based on a several systematic reviews (Costigan et al., 2015; Eddolls et al., 2017; García-Hermoso et al., 2016; Martin-Smith et al., 2020), interval training can elicit improvements in body composition values in children and adolescents. The current study results showed a significant decrease in BF % at post-training in the SIT group. Although the between group change was not significant (p = 0.067), the result showed a trend for decline, and almost with a large ES (η^2= 0.13) it could be considered as practical difference. The result obtained in current study is supported by the knowledge that interval training significantly improves BF % in comparison to non-training control group (Costigan et al., 2015). The SIT training in current study did not elicit decreases in body mass, BMI, FM and WC in adolescent boys with obesity. However, it must be acknowledged that findings in body composition changes after interval training among youth with obesity are quite controversial. For instance, decrease in BF % with an additional reduction in total body mass, BMI, FM and WC were observed in adolescent females with obesity after 12-week high-intensity running sprints (Racil et al., 2013; Racil et al., 2016). On contrary, no significant intervention effects on body mass, BMI, FM and BF % among adolescents with obesity after 12-week interval training are reported (Cvetković et al., 2018; Dias et al., 2018; Murphy et al., 2015) or even after 13-week intervention (Ingul et al., 2010). Diet or caloric restriction on weekly basis throughout the intervention period could give a significant contribution to a better result in body composition including WC parameter just as noted by several authors (Lazzer et al., 2017; Morrissey et al., 2018; Racil et al., 2013; Tjønna et al., 2009; Tong et al., 2018; Zhang et al., 2017), but this was not present in the current study. The absence of substantial changes in body mass, BMI and FM after training in SIT group were not quite as we expected. But again, the absence of changes in WC is not unexpected, since based on the meta-analysis (Costigan et al., 2015), the effect of interval exercise training on WC is small and not statistically significant in adolescents. After 12-week period, both groups had a significant increase in height and LBM. It has to be considered that the participants in SIT and CONT groups were at their puberty (average age 13.1 ± 0.3 years, and,

average age 13.7 ± 0.4 years, respectively). During this maturation period, the growth of body height peaks in boys at the age of 13.5 (Berenson, 2009), and compared to baseline, both SIT and CONT group had a similar increase in body height and LBM (Table 4). In support with current study findings, 12-week HIIT among children with obesity with a mean age of 12.0 ± 2.3 years showed no changes in body mass, even though the participants height increased over the intervention period (Dias et al., 2018).

The improvement in $VO_2peak/_{kg}$ (by 11.2%) observed after 12-week SIT program provides a basis to use SIT as an intervention method to provoke rapid favorable changes in CRF in adolescent boys with obesity. Similarly to our results, a recent systematic review and meta-analysis support the effect of interval training in improving CRF in healthy adolescents with overweight and obesity (Martin-Smith et al., 2020). The increase in $VO_2peak/_{kg}$ by 3.7 $mL.kg^{-1}.min^{-1}$. observed after 12-week SIT in our study population is likely to confer significant cardioprotective benefits while a 3.5 $mL.kg^{-1}.min^{-1}$ increase in VO_2peak in adults is associated with a 10–25% improvement in survival (Ross et al., 2016). As the general guidelines suggest 75 min of vigorous PA per week (WHO, 2014), then current SIT protocol with total of 87–114 min per week, already increased CRF in adolescent boys with obesity. The effect of interval training on CRF depends on its intensity (Ciolac et al., 2011) and duration (Vollaard & Metcalfe, 2017) and that the greatest increase in VO_2peak is achieved at very high training intensity as an all-out maximal effort at relatively low training volume (Burgomaster et al., 2008). In children and adolescents, interval training sessions at an intensity of ≥ 90% HR maximum or 100–130% maximal aerobic capacity elucidates greatest CRF improvements (Eddolls et al., 2017). In the current study, the improvement in VO_2peak in SIT group may also be related to a shorter workload duration or to a prolonged recovery periods between sprints. For instance, Higgins et al. (2016) demonstrated after a 5–7 x 30 s all-out cycle ergometer sprints with 4 min active recovery a remarkable increase in $VO_2peak/_{kg}$ (14.1%) compared to baseline in SIT group among young females with overweight. The SIT recovery period in the current study was similar to those reported by Dias et al. (2018) and Trilk et al. (2011) where a 4 min active rest period between the intervals caused a significant increase in $VO_2peak/_{kg}$ (14.7%, and 12.0%, respectively) after 12-week training intervention among adolescent girls with obesity. Therefore, it can be suggested that prolonged recovery periods, in participants with obesity, are effective in ensuring that maximal exertion is met on each high-intensity interval bout. In the current study, the SIT group had also a significant decrease in HR_{rest} following the 12-week period, with a significant increase reported in the CONT group. The decrease in HR_{rest} after high-intermittent trainings is observed only in the training group (Dias et al., 2018; Racil et al., 2016; Wong et al., 2008) or not reported at all (Lee, et al. 2017b; Murphy et al., 2015; Tjønna et al., 2009). The dissimilarities in results are explicable by different implemented interval training regimens or intervention periods. In addition, such factors as participants' age and sex (Ostchega et al., 2011) may contribute to unequal extent of change in

HR variability. Also, exercise trainings and increased CRF have been found a beneficial effect on HR variability profiles and to autonomic control modulation in youth (Gutin et al., 2005). Resting HR, the marker of cardiac autonomic function, is one of a vital sign regularly measured in clinical practice, and with the clinical relevance, increased HR_{rest} above its reference value appears to be associated with CVD and metabolic disorders later in adult life (Nagai & Moritani, 2004; Ostchega et al., 2011). Therefore, observed decrease in HR_{rest} in SIT group after intervention supports the therapeutic role of exercise in improving autonomic function and overall physical health among adolescent boys with obesity.

The results of this study showed that SIT program, done as 4–6 x 30 s all-out cycling sprints, provides sufficient stimulus to improve body composition and enhance aerobic capacity despite its low volume in adolescent boys with obesity.

6.2. Cardiometabolic risk factors and adipokine levels after 12-week sprint interval training in adolescent boys with obesity

The main finding was that a 30 s all-out SIT program evoked favorable changes in the MSSS. It is noted that MSSS is related to future type 2 diabetes and CVD risk (Lee et al., 2016; Lee et al., 2017a): every one-unit elevation in childhood MSSS increases the odds of type 2 diabetes nearly three-fold, and the risk of CVD nearly 10-fold by 38 years of age (DeBoer et al., 2015a, 2015b). Such knowledge may provide a good foundation for the use of sex- and racial/ethnicity-specific MSSS more often in clinical settings or physical therapy programs as it may better reflect the individual's overall cardiometabolic risk status than following changes in multiple cardiometabolic biomarkers (DeBoer & Gurka, 2017). Therefore, improved ($p < 0.05$) MSSS after 12 weeks of SIT shows training therapy effectiveness among adolescent boys with obesity.

After the 12-week study, a large and significant difference ($p = 0.025$, $\eta^2 = 0.19$) between the two groups was observed only in the LDLc variable. Although the within-group change after the study did not reach statistical significance in either group, the between-group change observed in the current study may suggest a health benefit value as the reduction of LDLc even by 1% decreases the prevalence of coronary heart disease by 2% (Pedersen et al., 1998). Previously, different studies reported positive alterations in lipid profile in response to interval training together with weight loss and changes in body composition in adolescents with obesity (Koubaa, 2013; Racil et al., 2013; Racil et al., 2016), but the others have not shown the effects of interval training on lipids (Ardoy et al., 2013; Dias et al., 2018; Silva et al., 2015). Accordingly, unchanged LDLc levels were observed even after 12 weeks of 2 min of running at 80–90% VO_2peak interspersed with 1 min recovery among adolescent boys with obesity (mean age of 13.0 ± 0.8 years) with simultaneous positive changes

in body composition and TG levels (Koubaa, 2013). In contrast, a study conducted by Ouerghi et al. (2017) showed that after 8 weeks of 16 × 30 s runs at 100–110% maximal aerobic speed with a recovery of 30 s induced a significant decrease in LDLc concentration, body composition parameters, and TG and TC levels among young men with overweight and obesity (17–20 years). The levels of blood lipids are dependent on age, gender, physical activity, and body fatness (Dai et al., 2009). Further, studies with adolescents with obesity have shown an increase (Koubaa, 2013; Racil et al., 2013) or no change (Dias et al., 2018; Ouerghi et al., 2017; Silva et al., 2015) in HDLc after different interval training protocols. In the present study, intriguingly, the post-intervention levels of HDLc decreased in both groups ($p < 0.05$) compared to baseline values. One explanation could be the age factor, as both groups were at the mean age of 13.1 ± 1.3 years for SIT and 13.7± 1.6 years for CONT. It appears that HDLc levels follow certain age- and sex-related patterns where it decreases up to 16 years in boys and up to 14 years in girls (Dai et al., 2009), especially in individuals with obesity (Panagopoulou et al., 2008). For instance, increased HDLc levels after 12-week running-based SIT were observed among girls with obesity with a mean age of 15.6 ± 0.7 years (Racil et al., 2013). Still, the current study's finding contradicts Koubaa (2013) study population (adolescent boys with obesity with a mean age of 13 ± 0.8 years), whose HDLc significantly increased after 12-week running-based HIIT. These investigations confirm a large controversy regarding the impact of SIT on lipid profile and support the fact that different demographic characteristics (age, gender), training intervention protocols, and changes in body composition may be the confounding factors in how different metabolic biomarkers change on each individual after interval training.

It has been reported that HOMA-IR correlates with age as it increases from 10 to 13 years of age in adolescent boys with obesity and, afterward, starts decreasing again (Shashaj et al., 2016). Although the groups did not significantly differ in age at baseline, it was seen that the CONT group was 0.6 years older, and individual observation showed that there were more boys in Tanner 5 stage compared to the SIT group. Accordingly, it was speculated that the CONT group may have had their physiological rise in HOMA-IR level due to their Tanner stage (Kurtoglu et al., 2010). Following the 12-week study period, both groups reduced fasting glucose, insulin, and HOMA-IR scores compared to baseline values, but none of the changes were significant. In clinical research, reliable HOMA-IR is a frequently used method in children and adolescents with obesity for determining IR (Shashaj et al., 2016), and even a small reduction in body fat is effective in improving IR (Blackburn, 1995). Therefore, it was surprising that after a significant loss in BF % in the SIT group after the 12-week training period, the HOMA-IR index remained unchanged. Similar to the current study's results, Morrissey et al. (2018) found that 12 weeks of 4–6 120 s shuttle runs at 90–95% HR_{max} with active rest favorably altered body composition, while fasting insulin and HOMA-IR scores stayed unchanged in adolescent boys and girls with obesity. In contrast, Racil et al. (2016) found that the positive changes in body composition after 12-week SIT training resulted in

a decrease in insulin levels and HOMA-IR scores in adolescent females with obesity.

Children and adolescents with overweight and obesity are more prone to lower circulating levels of adiponectin and higher leptin levels (Hejazi & Ferrari, 2022). A decrease in adiponectin levels after the 12-week study period was observed in both groups, while no reduction was seen in fasting leptin in both groups. These findings are controversial to Racil et al. (2013) results, where an increase of adiponectin was seen after 12-week SIT training. It has been described that adiponectin declines throughout puberty, with the lowest levels among pubertal boys with obesity compared to girls with obesity in puberty and post-puberty (Panagopoulou et al., 2008). The study population in Racil et al. (2013) consisted of girls at a mean age of 15.9 ± 0.3 years, whose adiponectin levels had already started to physiologically increase due to their pubertal status. Therefore, adiponectin levels change during puberty and may influence boys more than girls. In addition, adiponectin levels are correlated with BMI, insulin, HOMA-IR, and HDLc (Panagopoulou et al., 2008). Improvements in all aforementioned indices after 12-week SIT were seen in Racil et al. (2013) but not in the present study. This could be another explanation for why no favorable changes in adiponectin levels were found in the current study. Moreover, it could be speculated that the work modality used in SIT protocols may be another factor influencing the differences between the studies. For instance, 60 × 8 s all-out cycling sprints evoked no positive changes in adiponectin levels even after a 15-week SIT training in young women (mean age of 20.2 years) (Trapp et al., 2008), whereas a 12-week SIT total of 12–16 × 30 s shuttle runs at 100–110% maximal aerobic speed among girls with obesity significantly increased adiponectin levels (Racil et al., 2013). The exercise intensity in the Racil et al. (2013) study was based on the speed associated with VO_2peak, which was increased over the 12-week period. In the current study, the employed training intensity was founded on the % HR_{max}, which remained the same during the whole training period. It is assumed that training intensity should be adjusted according to the training progression not only by sprint numbers but also by adjusting exercise intensity throughout the intervention period. As the change in FM was not different between the groups, the current study did not see significant changes in leptin levels within or between the groups, similar to the study in young women with overweight and obesity at a mean age of 19.4 years, where no changes were also observed among body composition or any other cardiometabolic risk factors (Kong et al., 2016b).

6.3. Bone mineral characteristics and osteokine levels after 12-week sprint interval training in adolescent boys with obesity

Our study demonstrated that 12 weeks of SIT improved bone mineral characteristics without changes in serum osteokine levels in adolescent boys with obesity.

Several studies evaluating the effect of interval training on bone-derived markers have shown a positive effect (Atashak et al., 2022; Kim et al., 2015), while others have demonstrated a negative or no effect of exercise training (Choi et al., 2009; Nakai et al., 2021) among adults with overweight and obesity. In the current study, none of the measured osteokines showed any favorable within- or between-group change after the study period. However, opposite trends, although not significant, were seen in serum osteocalcin levels in this study. One possible explanation might be the age range of our subjects, during which the variation in serum osteocalcin levels starts to increase, and many our subjects might have reached the maturity when osteocalcin levels begin to decline (Paldánius et al., 2021). We still observed that the decrease of the osteocalcin level in the SIT group was smaller compared to the CONT group (-1.22 ± 2.6 ng.mL^{-1} vs. -3.95 ± 2.6 ng.mL^{-1}, respectively) showing possible effects of the 12-week SIT training on serum osteocalcin levels. These findings are similar to Josse et al. (2020), where no change in osteocalcin and sclerostin levels was seen after 12-week aerobic and resistance training among adolescent girls with overweight and obesity. In contrast, a significant decrease in serum osteocalcin was observed after 8-weeks of interval training (4 × 4 min running/walking at 85–95% HR_{max} interspersed with 3 min active rest) among young females with obesity (Bouri et al., 2015). It appears that undercarboxylated osteocalcin is a biologically more active form related to energy expenditure, and therefore it should be considered to measure in addition to total osteocalcin (Lee et al., 2007). Accordingly, 8-week MICT exercise program showed a significant increase in undercarboxylated osteocalcin level in young males with obesity, whereas total osteocalcin levels showed downward trend (Kim et al., 2015). Additionally, the serum level of osteocalcin is significantly lower in subjects with obesity compared to lean peers (Oh et al., 2019; Pimentel et al., 2021; Reinehr & Roth, 2010). This finding is supported by the results from the current study, where a negative association between change in osteocalcin and change in BMI values was found in the SIT group. Similar association was observed in previous studies (Jürimäe et al., 2015; Oh et al., 2019) – the lower the osteocalcin level, the higher BMI and FM (both for kg and %). The observed correlation between osteocalcin and BMI confirms the fact that osteocalcin affects fat metabolism (Kord-Varkaneh et al., 2017), and that this bone-derived hormone is involved not only in the bone formation process, but also plays a role in the fat amount already in puberty. Reduction of adiposity can positively influence bone metabolism by increasing osteocalcin levels as well as im-

proving body glucose homeostasis by better insulin secretion and sensitivity (Kord-Varkaneh et al., 2017).

Although the change in serum lipocalin-2 concentration between the groups was not significant, to our best knowledge, this is the first study investigating possible changes in this bone-derived marker among adolescent boys with obesity after specific SIT protocol. Nazari et al. (2020) found that a rope jump exercise protocol practiced for 8 weeks (3 days/week) among adolescent boys with obesity resulted in significant within-group decreases in body mass and BMI together with a decrease in serum lipocalin-2 levels. Results revealed a significant between-group difference in all aforementioned obesity characteristics but not in lipocalin-2 level between the rope jump and control groups. In our study, changes in body mass and BMI or lipocalin-2 levels in the SIT group did not reach the statistical significance level. Present study results are not in line with Nazari et al. (2020), and the reasons for the differences in the results of these two studies may be the personal variations of subjects, controlled or uncontrolled dietary intake, differences in training protocols or the magnitude of the change in different adiposity characteristics. Based on that, it can be hypothesized that a decrease in body mass and BMI after 12-week SIT program in the present study could have led to a significant decrease in lipocalin-2 levels in adolescent boys with obesity. A very interesting finding of our study was a significant correlation between change in BMI and change in lipocalin-2 in the SIT group. It has been shown that lipocalin-2 levels are higher in obese compared to lean individuals (Zaki et al., 2015), and that there lies a positive relationship between serum lipocalin-2 levels and the variables of obesity such as body mass and BMI (Takaya et al., 2021; Zaki et al., 2015), similarly to our study where the decrease in lipocalin-2 concentration was associated with a decrease in BMI in the SIT group. In individuals with excessive body FM, lipocalin-2 is an inflammatory marker produced by adipocytes and being so as a mediator for chronic low-grade inflammation, it subsequently disturbs insulin signaling and contributes to the development of IR (Moschen et al., 2017).

It is reported that cardio-type exercise training at an intensity of 85–90% HR_{max} with a frequency of three times per week with a minimum duration of 30 min performed at least 12 weeks decreases sclerostin levels in adults (Luziani et al., 2022). Serum sclerostin concentration is also positively associated with body fat values in children (Jürimäe et al., 2021). In the current study, sclerostin levels stayed unchanged together with no changes in body mass and BMI values in the SIT group. It has been found that the change of sclerostin depends on the training modality – running seems to have more positive impact on the concentration of sclerostin than cycling, done with the same amount of time and intensity, both in young males (Dror et al., 2022; Kouvelioti et al., 2019) and young females (Kouvelioti et al., 2018). Nevertheless, results concerning the effect of exercise training, especially specific high-intensity interval training among young population, are still incomplete (Luziani et al., 2022). In addition to osteocalcin and lipocalin-2, serum sclerostin levels are also correlated with fasting glucose, IR and with several inflammatory and metabolic conditions

among youth with obesity (D'Onofrio et al., 2020; Kim et al., 2021). Therefore, it is crucial to continue to search for such associations between osteokines and other indices of adiposity, not just BMI, as it may abate CVD risk factors and obesity-related metabolic disorders in adolescents with obesity.

It is reported that children with obesity due to their greater mechanical load on bones have a significantly higher bone mass compared to lean peers as estimated by BMD and BMC (Fintini et al., 2020). Current study results confirm it, as the increase in WB BMC was seen in both obese groups after the study period. Secondly, it is known that exercise training during adolescence has an anabolic effect on bone tissue and therefore increases BMD and BMC during teenage years (Fintini et al., 2020). The increase in LL BMD, as seen in the SIT group but not in the CONT group after the 12-week period in this study, affirms the positive effect of exercise training on bone tissue. These findings are in line with a study among adolescent girls and boys with obesity, where 16-weeks of 30 s of cycling sprints at 75–90% VO_2peak interspersed with 30 s active rest improved BMD and BMC in the whole body, lumbar spine and the hip region (Julian et al., 2020). Klentrou & Kouvelioti (2020) suggested that the response of bone turnover to training is heavily reliant on the exercise mode, duration and intensity, along with the maturity and the gender of participants. Although excessive body mass, particularly in youth, may compromise the skeleton by hormonal regulation pathways (Pimentel et al., 2021), SIT done as cycling sprints may contribute to higher LL BMD as seen in the current study. One of the obesity-related morbidities is different musculoskeletal disorders (Tremmel et al., 2017). The major benefit of implementing cycling SIT among obese populations is the reduction of increased mechanical stress on the body during joint movements. Therefore, currently used SIT protocol can be an effective training modality for improving overall bone health among obese adolescents without straining the joints, and therefore, may have a crucial role not only in the prevention of CVD risk but also osteoporotic-related fractures in later life (Klentrou & Kouvelioti, 2020).

6.4. Limitations

This investigation has some limitations that need to be addressed. Initially, a relatively small sample size can be considered as a limitation of the study, which may have influenced the statistical power to discover the differences between the groups and also could limit generalizability. However, our number of subjects is consistent with similar studies (Koubaa, 2013; Lee et al., 2017b; Meng et al., 2022; Racil et al., 2013; Starkoff et al., 2014). Unfortunately, as post-intervention dietary and total PA data were insufficiently reported by the participants, these data were excluded from the final analysis, and therefore, it limited the analysis concerning dairy product intake and its associations with circulating levels of adipokines and osteokines. Additionally, the participants did not receive any nutritional counselling, nor did they have a caloric

restriction during the study period. It has been shown that diet intervention or nutritional education during the training period plays an important role in regulating osteokine values (Josse et al., 2020) and thus, produces better results in body mass regulation and in other cardiometabolic risk factors (Julian et al., 2020) in individuals with obesity. Another potential constraining factor of the study results was the measurement of total osteocalcin, and not undercarboxylated form of osteocalcin. The latter is a more biologically active form related to energy expenditure (Lee et al., 2007).

7. CONCLUSIONS

Based on the findings of the 12-week supervised all-out sprint interval training it can be concluded that:

1. sprint interval training reduced body fat percentage and improved cardio-respiratory fitness in adolescent boys with obesity;
2. sprint interval training improved metabolic syndrome severity risk z-score in adolescent boys with obesity;
3. sprint interval training increased lower limbs region bone mineral density in adolescent boys with obesity.

8. REFERENCES

Alahmadi, M. (2014). High-intensity interval training and obesity. *Journal of Novel Fysiotherapy*, 4(3), 211. http://dx.doi.org/10.4172/2165-7025.1000211

Allison, M. K., Baglole, J. H., Martin, B. J., MacInnis, M. J., Gurd, B. J., & Gibala, M. J. (2017). Brief intense stair climbing improves cardiorespiratory fitness. *Medicine & Science in Sports & Exercise*, *49*(2), 298–307. https://doi.org/10.1249/MSS.0000000000001188

Amrein, K., Amrein, S., Drexler, C., Dimai, H. P., Dobnig, H., Pfeifer, K., … Fahrleitner-Pammer, A. (2012). Sclerostin and its Association with physical activity, age, gender, body composition, and bone mineral content in healthy adults. *The Journal of Clinical Endocrinology & Metabolism*, *97*(1), 148–154. https://doi.org/10.1210/jc.2011-2152

Andersen, L. B., Sardinha, L., Froberg, K., Riddoch, C. J., Page, A. S,, & Anderssen, S. A. (2008). Fitness, adiposity and clustering of cardiovascular risk factors in children from Denmark, Estonia and Portugal: The European Youth Heart Study. *International Journal of Pediatric Obesity*, 3, 58–66. https://doi.org/10.1080/17477160801896366

Arboleda Serna, V. H., Arango Vélez, E. F., Gómez Arias, R. D., & Feito, Y. (2016). Effects of a high-intensity interval training program versus a moderate-intensity continuous training program on maximal oxygen uptake and blood pressure in healthy adults: study protocol for a randomized controlled trial. *Trials*, *17*(1), 1–7. https://doi.org/10.1186/s13063-016-1522-y

Ardawi, M.-S. M., Rouzi, A. A., & Qari, M. H. (2012). Physical activity in relation to serum sclerostin, insulin-like growth factor-1, and bone turnover markers in healthy premenopausal women: a cross-sectional and a longitudinal study. *The Journal of Clinical Endocrinology & Metabolism*, *97*(10), 3691–3699. https://doi.org/10.1210/jc.2011-3361

Ardoy, D. N., Artero, E. G., Ruiz, J. R., Labayen, I., Sjöström, M., Castillo, M. J., & Ortega, F. B. (2013). Effects on adolescents' lipid profile of a fitness-enhancing intervention in the school setting; the EDUFIT study. *Nutricion Hospitalaria*, *28*(1), 119–126. https://doi.org/10.3305/nh.2013.28.1.6146

Argente, J., Barrios, V., Chowen, J. A., Sinha, M. K., & Considine, R. V. (1997). Leptin plasma levels in healthy Spanish children and adolescents, children with obesity, and adolescents with anorexia nervosa and bulimia nervosa. *The Journal of Pediatrics*, *131*(6), 833–838. https://doi.org/10.1016/S0022-3476(97)70029-5

Armstrong, N., & Welsman, J. (2020). Multilevel allometric modelling of maximum cardiac output, maximum arteriovenous oxygen difference, and peak oxygen uptake in 11–13-year-olds. *European Journal of Applied Physiology*, *120*(2), 527–537. https://doi.org/10.1007/s00421-020-04300-0

Astorino, T. A., Allen, R. P., Roberson, D. W., & Jurancich, M. (2012). Effect of high-intensity interval training on cardiovascular function, V̇o2max, and muscular force. *Journal of Strength and Conditioning Research*, *26*(1), 138–145. https://doi.org/10.1519/JSC.0b013e318218dd77

Atashak, S., Stannard, S. R., Daraei, A., Soltani, M., Saeidi, A., Moradi, F., … Zouhal, H. (2022). High-intensity interval training improves lipocalin-2 and omentin-1 levels in men with obesity. *International Journal of Sports Medicine*, *43*(4), 328–335. https://doi.org/10.1055/a-1560-5401

Ayer, J., Charakida, M., Deanfield, J. E., & Celermajer, D. S. (2015). Lifetime risk: childhood obesity and cardiovascular risk. *European Heart Journal*, *36*(22), 1371–1376. https://doi.org/10.1093/eurheartj/ehv089

Bass, R., & Eneli, I. (2015). Severe childhood obesity: an under-recognised and growing health problem. *Postgraduate Medical Journal*, *91*(1081), 639–645. https://doi.org/10.1136/postgradmedj-2014-133033

Bass, S., Delmas, P. D., Pearce, G., Hendrich, E., Tabensky, A., & Seeman, E. (1999). The differing tempo of growth in bone size, mass, and density in girls is region-specific. *Journal of Clinical Investigation*, *104*(6), 795–804. https://doi.org/10.1172/JCI7060

Batacan, R. B., Duncan, M. J., Dalbo, V. J., Tucker, P. S., & Fenning, A. S. (2017). Effects of high-intensity interval training on cardiometabolic health: a systematic review and meta-analysis of intervention studies. *British Journal of Sports Medicine*, *51*(6), 494–503. https://doi.org/10.1136/bjsports-2015-095841

Berenson, G. S. (2009). Cardiovascular risk begins in childhood. A time for action. *American Journal of Preventive Medicine*, *37*(1 SUPPL.), S1–S2. https://doi.org/10.1016/j.amepre.2009.04.018

Berndtsson, G., Mattsson, E., Marcus, C., & Larsson, U. E. (2007). Age and gender differences in VO_2max in Swedish obese children and adolescents. *Acta Paediatrica*, 96, 567-571. https://doi.org/10.1111/j.1651-2227.2007.00139.x

Biddle, S. J. H., Atkin, A. J., Cavill, N., & Foster, C. (2011). Correlates of physical activity in youth: a review of quantitative systematic reviews. *International Review of Sport and Exercise Psychology*, *4*(1), 25–49. https://doi.org/10.1080/1750984X.2010.548528

Blackburn, G. (1995). Effect of degree of weight loss on health benefits. *Obesity Research*, *3*(S2), 211s-216s. https://doi.org/10.1002/j.1550-8528.1995.tb00466.x

Blais, S., Berbaru, J., Council, FB., & Dallaire, F. (2015). A systematic review of reference values in pediatric cardiopulmonary exercise testing. *Pediatric Cardiology*, 36(8), 1553-1564. http://doi.org/10.1007/s00246-015-1205-6

Blüher, S., Käpplinger, J., Herget, S., Reichardt, S., Böttcher, Y., Grimm, A., … Petroff, D. (2017). Cardiometabolic risk markers, adipocyte fatty acid binding protein (aFABP) and the impact of high-intensity interval training (HIIT) in obese adolescents. *Metabolism: Clinical and Experimental*, *68*, 77–87. https://doi.org/10. 1016/j.metabol.2016.11.015

Bonthius, M., van Stralen, K. J., Verrina, E., Edefonti, A., Molchanova, E. A., Hokken-Koelega, A. C. S. ... Jager, K. J. (2012). Use of national and international growth charts for studying height in European children: development of up-to-date European height-for-age charts. PLoS ONE, 7(8), e42506. https://dx.plos.org/10.1371/journal.pone.0042506

Boroujerdi, S. S., Rahimi, R., & Noori, S. R. (2009). Optimal cadence selection during cycling. *International SportMed Journal*, *10*(2), 95–100. Retrieved from https://hdl.handle.net/10520/EJC48370

Bouri, Z. S., Peeri, M., Azarbayjani, M., & Ahangarpour, A. (2015). The effect of physical activity on adiponectin and osteocalcin in overweight young females. *International Medical Journal*, *22*(1), 43–46. Retrieved from http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L607228049

Boutcher, S. (2011). High-intensity intermittent exercise and fat loss. *Journal of Obesity*, 2011, 1–11. https://doi.org/10.1155/2011/868305

Buchheit, M., & Laursen, P. B. (2013). High-intensity interval training, solutions to the programming puzzle. *Sports Medicine*, *43*(5), 313–338. https://doi.org/10.1007/s40279-013-0029-x

Burgomaster, K. A., Howarth, K. R., Phillips, S. M., Rakobowchuk, M., MacDonald, M. J., McGee, S. L., & Gibala, M. J. (2008). Similar metabolic adaptations during exercise after low volume sprint interval and traditional endurance training in humans. *The Journal of Physiology*, *586*(1), 151–160. https://doi.org/10.1113/jphysiol.2007.142109

Burgomaster, K. A., Hughes, S. C., Heigenhauser, G. J. F., Bradwell, S. N., & Gibala, M. J. (2005). Six sessions of sprint interval training increases muscle oxidative potential and cycle endurance capacity in humans. *Journal of Applied Physiology*, *98*(6), 1985–1990. https://doi.org/10.1152/japplphysiol.01095.2004

Busnatu, S. S., Serbanoiu, L. I., Lacraru, A. E., Andrei, C. L., Jercalau, C. E., Stoian, M., & Stoian, A. (2022). Effects of exercise in improving cardiometabolic risk factors in overweight children: a systematic review and meta-analysis. *Healthcare*, *10*(1), 82. https://doi.org/10.3390/healthcare10010082

Cao, M., Quan, M., & Zhuang, J. (2019). Effect of high-intensity interval training versus moderate-intensity continuous training on cardiorespiratory fitness in children and adolescents: a meta-analysis. *International Journal of Environmental Research and Public Health*, *16*(9), 1533. https://doi.org/10.3390/ijerph16091533

Choi, K. M., Kim, T. N., Yoo, H. J., Lee, K. W., Cho, G. J., Hwang, T. G., … Kim, S. M. (2009). Effect of exercise training on A-FABP, lipocalin-2 and RBP4 levels in obese women. *Clinical Endocrinology*, *70*(4), 569–574. https://doi.org/10.1111/j.1365-2265.2008.03374.x

Ciolac, E. G., Bocchi, E. A., Greve, J. M. D., & Guimarães, G. V. (2011). Heart rate response to exercise and cardiorespiratory fitness of young women at high familial risk for hypertension: effects of interval vs continuous training. *European Journal of Cardiovascular Prevention & Rehabilitation*, *18*(6), 824–830. https://doi.org/10.1177/1741826711398426

Cole, T. J., Bellizzi, M. C., Flegal, K. M., Dietz, W. H. (2000). Establishing a standard definition for child overweight and obesity worldwide: international survey. *MBJ*, 320 (7244), 1240-1240. https://doi.org/10.1136/bmj.320.7244.1240

Cooper, D., Weiler-Ravell, D., Whipp, B. J., & Wasserman, K. (1984). Aerobic parameters of exercise as a function of body size during growth in children. *Journal of Applied Physiology*, 56(3), 628-634. https://doi.org/10.1152/jappl.1984.56.3.628

Corte de Araujo, A. C., Roschel, H., Picanço, A. R., do Prado, D. M. L., Villares, S. M. F., de Sá Pinto, A. L., & Gualano, B. (2012). Similar health benefits of endurance and high-intensity interval training in obese children. *PLoS ONE*, *7*(8), e42747. https://doi.org/10.1371/journal.pone.0042747

Costigan, S. A., Eather, N., Plotnikoff, R. C., Taaffe, D. R., & Lubans, D. R. (2015). High-intensity interval training for improving health-related fitness in adolescents: a systematic review and meta-analysis. *British Journal of Sports Medicine*, *49*(19), 1253–1261. https://doi.org/10.1136/bjsports-2014-094490

Cvetković, N., Stojanović, E., Stojiljković, N., Nikolić, D., Scanlan, A. T., & Milanović, Z. (2018). Exercise training in overweight and obese children: Recreational football and high-intensity interval training provide similar benefits to physical fitness. *Scandinavian Journal of Medicine & Science in Sports*, *28*(July), 18–32. https://doi.org/10.1111/sms.13241

D'Onofrio, L., Maddaloni, E., & Buzzetti, R. (2020). Osteocalcin and sclerostin: background characters or main actors in cardiovascular disease? *Diabetes/Metabolism Research and Reviews*, *36*(1), 10–12. https://doi.org/10.1002/dmrr.3217

Dai, S., Fulton, J. E., Harrist, R. B., Grunbaum, J. A., Steffen, L. M., & Labarthe, D. R. (2009). Blood lipids in children: age-related patterns and association with body-fat indices. Project HeartBeat! *American Journal of Preventive Medicine*, *37*(1 SUPPL.), S56–S64. https://doi.org/10.1016/j.amepre.2009.04.012

Davis, J. (2006). *Direct determination of aerobic power. In: Physiological assessment of human fitness.* (P. Maud & C. Foster, Eds.) (2nd editio). Human Kinetics. Retrieved from https://books.google.ee/books?hl=en&lr=&id=rtTokQPt9rIC&oi=fnd&pg=PA1&dq=Physiological+assessment+of+human+fitness.&ots=j4lE1UaFTn&sig=zujyiJKXc3wHZHXypdQ4uyGwsIA&redir_esc=y#v=onepage&q=Physiological assessment of human fitness.&f=false

DeBoer, M. D., & Gurka, M. J. (2017). Clinical utility of metabolic syndrome severity scores: considerations for practitioners. *Diabetes, Metabolic Syndrome and Obesity: Targets and Therapy*, *Volume 10*, 65–72. https://doi.org/10.2147/DMSO.S101624

DeBoer, M. D., Gurka, M. J., Woo, J. G., & Morrison, J. A. (2015a). Severity of metabolic syndrome as a predictor of cardiovascular disease between childhood and adulthood: the Princeton Lipid Research cohort study. *Journal of the American College of Cardiology*, *66*(6), 755–757. https://doi.org/10.1016/j.jacc.2015.05.061

DeBoer, M. D., Gurka, M. J., Woo, J. G., & Morrison, J. A. (2015b). Severity of the metabolic syndrome as a predictor of type 2 diabetes between childhood and adulthood: the Princeton Lipid Research Cohort Study. *Diabetologia*, *58*(12), 2745–2752. https://doi.org/10.1007/s00125-015-3759-5

Dias, K. A., Ingul, C. B., Tjønna, A. E., Keating, S. E., Gomersall, S. R., Follestad, T., … Coombes, J. S. (2018). Effect of high-intensity interval training on fitness, fat mass and cardiometabolic biomarkers in children with obesity: A Randomised Controlled Trial. *Sports Medicine*, *48*(3), 733–746. https://doi.org/10.1007/s40279-017-0777-0

Dror, N., Carbone, J., Haddad, F., Falk, B., Klentrou, P., & Radom-Aizik, S. (2022). Sclerostin and bone turnover markers response to cycling and running at the same moderate-to-vigorous exercise intensity in healthy men. *Journal of Endocrinological Investigation*, *45*(2), 391–397. https://doi.org/10.1007/s40618-021-01659-5

Dumith, S. C., Gigante, D. P., Domingues, M. R., & Kohl, H. W. (2011). Physical activity change during adolescence: a systematic review and a pooled analysis. *International Journal of Epidemiology*, *40*(3), 685–698. https://doi.org/10.1093/ije/dyq272

Eddolls, W. T. B., McNarry, M. A., Stratton, G., Winn, C. O. N., & Mackintosh, K. A. (2017). High-intensity interval training interventions in children and adolescents: a systematic review. *Sports Medicine*, *47*(11), 2363–2374. https://doi.org/10.1007/s40279-017-0753-8

El Hage, R., Moussa, E., & Jacob, C. (2010). Bone mineral content and density in obese, overweight, and normal-weighted sedentary adolescent girls. *Journal of Adolescent Health*, 47(6), 591–595. https://pubmed.ncbi.nlm.nih.gov/21094436/

Farah, B. Q., Ritti-Dias, R. M., Balagopal, P. B., Hill, J. O., & Prado, W. L. (2014). Does exercise intensity affect blood pressure and heart rate in obese adolescents? A 6-month multidisciplinary randomized intervention study. *Pediatricic Obesity*, *9*(2), 111–120. https://doi.org/10.1111/j.2047-6310.2012.00145.x

Fehr, C. M., McEwen, G., & Robinson, C. (2022). The effects of "Physical BEMER ® Vascular Therapy" on work performed during repeated wingate sprints. *Research Quarterly for Exercise and Sport*, *00*(00), 1–6. https://doi.org/10.1080/02701367.2022.2053040

Fintini, D., Brufani, C., Grossi, A., Ubertini, G., Fiori, R., Pecorelli, L. ... Cappa, M. (2011). Gender differences in bone mineral density in obese children during pubertal development. J*ournal of Endocrinological Investigation*, 34(4), e86-91. https://pubmed.ncbi.nlm.nih.gov/20855933/

Fintini, D., Cianfarani, S., Cofini, M., Andreoletti, A., Ubertini, G. M., Cappa, M., & Manco, M. (2020). The bones of children with obesity. *Frontiers in Endocrinology*, *11*(April), 1–16. https://doi.org/10.3389/fendo.2020.00200

Galic, S., Oakhill, J. S., & Steinberg, G. R. (2010). Adipose tissue as an endocrine organ. *Molecular and Cellular Endocrinology*, *316*(2), 129–139. https://doi.org/10.1016/j.mce.2009.08.018

García-Hermoso, A., Cerrillo-Urbina, A. J., Herrera-Valenzuela, T., Cristi-Montero, C., Saavedra, J. M., & Martínez-Vizcaíno, V. (2016). Is high-intensity interval training more effective on improving cardiometabolic risk and aerobic capacity than other forms of exercise in overweight and obese youth? A meta-analysis. *Obesity Reviews*, *17*(6), 531–540. https://doi.org/10.1111/obr.12395

Gibala, M. J. (2018). Interval training for cardiometabolic health: why such a HIIT? *Current Sports Medicine Reports*, *17*(5), 148–150. https://doi.org/10.1249/JSR.0000000000000483

Gibala, M. J., Gillen, J. B., & Percival, M. E. (2014). Physiological and health-related adaptations to low-volume interval training: influences of nutrition and sex. *Sports Medicine*, *44*(S2), 127–137. https://doi.org/10.1007/s40279-014-0259-6

Gibala, M. J., Little, J. P., Macdonald, M. J., & Hawley, J. A. (2012). Physiological adaptations to low-volume, high-intensity interval training in health and disease. *Journal of Physiology*, *590*(5), 1077–1084. https://doi.org/10.1113/jphysiol.2011.224725

Gillen, J. B., Martin, B. J., MacInnis, M. J., Skelly, L. E., Tarnopolsky, M. A., & Gibala, M. J. (2016). Twelve weeks of sprint interval training Iimproves indices of cardiometabolic health similar to traditional endurance training despite a five-fold lower exercise volume and time commitment. *PLOS ONE*, *11*(4), e0154075. https://doi.org/10.1371/journal.pone.0154075

Gist, N. H., Fedewa, M. V., Dishman, R. K., & Cureton, K. J. (2014). Sprint interval training effects on aerobic capacity: a systematic review and meta-analysis. *Sports Medicine*, *44*(2), 269–279. https://doi.org/10.1007/s40279-013-0115-0

Gonzalez-Gil, A. M., & Elizondo-Montemayor, L. (2020). The role of exercise in the interplay between myokines, hapatokines, osteokines, adipokines, and modulation of inflammation for energy subrstrate redistribution and fat mass loss: a review. *Nutrients*, 12, 1899. https://doi.org/10.3390/nu12061899

Grünberg, H., Adojaan, B., & Thetloff, M. (1998). *Kasvamine ja kasvuhäired: metoodiline juhend laste füüsilise arengu hindamiseks.* Tartu: Tartu Ülikool.

Gurka, M. J., Ice, C. L., Sun, S. S., & DeBoer, M. D. (2012). A confirmatory factor analysis of the metabolic syndrome in adolescents: an examination of sex and racial/ethnic differences. *Cardiovascular Diabetology*, 11(1), 128. https://doi.org/10.1186/1475-2840-11-128

Gutin, B., Howe, C. A., Johnson, M. H., Humphries, M. C., Snieder, H., & Barbeau, P. (2005). Heart rate variability in adolescents: relations to physical activity, fitness,

and adiposity. *Medicine & Science in Sports & Exercise*, *37*(11), 1856–1863. https://doi.org/10.1249/01.mss.0000175867.98628.27

Hejazi, K., & Ferrari, F. (2022). Effects of physical exercise on cardiometabolic biomarkers and inflammatory markers in children: a systematic review and meta-analysis of randomized controlled trials. *Biological Research For Nursing*, *24*(4), 519–529. https://doi.org/10.1177/10998004221099573

Higgins, S., Fedewa, M. V., Hathaway, E. D., Schmidt, M. D., & Evans, E. M. (2016). Sprint interval and moderate-intensity cycling training differentially affect adiposity and aerobic capacity in overweight young-adult women. *Applied Physiology, Nutrition, and Metabolism*, *41*(11), 1177–1183. https://doi.org/10.1139/apnm-2016-0240

Hills, A., King, N., & Byrne, N. (2007). *Children, Obesity and Exercise. A practical approach to prevention, treatment and management of childhood adolescent obesity.* New York: Routledge.

Hinton, P. S., Nigh, P., & Thyfault, J. (2017). Serum sclerostin decreases following 12months of resistance- or jump-training in men with low bone mass. *Bone*, *96*, 85–90. https://doi.org/10.1016/j.bone.2016.10.011

Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports and Exercise*, *41*(1), 3–12. https://doi.org/10.1249/MSS.0b013e31818cb278

Hou, J., He, C., He, W., Yang, M., Luo, X., & Li, C. (2020). Obesity and bone health: a complex link. *Frontiers in Cell and Development Biology*, 8(12), 1–16. https://www.frontiersin.org/articles/10.3389/fcell.2020.600181/full

IDF, The IDF consensus worldwide definition of the metabolic syndrome. Journal American Medical Association; 2005

Ingul, C. B., Dias, K. A., Tjonna, A. E., Follestad, T., Hosseini, M. S., Timilsina, A. S., … Coombes, J. S. (2018). Effect of high intensity interval training on cardiac function in children with obesity: a randomised controlled trial. *Progress in Cardiovascular Diseases*, *61*(2), 214–221. https://doi.org/10.1016/j.pcad.2018. 01.012

Ingul, C. B., Tjonna, A. E., Stolen, T. O., Stoylen, A., & Wisloff, U. (2010). Impaired cardiac function among obese adolescents. *Archives of Pediatrics & Adolescent Medicine*, *164*(9), 852–859. https://doi.org/10.1001/archpediatrics.2010.158

Johansson, L., Brissman, M., Morinder, G., Westerståhl, M., & Marcus, C. (2020). Reference values and secular trends for cardiorespiratory fitness in children and adolescents with obesity. *Acta Paediatrica*, 109(8); 1665-1671. https://doi.org/10.1111/apa.15163

Josse, A. R., Ludwa, I. A., Kouvelioti, R., Calleja, M., Falk, B., Ward, W. E., & Klentrou, P. (2020). Dairy product intake decreases bone resorption following a 12-week diet and exercise intervention in overweight and obese adolescent girls. *Pediatric Research*, *88*(6), 910–916. https://doi.org/10.1038/s41390-020-0834-5

Julian, V., Thivel, D., Miguet, M., Brengues, C., Pereira, B., Courteix, D., … Duclos, M. (2020). Bone response to eccentric versus concentric cycling in adolescents with obesity. *Obesity Research & Clinical Practice*, *14*(6), 554–560. https://doi.org/10.1016/j.orcp.2020.10.002

Jürimäe, J., Karvelyte, V., Remmel, L., Tamm, A.-L., Purge, P., Gruodyte-Raciene, R., … Tillmann, V. (2021). Serum sclerostin concentration is associated with specific adipose, muscle and bone tissue markers in lean adolescent females with increased physical activity. *Journal of Pediatric Endocrinology and Metabolism*, *34*(6), 755–761. https://doi.org/10.1515/jpem-2020-0662

Jürimaë, J., Lätt, E., Maëstu, J., Saar, M., Purge, P., Maasalu, K., & Jürimaë, T. (2015). Osteocalcin is inversely associated with adiposity and leptin in adolescent boys. *Journal of Pediatric Endocrinology and Metabolism*, *28*(5–6), 571–577. https://doi.org/10.1515/jpem-2014-0432

Kabasakalis, A., Nikolaidis, S., Tsalis, G., & Mougios, V. (2020). Response of blood biomarkers to sprint interval swimming. *International Journal of Sports Physiology and Performance*, *15*(10), 1442–1447. https://doi.org/10.1123/ijspp.2019-0747

Kansra, A. R., Lakkunarajah, S., & Jay, M. S. (2021). Childhood and adolescent obesity: a review. *Frontiers in Pediatrics*, *8*(January), 1–16. https://doi.org/10.3389/fped.2020.581461

Kaspar, F., Jelinek, H. F., Perkins, S., Al-Aubaidy, H. A., Dejong, B., & Butkowski, E. (2016). Acute-phase inflammatory response to single-bout HIIT and endurance training: a comparative study. *Mediators of Inflammation*, *2016*. https://doi.org/10.1155/2016/5474837

Kavey, RE., Daniels, S. R., Lauer, R. M., Atkins, D. L., Hayman, L. L., & Taubert, K. (2003). American Heart Association guidelines for primary prevention for atherosclerotic cardiovascular disease beginning in childhood. *Circulation*, 107(11), 1562–1566. https://www.ahajournals.org/doi/10.1161/01.CIR.0000061521.15730.6E

Keating, S. E., Johnson, N. A., Mielke, G. I., & Coombes, J. S. (2017). A systematic review and meta-analysis of interval training versus moderate-intensity continuous training on body adiposity. *Obesity Reviews*, *18*(8), 943–964. https://doi.org/10.1111/obr.12536

Kelly, A. S., Barlow, S. E., Rao, G., Inge, T. H., Hayman, L. L., Steinberger, J., … Daniels, S. R. (2013). Severe obesity in children and adolescents: Identification, associated health risks, and treatment approaches: A scientific statement from the American Heart Association. *Circulation*, *128*(15), 1689–1712. https://doi.org/10.1161/CIR.0b013e3182a5cfb3

Kessler J, Koebnick C, Smith N, & Adams A. (2013). Childhood obesity is associated with increased risk of most lower extremity fractures. *Clinical Orthopaedics and Related Research*, 471:1199–207. doi: 10.1007/s11999-012-2621-z

Kim, S.-H., Choi, Y. J., Ahn, M. B., Cho, W. K., Cho, K. S., Jung, M. H., & Suh, B.-K. (2021). Associations between cclerostin and anthropometric and metabolic parameters in children and adolescents. *Children*, *8*(9), 788. https://doi.org/10. 3390/children8090788

Kim, Y.-S., Nam, J. S., Yeo, D.-W., Kim, K. R., Suh, S.-H., & Ahn, C. W. (2015). The effects of aerobic exercise training on serum osteocalcin, adipocytokines and insulin resistance on obese young males. *Clinical Endocrinology*, *82*(5), 686–694. https://doi.org/10.1111/cen.12601

King, D. E., Carek, P., Mainous, A. G., & Pearson, W. S. (2003). Inflammatory markers and exercise: differences related to exercise type. *Medicine & Science in Sports & Exercise*, *35*(4), 575–581. https://doi.org/10.1249/01.MSS.0000058440.28108.CC

Kirk, B., Feehan, J., Lombardi, G., & Duque, G. (2020). Muscle, bone, and fat crosstalk: the biological role of myokines, osteokines, and adipokines. *Current Osteoporosis Reports*, *18*(4), 388–400. https://doi.org/10.1007/s11914-020-00599-y

Kirk, R. E. (1996). Practical significance: a concept whose time has come. *Educational and Psychological Measurement*, *56*(5), 746–759. https://doi.org/10.1177/0013164496056005002

Klentrou, P., & Kouvelioti, R. (2020). Biochemistry of exercise training: effects on bone. In *The Routledge Handbook on Biochemistry of Exercise* (pp. 513–531). Routledge. https://doi.org/10.4324/9781003123835-32

Kong, Z., Fan, X., Sun, S., Song, L., Shi, Q., & Nie, J. (2016a). Comparison of high-intensity interval training and moderate-to-vigorous continuous training for cardio-metabolic health and exercise enjoyment in obese young women: A randomized controlled trial. *PLOS ONE*, *11*(7), e0158589. https://doi.org/10.1371/ journal.pone. 0158589

Kong, Z., Sun, S., Liu, M., & Shi, Q. (2016b). Short-term high-intensity interval training on body composition and blood glucose in overweight and obese young women. *Journal of Diabetes Research*, 2016, 1–9. https://doi.org/10.1155/ 2016/ 4073618

Kord-Varkaneh, H., Djafarian, K., khorshidi, M., & Shab-Bidar, S. (2017). Association between serum osteocalcin and body mass index: a systematic review and meta-analysis. *Endocrine*, *58*(1), 24–32. https://doi.org/10.1007/s12020-017-1384-4

Kostovski, M., Simeonovski, V., Mironska, K., Tasic, V., & Gucev, Z. (2018). Metabolic profiles in obese children and adolescents with insulin resistance. *Open Access Macedonian Journal of Medical Sciences*, *6*(3), 511–518. https://doi.org/10.3889/ oamjms.2018.097

Koubaa, A. (2013). Effect of intermittent and continuous training on body composition cardiorespiratory fitness and lipid profile in obese adolescents. *IOSR Journal of Pharmacy (IOSRPHR)*, *3*(2), 31–37. https://doi.org/10.9790/3013-32103137

Kouvelioti, R., Kurgan, N., Falk, B., Ward, W. E., Josse, A. R., & Klentrou, P. (2018). Response of sclerostin and bone turnover markers to high intensity interval exercise in young women: Does impact matter? *BioMed Research International*, *2018*, 1–8. https://doi.org/10.1155/2018/4864952

Kouvelioti, R., LeBlanc, P., Falk, B., Ward, W. E., Josse, A. R., & Klentrou, P. (2019). Effects of high-intensity interval running versus cycling on sclerostin, and markers of bone turnover and oxidative stress in young men. *Calcified Tissue International*, *104*(6), 582–590. https://doi.org/10.1007/s00223-019-00524-1

Kurgan, N., Islam, H., Matusiak, J. B. L., Baranowski, B. J., Stoikos, J., Fajardo, V. A., … Klentrou, P. (2022). Subcutaneous adipose tissue sclerostin is reduced and Wnt signaling is enhanced following 4-weeks of sprint interval training in young men with obesity. *Physiological Reports*, *10*(6), 1–14. https://doi.org/10.14814/phy2. 15232

Kurgan, N., McKee, K., Calleja, M., Josse, A. R., & Klentrou, P. (2020). Cytokines, adipokines, and bone markers at rest and in response to plyometric exercise in obese vs normal weight adolescent females. *Frontiers in Endocrinology*, *11*(December). https://doi.org/10.3389/fendo.2020.531926

Kurtoglu, S., Hatipoglu, N., Mazcoglu, M., Kendirci, M., Keskin, M., & Kondolot, M. (2010). Insulin resistance in obese children and adolescents: HOMA-IR cut-off levels in the prepubertal and pubertal periods. *JCRPE Journal of Clinical Research in Pediatric Endocrinology*, *2*(3), 100–106. https://doi.org/10.4274/jcrpe.v2i3.100

Kwak, S. K., & Kim, J. H. (2017). Statistical data preparation: management of missing values and outliers. *Korean Journal of Anesthesiology*, *70*(4), 407. https://doi.org/ 10.4097/kjae.2017.70.4.407

Léger, L. A., Mercier, D., Gadoury, C., & Lambert, J. (1988). The multistage 20 metre shuttle run test for aerobic fitness. *Journal of Sports Science*, 6(2), 93–101. https://doi.org/10.1080/02640418808729800

Levy-Marchal, C., Arslanian, S., Cutfield, W., Sinaiko, A., Druet, C., Marcovecchio, M. L., Chiarelli, F. (2010), Insulin resistance in children: consensus, perspective, and future directions. *Journal of Clinical Endocrinology and Metabolism*, 95(12), 5189-5198. https://academic.oup.com/jcem/article-lookup/doi/10.1210/jc.2010-1047

Lazcano-Ponce, E., Tamayo, J., Cruz-Valdez, A., Díaz, R., Hernández, B., Del Cueto, R., & Hernández-Avila, M. (2003). Peak bone mineral area density and determinants among females aged 9 to 24 years in Mexico. *Osteoporosis International*, *14*(7), 539–547. https://doi.org/10.1007/s00198-002-1363-2

Lazzer, S., Tringali, G., Caccavale, M., De Micheli, R., Abbruzzese, L., & Sartorio, A. (2017). Effects of high-intensity interval training on physical capacities and substrate oxidation rate in obese adolescents. *Journal of Endocrinological Investigation*, *40*(2), 217–226. https://doi.org/10.1007/s40618-016-0551-4

Lee, N. K., Sowa, H., Hinoi, E., Ferron, M., Ahn, J. D., Confavreux, C., … Karsenty, G. (2007). Endocrine regulation of energy metabolism by the skeleton. *Cell*, *130*(3), 456–469. https://doi.org/10.1016/j.cell.2007.05.047

Lee, A. M., Gurka, M. J., Deboer, M. D., States, U., & States, U. (2016). A MetS severity score to estimate risk in adolescents and adults: current evidence and future potential. *Expert Reivion Cardiovascular Therapy*, *14*(4), 411–413. https://doi.org/10.1586/14779072.2016.1143360.A

Lee, A. M., Gurka, M. J., & Deboer, M. D. (2017a). Correlation of metabolic syndrome severity with cardiovascular health markers in adolescents. *Metabolism*, *69*, 87–95. https://doi.org/10.1016/j.metabol.2017.01.008.Correlation

Lee, S. J., Spector, J., & Reilly, S. (2017b). High-intensity interval training programme for obese youth (HIP4YOUTH): a pilot feasibility study. *Journal of Sports Sciences*, *35*(18), 1794–1798. https://doi.org/10.1080/02640414.2016.1237671

Lelis, D. de F., Freitas, D. F. de, Machado, A. S., Crespo, T. S., & Santos, S. H. S. (2019). Angiotensin-(1-7), adipokines and inflammation. *Metabolism: Clinical and Experimental*, *95*, 36–45. https://doi.org/10.1016/j.metabol.2019.03.006

Liu, X., Hamnvik, O-P. R., Petrou, M., Gong, H., Chamberland, J. P., Christophi, C. A. ... Mantzoros, C. S. (2011). Circulating lipocalin 2 is associated with body fat distribution at baseline but is not an independent predictor of insulin resistance: the prospective Cyprus Metabolism Study. *European Journal of Endocrinology*, 165(5), 805-812. https://doi.org/ 10.1530/EJE-11-0660

Logan, G. R. M., Harris, N., Duncan, S., & Schofield, G. (2014). A review of adolescent high-intensity interval training. *Sports Medicine*, *44*(8), 1071–1085. https://doi.org/10.1007/s40279-014-0187-5

Luziani, S., Candy, H., Angraini, R., Darma, P., Juniari, S., Juhanna, I. V., & Adiatmika, I. P. G. (2022). Effect of exercise on sclerostin concentrationsin blood serum. *Sport and Fitness Journal*, *10*(2), 138–147. Retrieved from https://www.xjournals.com/collections/articles/Article?qt=7PzIpVggCvea+kXIRpdER/MOtBEV9VfYCteFUQjiP38s6cyUPICJRTVTu8psK1Zl

Lätt, Evelin, Mäestu, J., Ortega, F. B., Rääsk, T., Jürimäe, T., & Jürimäe, J. (2015). Vigorous physical activity rather than sedentary behaviour predicts overweight and obesity in pubertal boys: A 2-year follow-up study. *Scandinavian Journal of Public Health*, *43*(3), 276–282. https://doi.org/10.1177/1403494815569867

Lätt, E., Mäestu, J., Rääsk, T., Jürimäe, T., & Jürimäe, J. (2016). Cardiovascular fitness, physical activity, and metabolic syndrome risk factors among adolescent estonian boys: A longitudinal study. *American Journal of Human Biology*, *28*(6), 782–788. https://doi.org/10.1002/ajhb.22866

Lätt, E., Jürimäe, J., Harro, J., Loit, H. M., & Mäestu, J. (2018). Low fitness is associated with metabolic risk independently of central adiposity in a cohort of 18-year-olds. *Scandinavian Journal of Medicine and Science in Sports*, *28*(3), 1084–1091. https://doi.org/10.1111/sms.13002

Mancuso, P. (2016). The role of adipokines in chronic inflammation. *ImmunoTargets and Therapy*, *5*, 47. https://doi.org/10.2147/ITT.S73223

Martin-Smith, R., Cox, A., Buchan, D. S., Baker, J. S., Grace, F., & Sculthorpe, N. (2020). High intensity interval training (HIIT) improves cardiorespiratory fitness (CRF) in healthy, overweight and obese adolescents: a systematic review and meta-analysis of controlled studies. *International Journal of Environmental Research and Public Health*, *17*(8), 2955. https://doi.org/10.3390/ijerph17082955

Matthews, D. R., Hosker, J. P., Rudenski, A. S., Naylor, B. A., Treacher, D. F., Turner, R. C. (1985). Homeostasis model assessment: insulin resistance and beta-cell function from fasting plasma glucose and insulin concentrations in man. *Diabetologia*, 28, 412-419. https://doi.org/10.1007/BF00280883

Meng, C., Yucheng, T., Shu, L., & Yu, Z. (2022). Effects of school-based high-intensity interval training on body composition, cardiorespiratory fitness and cardiometabolic markers in adolescent boys with obesity: a randomized controlled trial. *BMC Pediatrics*, *22*(1), 1–11. https://doi.org/10.1186/s12887-021-03079-z

Mengel, E., Tillmann, V., Remmel, L., Kool, P., Purge, P., Lätt, E., & Jürimäe, J. (2017). Changes in inflammatory markers in estonian pubertal boys with different BMI values and increments: A 3-Year Follow-Up Study. *Obesity*, *25*(3), 600–607. https://doi.org/10.1002/oby.21756

Metsoja, A., Nelis, L., & Nurk, E. (2018). *WHO Childhood Obesity Surveillance Initiative (COSI). Estonian study report for the academic year 2015/2016.* Tallinn. Retrieved from https://www.tai.ee/sites/default/files/2021-03/152586931296_WHO_Childhood_Obesity_Surveillance_Initiative_COSI.pdf

Mintjens, S., Menting, M. D., Daams, J. G., van Poppel, M. N. M., Roseboom, T. J., & Gemke, R. J. B. J. (2018). Cardiorespiratory fitness in childhood and adolescence affects future cardiovascular risk factors: A Systematic Review of Longitudinal Studies. *Sports Medicine*, *48*(11), 2577–2605. https://doi.org/10.1007/s40279-018-0974-5

Morrissey, C., Montero, D., Raverdy, C., Masson, D., Amiot, M.-J., & Vinet, A. (2018). Effects of exercise intensity on microvascular function in obese adolescents. *International Journal of Sports Medicine*, *39*(06), 450–455. https://doi.org/ 10.1055/a-0577-4280

Moschen, A. R., Adolph, T. E., Gerner, R. R., Wieser, V., & Tilg, H. (2017). Lipocalin-2: a master mediator of intestinal and metabolic inflammation. *Trends in Endocrinology and Metabolism*, *28*(5), 388–397. https://doi.org/10.1016/j.tem.2017.01.003

Mosialou, I., Shikhel, S., Liu, J.-M., Maurizi, A., Luo, N., He, Z., … Kousteni, S. (2017). MC4R-dependent suppression of appetite by bone-derived lipocalin 2. *Nature*, *543*(7645), 385–390. https://doi.org/10.1038/nature21697

Murphy, A., Kist, C., Gier, A. J., Edwards, N. M., Gao, Z., & Siegel, R. M. (2015). The feasibility of high-intensity interval exercise in obese adolescents. *Clinical Pediatrics*, *54*(1), 87–90. https://doi.org/10.1177/0009922814528038

Mäestu, E., Harro, J., Veidebaum, T., Kurrikoff, T., Jürimäe, J., & Mäestu, J. (2020). Changes in cardiorespiratory fitness through adolescence predict metabolic

syndrome in young adults. *Nutrition, Metabolism and Cardiovascular Diseases*, *30*(4), 701–708. https://doi.org/10.1016/j.numecd.2019.12.009

Nagai, N., & Moritani, T. (2004). Effect of physical activity on autonomic nervous system function in lean and obese children. *International Journal of Obesity*, *28*(1), 27–33. https://doi.org/10.1038/sj.ijo.0802470

Nakai, M. E., Denham, J., Prestes, P. R., Eikelis, N., Lambert, E. A., Straznicky, N. E., … Marques, F. Z. (2021). Plasma lipocalin-2/NGAL is stable over 12 weeks and is not modulated by exercise or dieting. *Scientific Reports*, *11*(1), 1–13. https://doi.org/10.1038/s41598-021-83472-x

Nazari, S., Taheri Chadorneshin, H., Marefati, H., & Eivary Abtahi, S.-H. (2020). The effect of rope jump training on serum levels of lipocalin-2, anthropometric parameters, and aerobic power in obese adolescent boys. *Journal of Sports Science and Clinical Biochemistry*, *7*(3), 7–18. Retrieved from https://jbrms.medilam.ac.ir/browse.php?sid=1&a_id=459&slc_lang=en&ftxt=1

Nichols, M., Townsend, N., Scarborough, P., & Rayner, M. (2014). Cardiovascular disease in Europe 2014: epidemiological update. *European Heart Journal*, *35*(42), 2950–2959. https://doi.org/10.1093/eurheartj/ehu299

Noll, M., Mendonca, C. R., Rodrigues, A. P. dos S., de Almeida, A. A., & Noll, P. R. E. S. (2021). Narrative review of the influence of high-intensity interval trainin on adolescents' bone health. *Translational Pediatrics*, 10 (1):160–164. http://dx.doi.org/10.21037/tp-20-166

Oh, S. Bin, Lee, W. Y., Nam, H.-K., Rhie, Y.-J., & Lee, K.-H. (2019). Serum osteocalcin levels in overweight children. *Annals of Pediatric Endocrinology & Metabolism*, *24*(2), 104–107. https://doi.org/10.6065/apem.2019.24.2.104

Ortega, F. B., Ruiz, J. R., Castillo, M. J., & Sjöström, M. (2008). Physical fitness in childhood and adolescence: a powerful marker of health. *International Journal of Obesity*, *32*(1), 1–11. https://doi.org/10.1038/sj.ijo.0803774

Ortega, F. B., Ruiz, J. R., Labayen, I., Lavie, C. J., & Blair, S. N. (2018). The fat but fit paradox: what we know and don't know about it. *British Journal of Sports Medicine*, *52*(3), 151–153. https://doi.org/10.1136/bjsports-2016-097400

Ortega, F. B., Ruiz, J. R., Mesa, J. L., Gutiérrez, Á., & Sjöström, M. (2007). Cardiovascular fitness in adolescents: the influence of sexual maturation status—The AVENA and EYHS studies. *American Journal of Human Biology*, *19*(6), 801–808. https://doi.org/10.1002/ajhb.20640

Ostchega, Y., Porter, K. S., Hughes, J., Dillon, C. F., Nwankwo, T., & Surveys, N. E. (2011). Resting pulse rate reference data for children, adolescents, and adult: Unites States, 1999-2008, *24*(41), 1999–2008.

Ouerghi, N., Fradj, M. K. Ben, Bezrati, I., Khammassi, M., Feki, M., Kaabachi, N., & Bouassida, A. (2017). Effects of high-intensity interval training on body composition, aerobic and anaerobic performance and plasma lipids in overweight/obese and normal-weight young men. *Biology of Sport*, *34*(4), 385–392. https://doi.org/10.5114/biolsport.2017.69827

Paldánius, P. M., Ivaska, K. K., Mäkitie, O., & Viljakainen, H. (2021). Serum and Urinary Osteocalcin in healthy 7- to 19-year-old Finnish children and adolescents. *Frontiers in Pediatrics*, *9*(August), 1–11. https://doi.org/10.3389/fped.2021.610227

Panagopoulou, P., Galli-Tsinopoulou, A., Fleva, A., Pavlitou-Tsiontsi, E., Vavatsi-Christaki, N., & Nousia-Arvanitakis, S. (2008). Adiponectin and insulin resistance in childhood obesity. *Journal of Pediatric Gastroenterology & Nutrition*, *47*(3), 356–362. https://doi.org/10.1097/MPG.0b013e31817fcb67

Pedersen, T. R., Olsson, A. G., F'rgeman, O., Kjekshus, J., Wedel, H., Kjekshus, K., … Cook, T. J. (1998). Lipoprotein changes and reduction in the incidence of major coronary heart disease events in the Scandinavian Simvastatin Survival Study (4S). *Circulation*, *97*, 1453–1460. https://doi.org/10.1016/j.atherosclerosissup.2004.08.030

Pimentel, D. V., Suttkus, A., Vogel, M., Lacher, M., Jurkutat, A., Poulain, T., … Mayer, S. (2021). Effect of physical activity and BMI SDS on bone metabolism in children and adolescents. *Bone*, *153*(January), 116131. https://doi.org/10.1016/j.bone.2021.116131

Racil, G., Ben Ounis, O., Hammouda, O., Kallel, A., Zouhal, H., Chamari, K., & Amri, M. (2013). Effects of high vs. moderate exercise intensity during interval training on lipids and adiponectin levels in obese young females. *European Journal of Applied Physiology*, *113*(10), 2531–2540. https://doi.org/10.1007/s00421-013-2689-5

Racil, Ghazi, Coquart, J., Elmontassar, W., Haddad, M., Goebel, R., Chaouachi, A., … Chamari, K. (2016). Greater effects of high- compared with moderate-intensity interval training on cardio-metabolic variables, blood leptin concentration and ratings of perceived exertion in obese adolescent females. *Biology of Sport*, *33*(2), 145–152. https://doi.org/10.5604/20831862.1198633

Raghuveer, G., Hartz, J., Lubans, D. R., Takken, T., Wiltz, J. L., Mietus-Snyder, M., … Edwards, N. M. (2020). Cardiorespiratory fitness in youth: an important marker of health: a scientific statement from the American Heart Association. *Circulation*, *142*(7), E101–E118. https://doi.org/10.1161/CIR.0000000000000866

Raj, M., & Kumar, K. (2010). Obesity in children. *BMJ Clinical Evidence*, *132*, 598–607. http://www.ncbi.nlm.nih.gov/pubmed/19454076

Ramos, J. S., Dalleck, L. C., Tjonna, A. E., Beetham, K. S., & Coombes, J. S. (2015). The impact of high-intensity interval training versus moderate-intensity continuous training on vascular function: a Systematic Review and Meta-Analysis. *Sports Medicine*, 45(5), 679-692. http://link.springer.com/10.1007/s40279-015-0321-z

Reinehr, T., & Roth, C. L. (2010). A new link between skeleton, obesity and insulin resistance: Relationships between osteocalcin, leptin and insulin resistance in obese children before and after weight loss. *International Journal of Obesity*, *34*(5), 852–858. https://doi.org/10.1038/ijo.2009.282

Rosa, J. S., Heydari, S., Oliver, S. R., Rebecca, L. F., Pontello, A., Ibardolaza, M., & Galassetti, P. R. (2011). Inflammatory cytokine profiles during exercise in obese, diabetic, and healthy children. *Journal of Clinical Research in Pediatric Endocrinology*, 3(3), 115-121. http://cms.galenos.com.tr/Uploads/Article_103/JCRPE-3-115-En.pdf

Ross, R., Blair, S. N., Arena, R., Church, T. S., Després, J. P., Franklin, B. A., … Wisløff, U. (2016). Importance of assessing cardiorespiratory fitness in clinical practice: a case for fitness as a clinical vital sign: a scientific statement from the American Heart Association. *Circulation*, 134(24), e653-e699. https://doi.org/10.1161/CIR.0000000000000461

Ruiz, J. R., Ortega, F. B., Warnberg, J., & Sjöström, M. (2007). Associations of low-grade inflammation with physical activity, fitness and fatness in prepubertal children; The European Youth Heart Study. *International Journal of Obesity*, *31*(10), 1545–1551. https://doi.org/10.1038/sj.ijo.0803693

Ruiz, J. R., Cavero-Redondo, I., Ortega, F. B., Welk, G. J., Andersen, L. B., & Martinez-Vizcaino, V. (2016). Cardiorespiratory fitness cut points to avoid cardiovascular disease risk in children and adolescents; what level of fitness should raise a

red flag? A systematic review and meta-analysis. *British Journal of Sports Medicine*, *50*(23), 1451–1458. https://doi.org/10.1136/bjsports-2015-095903

Sahoo, K., Sahoo, B., Choudhury, A. K., Sofi, N. Y., Kumar, R., & Bhadoria, A. S. (2015). Childhood obesity: Causes and consequences. *Journal of Family Medicine and Primary Care*, *4*(2), 187–192. https://doi.org/10.4103/2249-4863.154628

Sahrir, N. A., & Ooi, F. K. (2018). Physical activity, bone remodelling and bone metabolism markers. *Journal of Exercise, Sports & Orthopedics*, 5(2), 1-4. https://doi.org/ 10.15226/2374-6904/5/2/00171

Sansoni, V., Perego, S., Vernillo, G., Barbuti, A., Merati, G., La Torre, A., … Lombardi, G. (2018). Effects of repeated sprints training on fracture risk-associated miRNA. *Oncotarget*, *9*(26), 18029–18040. https://doi.org/10.18632/oncotarget. 24707

Sarvottam, K., & Yadav, R. K. (2014). Obesity-related inflammation & cardiovascular disease: efficacy of a yoga-based lifestyle intervention. *The Indian Journal of Medical Research*, *139*(6), 822–834. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/25109716

Sayers, A., Mattocks, C., Deere, K., Ness, A., Riddoch, C., & Tobias, J. H. (2011). Habitual levels of vigorous, but not moderate or light, physical activity is positively related to cortical bone mass in adolescents. *Journal of Clinical Endocrinology and Metabolism*, *96*(5), 793–802. https://doi.org/10.1210/jc.2010-2550

Savvidis, C., Tournis, S., & Dede, A. D. (2018). Obesity and bone metabolism. *Hormones*, 17(2), 205-217. http://link.springer.com/10.1007/s42000-018-0018-4

Schoenmakers, P. P. J. M., & Reed, K. E. (2019). The effects of recovery duration on physiological and perceptual responses of trained runners during four self-paced HIIT sessions. *Journal of Science and Medicine in Sport*, *22*(4), 462–466. https://doi.org/10.1016/j.jsams.2018.09.230

Seeman, E. (2003). Physiology of aging invited review : pathogenesis of osteoporosis. *Journal of Applied Physiology (Bethesda, Md. : 1985)*, *95*(5), 2142–2151.

Sgro, M., McGuigan, M. R., Pettigrew, S., & Newton, R. U. (2009). The effect of duration of resistance training interventions in children who are overweight or obese. *Journal of Strength and Conditioning Research*, *23*(4), 1263–1270. https://doi.org/10.1519/JSC.0b013e3181910746

Shah, B., Tombeau Cost, K., Fuller, A., Birken, C. S., & Anderson, L. N. (2020). Sex and gender differences in childhood obesity: contributing to the research agenda. *BMJ Nutrition, Prevention & Health*, *3*(2), 387–390. https://doi.org/10.1136/bmjnph-2020-000074

Shashaj, B., Luciano, R., Contoli, B., Morino, G. S., Spreghini, M. R., Rustico, C., … Manco, M. (2016). Reference ranges of HOMA-IR in normal-weight and obese young Caucasians. *Acta Diabetologica*, *53*(2), 251–260. https://doi.org/10.1007/s00592-015-0782-4

Silva, G., Aires, L., Martins, C., Mota, J., Oliveira, J., & Ribeiro, J. C. (2013). Cardiorespiratory fitness associates with metabolic risk independent of central adiposity. *International Journal of Sports Medicine*, 34(10), 912–916. https://doi.org/10.1055/s-0033-1334967

Silva, H. J. G., Andersen, L. B., Lofrano-Prado, M. C., Barros, M. V. G., Freitas, I. F., Hill, J., & do Prado, W. L. (2015). Improvements on cardiovascular diseases risk factors in obese adolescents: a randomized exercise intervention study. *Journal of Physical Activity and Health*, *12*(4), 553–560. https://doi.org/10.1123/jpah.2013-0199

Sink, K. M., Espeland, M. A., Castro, C. M., Church, T., Cohen, R., Dodson, J. A., … Williamson, J. D. (2015). Effect of a 24-month physical activity intervention vs health education on cognitive outcomes in sedentary older adults. *JAMA*, *314*(8), 781. https://doi.org/10.1001/jama.2015.9617

Sloth, M., Sloth, D., Overgaard, K., & Dalgas, U. (2013). Effects of sprint interval training on VO2max and aerobic exercise performance: A systematic review and meta-analysis. *Scandinavian Journal of Medicine & Science in Sports*, *23*(6), e341–e352. https://doi.org/10.1111/sms.12092

Spinelli, A., Buoncristiano, M., Nardone, P., Starc, G., Hejgaard, T., Júlíusson, P. B., … Breda, J. (2021). Thinness, overweight, and obesity in 6- to 9-year-old children from 36 countries: The World Health Organization European Childhood Obesity Surveillance Initiative—COSI 2015–2017. *Obesity Reviews*, *22*(S6), 1–15. https://doi.org/10.1111/obr.13214

Starkoff, B., Hoffman, R., Children, N., & Devor, S. T. (2014). Estimated aerobic capacity changes in adolescents with obesity following high intensity interval exercise. *International Journal of Kinesiology and Sports Science*, *2*(3), 1–8. https://doi.org/10.7575/aiac.ijkss.v.2n.3p.1

Sun, S., Zhang, H., Kong, Z., Shi, Q., Tong, T. K., & Nie, J. (2019). Twelve weeks of low volume sprint interval training improves cardio-metabolic health outcomes in overweight females. *Journal of Sports Sciences*, *37*(11), 1257–1264. https://doi.org/10.1080/02640414.2018.1554615

Tagi, V. M., Giannini, C., & Chiarelli, F. (2019). Insulin resistance in children. *Frontiers in Endocrinology*, 10(JUN), 1–13. https://doi.org/10.3389/fendo.2019. 00342

Takashi, Y., & Kawanami, D. (2022). The role of bone-derived hormones in glucose metabolism, Diabetic Kidney Disease, and Cardiovascular Disorders. *International Journal of Molecular Sciences*, *23*(4), 2376. https://doi.org/10.3390/ijms23042376

Takaya, J., Tanabe, Y., & Kaneko, K. (2021). Increased lipocalin 2 levels in adolescents with type 2 diabetes mellitus. *Journal of Pediatric Endocrinology and Metabolism*, *34*(8), 979–985. https://doi.org/10.1515/jpem-2021-0216

Tanner, J. (1962). *Growth at adolescence* (2nd ed.). Oxford: Blackwell Scientific Publications.

Thivel, D., Masurier, J., Baquet, G., Timmons, B. W., Pereira, B., Berthoin, S., … Aucouturier, J. (2019). High-intensity interval training in overweight and obese children and adolescents: Systematic review and meta-analysis. *Journal of Sports Medicine and Physical Fitness*, 310–324. https://doi.org/10.23736/S0022-4707.18.08075-1

Thum, J. S., Parsons, G., Whittle, T., & Astorino, T. A. (2017). High-intensity interval training elicits higher enjoyment than moderate intensity continuous exercise. *PLOS ONE*, *12*(1), e0166299. https://doi.org/10.1371/journal.pone.0166299

Tjønna, A. E., Stølen, T. O., Bye, A., Volden, M., Slørdahl, S. A., Ødegård, R., … Wisløff, U. (2009). Aerobic interval training reduces cardiovascular risk factors more than a multitreatment approach in overweight adolescents. *Clinical Science*, *116*(4), 317–326. https://doi.org/10.1042/CS20080249

Tong, T. K., Zhang, H., Shi, H., Liu, Y., Ai, J., Nie, J., & Kong, Z. (2018). Comparing time efficiency of sprint vs. high-intensity interval training in reducing abdominal visceral fat in obese young women: A Randomized, Controlled Trial. *Frontiers in Physiology*, *9*(AUG), 1–9. https://doi.org/10.3389/fphys.2018.01048

Trapp, E. G., Chisholm, D. J., Freund, J., & Boutcher, S. H. (2008). The effects of high-intensity intermittent exercise training on fat loss and fasting insulin levels of young

women. *International Journal of Obesity*, *32*(4), 684–691. https://doi.org/10.1038/sj.ijo.0803781

Tremmel, M., Gerdtham, U.-G., Nilsson, P., & Saha, S. (2017). Economic burden of obesity: a systematic literature review. *International Journal of Environmental Research and Public Health*, *14*(4), 435–453. https://doi.org/10.3390/ijerph14040435

Trilk, J. L., Singhal, A., Bigelman, K. A., & Cureton, K. J. (2011). Effect of sprint interval training on circulatory function during exercise in sedentary, overweight/obese women. *European Journal of Applied Physiology*, *111*(8), 1591–1597. https://doi.org/10.1007/s00421-010-1777-z

Utsal, L., Tillmann, V., Zilmer, M., Mäestu, J., Purge, P., Saar, M., … Jürimäe, J. (2013). Negative correlation between serum IL-6 level and cardiorespiratory fitness in 10- to 11-year-old boys with increased BMI. *Journal of Pediatric Endocrinology and Metabolism*, *26*(5–6), 503–508. https://doi.org/10.1515/jpem-2012-0338

Vandoni, M., Calcaterra, V., Pellino, V. C., De Silvestri, A., Marin, L., Zuccotti, G. V., ... Lovecchio, N. (2021). "Fitness and fatness" in children and adolescents: an Italian cross-sectional study. *Children*, 8, 762. https://doi.org/10.3390/children8090762

Vella, C. A., Taylor, K., & Drummer, D. (2017). High-intensity interval and moderate-intensity continuous training elicit similar enjoyment and adherence levels in overweight and obese adults. *European Journal of Sport Science*, *17*(9), 1203–1211. https://doi.org/10.1080/17461391.2017.1359679

Viana, R. B., Naves, J. P. A., Coswig, V. S., de Lira, C. A. B., Steele, J., Fisher, J. P., & Gentil, P. (2019). Is interval training the magic bullet for fat loss? A systematic review and meta-analysis comparing moderate-intensity continuous training with high-intensity interval training (HIIT). *British Journal of Sports Medicine*, *53*(10), 655–664. https://doi.org/10.1136/bjsports-2018-099928

Vollaard, N. B. J., & Metcalfe, R. S. (2017). Research into the health benefits of sprint interval training should focus on protocols with fewer and shorter sprints. *Sports Medicine*, *47*(12), 2443–2451. https://doi.org/10.1007/s40279-017-0727-x

Wang, R., Zhang, X., Ren, H., Zhou, H., Yuan, Y., Chai, Y., & Hou, X. (2022). Effects of different exercise types on visceral fat in young individuals with obesity aged 6–24 years old: A systematic review and meta-analysis. *Frontiers in Physiology*, *13*(September). https://doi.org/10.3389/fphys.2022.987804

Ward, D. S., Evenson, K. R., Vaughn, A., Rodgers, A. B., & Troiano, R. P. (2005). Accelerometer use in physical activity: best practices and research recommendations. *Medicine & Science in Sports & Exercise*, *37*(11), S582–S588. https://doi.org/10.1249/01.mss.0000185292.71933.91

Weston, K. S., Wisløff, U., & Coombes, J. S. (2014). High-intensity interval training in patients with lifestyle-induced cardiometabolic disease: a systematic review and meta-analysis. *British Journal of Sports Medicine*, *48*(16), 1227–1234. https://doi.org/10.1136/bjsports-2013-092576

Wewege, M., van den Berg, R., Ward, R. E., & Keech, A. (2017). The effects of high-intensity interval training vs. moderate-intensity continuous training on body composition in overweight and obese adults: a systematic review and meta-analysis. *Obesity Reviews*, *18*(6), 635–646. https://doi.org/10.1111/obr.12532

WHO. Global Recommendations on Physical Activity for Health. Geneva: World Health Organization; 2014

WHO. Overweight and Obesity. Geneva: World Health Organization; 2021

Wong, P. C., Chia, M. Y., Tsou, I. Y., Wansaicheong, G. K., Tan, B., Wang, J. C., … Lim, D. (2008). Effects of a 12-week exercise training programme on aerobic

fitness, body composition, blood lipids and C-reactive protein in adolescents with obesity. *Annals Academy of Medicine*, *37*(4), 286–293. https://www.researchgate.net/publication/5392261

Wyckelsma, V. L., Venckunas, T., Brazaitis, M., Gastaldello, S., Snieckus, A., Eimantas, N., … Westerblad, H. (2020). Vitamin C and E treatment blunts sprint interval training–induced changes in inflammatory mediator-, calcium-, and mitochondria-related signaling in recreationally active elderly humans. *Antioxidants*, *9*(9), 879. https://doi.org/10.3390/antiox9090879

Xu, Y., Ma, X., Pan, X., He, X., Xiao, Y., & Bao, Y. (2018). Correlations between serum concentration of three bone-derived factors and obesity and visceral fat accumulation in a cohort of middle aged men and women. *Cardiovascular Diabetology*, *17*(1), 143. https://doi.org/10.1186/s12933-018-0786-9

Yin, J., Zhou, Z., & Lan, T. (2020). High-intensity interval training versus moderate-intensity continuous training on health outcomes for children and adolescents: a meta-analysis of randomized controlled trials. *BioMed Research International*, *2020*, 1–18. https://doi.org/10.1155/2020/9797439

Zabinski, M. F., Saelens, B. E., Stein, R. I., Hayden-Wade, H. A., & Wilfley, D. E. (2003). Overweight children's barriers to and support for physical activity. *Obesity Research*, *11*(2), 238–246. https://doi.org/10.1038/oby.2003.37

Zaki, M., El-Bassyouni, H., Youness, E., & Mohamed, N. (2015). Lipocalin-2 is an inflammatory biomarker associated with metabolic abnormalities in Egyptian obese children. *Journal of Applied Pharmaceutical Science*, *5*(5), 007–012. https://doi.org/10.7324/JAPS.2015.50502

Zhang, H., Tong, T. K., Qiu, W., Zhang, X., Zhou, S., Liu, Y., & He, Y. (2017). Comparable effects of high-intensity interval training and prolonged continuous exercise training on abdominal visceral fat reduction in obese young women. *Journal of Diabetes Research*, *2017*(2), 1–9. https://doi.org/10.1155/2017/5071740

SUMMARY IN ESTONIAN

Sprindi intervalltreeningu mõju rasvunud teismeealiste poiste keha koostisele, kardiorespiratoorsele võimekusele, vere biokeemilistele markeritele ning luutervisele

Rasvumine on kõige levinum krooniline terviseprobleem nii lapsepõlves kui ka puberteedieas. See on hilisemas elus südame- ja veresoonkonnahaiguste (SVH) ning II tüüpi diabeedi riskitegur (Ayer jt 2015). Peale tulevaste terviseriskide süvenemise on suur kehamassiindeks (KMI) märkimisväärne oht erinevate haiguste tekkeks. KMI või kogu keha rasvamassi sisalduse kasv ja rasvamassi protsent on seotud lipiidide ning lipoproteiinide ebasoodsa sisalduse, insuliiniresistentsuse, kõrge vererõhu ja adipokiinide suurenenud sisaldusega veres (Kelly jt 2013). Ülekaalulisus või rasvumus on pöördvõrdeliselt seotud kardiorespiratoorse võimekusega (KRV) lapsepõlves (Utsal jt 2013). On kindlaks tehtud, et KRV mõjutab noorukitel SVH ja kardiometaboolsete haiguste teket (Ortega jt 2008) ning et madala KRV-ga noorukitel on ligikaudu kuus korda suurem tõenäosus haigestuda SVH-sse kui normaalse KRV-ga noorukitel (Ruiz et al., 2016). Teadmine, et puberteedi ajal väheneb järsult igapäevane kehaline aktiivsus, samas kui põhiosa ajast veedetakse istudes (Lätt jt 2015), teeb kehalise treeningu kasvuperioodil asendamatuks strateegiavahendiks KRV ja teiste kardiometaboolsete näitajate paremaks muutmisel. Siiani on ülekaaluliste ja rasvunud noorukite tervisega seotud aspektide parandamiseks kõige sagedamini kasutatud mõõduka intensiivsusega kestvustreeningut (MIKT) (Sarvottam ja Yadav 2014). Hiljuti on MIKT-i kõrval hakatud soovitama ka kõrge intensiivsusega intervalltreeningut (HIIT), mis koosneb lühiajalistest väga intensiivsetest treeningintervallidest koos nende vahele jäävate taastumisperioodidega. HIIT on peaaegu 40% lühema treeningajaga kui MIKT, kuid on tervisele sama kasulik (Wewege jt 2017), eriti ülekaalulise ja rasvunud elanikkonna seas (Batacan jt 2017). Viimastel aastatel on treeningmaailmas populaarsust kasvatanud isegi veel intensiivsem intervalltreeningu vorm – sprindi intervalltreening (SIT), kus intervalltreeningu seeriad on ajaliselt veelgi lühemad, kuid palju kõrgema intensiivsusega kui HIIT-i puhul (Weston jt 2014). SIT parandab KRV-d ja kardiometaboolseid riskitegureid samal määral kui MIKT hoolimata viis korda väiksemast ajakulust ning treeningu mahust (Gillen jt 2016). Teadaolevalt ei ole siiani veel ühtegi veloergomeetrit kasutavat SIT-i treeningut rasvunud teismeealiste poiste seas läbi viidud.

Uurimustöö eesmärk ja ülesanded

Töö eesmärk oli uurida 12-nädalase juhendatud sprindi intervalltreeningu mõju rasvunud teismeealiste poiste keha koostisele, kardiorespiratoorsele võimekusele, vere biokeemilistele markeritele ning luutervisele. Eesmärgist tulenevalt olid ülesanded järgmised:

1. hinnata rasvunud teismeealiste poiste keha koostise ja kardiorespiratoorse võimekuse muutusi pärast sprindi intervalltreeningut;
2. hinnata rasvunud teismeealiste poiste kardiometaboolsete riskitegurite ja adipokiinide sisalduse muutusi pärast sprindi intervalltreeningut;
3. hinnata rasvunud teismeealiste poiste osteokiinide sisalduse ja luu mineraalsete parameetrite muutusi pärast sprindi intervalltreeningut.

Uuritavad ja metoodika

Uuringus osales algselt 37 12–16-aastast treenimata poissi alimentaarse rasvumusega, kellest 19 moodustasid sprind intervalltreeningu rühma (SIT) ja 18 kontrollrühma (KONT). Rasvumise kriteerium oli KMI ≥ 95. protsentiili Eesti laste KMI kasvukõveratel (Grünberg jt 1998). SIT-I rühma poisid osalesid 12 nädalat kestval treeningperioodil, kus sooritati 4–6 korda 30 sekundi jooksul maksimaalsel intensiivsusel rattasprinte (puhkus neli minutit iga sprindi vahel) sagedusega kolm korda nädalas. Kaheteistkümne nädala jooksul ei nõustatud mitte ühtegi uuritavat toitumise osas ning samuti paluti kõikidel jätkata oma tavapärase elustiiliga. Kõigil uuritavatel määrati üks nädal enne ja pärast 12-nädalast sekkumisperioodi KRV, kehamass, kehapikkus ning arvutati kehamassiindeks (KMI). Puberteedi aste määrati Tanneri skaala järgi. DXA aparaadiga määrati keha koostise näitajad, nii keha rasva- ja rasvavabamass kui kogu keha luumass ning luu mineraalne tihedus (nii kogu keha kui ka alajäsemete luu mineraalne tihedus). Vereanalüüsidest määrati erinevad vere biokeemilised markerid, sh kogu kolesterool, madala- ja kõrge tihedusega lipoproteiinid, triglütseriidid, glükoos, insuliin, insuliiniresistentsus, leptiin, adiponektiin, osteokaltsiin, lipokaliin-2 ja sklerostiin. Insuliiniresistentsus arvutati valemiga (insuliin × glükoos) / 22,5. Metaboolse sündroomi riskiskoori arvutamiseks kasutati metaboolse sündroomi raskuse z-skoori (ingl k *metabolic syndrome severity z-score, MSSS*). Uuring kooskõlastati Tartu Ülikooli inimuuringute eetika komiteega.

Tulemused

Uuringu lõpetas 28 uuritavat (SIT = 14, KONT = 14). Mõlemad rühmad ei olnud uuringut alustades erinevad ($p > 0,05$) nii antropomeetriliste parameetrite, keha koostise, kardiorespiratoorse võimekuse, puberteedi astme, kehalise aktiivsuse kui ka päevase kalorsuse põhjal. Peale 12-nädalast sprindi intervalltreeningut vähenes SIT-i rühmas keha rasvamassi protsent ($p = 0,006$), paranes kardiorespiratoorne võimekus ($p = 0,001$) ning langes südame löögisagedus rahuolekus ($p = 0,003$), samas täheldati KONT rühmas 12-nädalase sekkumisperioodi järel kehamassi ning südame rahuoleku löögisageduse tõusu (vastavalt $p = 0,002$ ja $p = 0,043$). Võrreldes algväärtustega, vähenes 12-nädalase sekkumisperioodi järgselt mõlemas grupis kõrge tihedusega lipoproteiini ning adiponektiini kontsentratsiooni tase (SIT grupis vastavalt $p = 0,028$ ja $p = 0,040$, ning KONT grupis vastavalt $p = 0,003$ ja $p = 0,006$). SIT-i rühmas vähenes

MSSS ($p < 0,050$) pärast 12-nädalast sekkumisperioodi. Pärast sekkumisperioodi ei täheldatud SIT-i ega KONT-i rühmas muutusi veres osteokiinide kontsentratsioonis, kuid võrreldes treeningueelsete tulemustega, paranes SIT-i rühmas märkimisväärselt nii kogu keha luumass ($p = 0,005$) kui ka alajäsemete luu mineraalne tihedus ($p = 0,025$). KONT-i rühmas paranes 12-nädalase sekkumisperioodi järel vaid kogu keha luumass ($p = 0,005$).

Järeldused

1. Sprindi intervalltreening vähendas keha rasvamassi protsenti ja parandas kardiorespiratoorset võimekust rasvunud teismeealistel poistel.
2. Sprindi intervalltreening parandas metaboolse sündroomi raskuse riskiskoori rasvunud teismeealistel poistel.
3. Sprindi intervalltreening suurendas alajäsemete luu mineraalset tihedust rasvunud teismeealistel poistel.

ACKNOWLEDGEMENTS

I would like to thank:

- My academic supervisors Professor Jaak Jürimäe and Professor Dr. Vallo Tillmann for all the advice, continuous support and inspiration throughout the process;
- Dear research colleagues Dr. Liina Remmel, Dr. Evelin Mäestu, Dr. Ülle Parm and Dr. Eve Unt with her high expertise team who helped and gave an excellent advice;
- Professor Francisco B. Ortega for his valuable scientific support;
- Mr. Mihkel Klementsov for giving the opportunity to use WattBike ergometers;
- All the subjects, who were kind enough to participate in this study;
- My mother Ingrid, two brothers Mart and Karl for their love and support throughout my life and my father who passed away too soon but whose words of wisdom will not be forgotten;
- My dear husband Ardi and two beautiful children Markus and Marii for all their understanding, patience and just being there for me.

This study was supported by Estonian Research Council grants PUT 1428 and PUT 1120.

PUBLICATIONS

CURRICULUM VITAE

Name: Marit Salus (born Kull)
Date of Birth: January 24, 1983
Citizenship: Estonian
Address: Sõnajala 13, 61709, Tartumaa
Phone: +372 5263535
E-mail: maritsalus@nooruse.ee, marit.salus@ut.ee

Education: University of Tartu, *MS*c, 2009

Languages: Estonian, English, Russian

Educational Career:

2018–2023	Doctoral study, Faculty of Exercise and Sport Sciences, University of Tartu, Estonia
2005–2009	MSc, Faculty of Exercise and Sport Sciences, University of Tartu, Estonia
2001–2005	BSc, Faculty of Exercise and Sport Sciences, University of Tartu, Estonia
1990–2001	Miina Härma Gymnasium, Tartu, Estonia

Professional Career:

2019–	Lecturer in Physiotherapy and Environmental Health Department, Tartu Health Care College, Estonia
2017–2019	Head teacher in Massage Department,Tartu Health Care College, Estonia
2011–2017	Head of rehabilitation team/physiotherapist, Dorpat Tervis OÜ, Estonia
2008–2018	Fitness coach, Fitness Club of University of Tartu, Estonia
2005–2009	Physiotherapist/masseuse, Academic Sportclub of University of Tartu, Estonia

ELULOOKIRJELDUS

Nimi: Marit Salus (snd Kull)
Sünniaeg: 24. jaanuar 1983
Kodakondsus: Eesti
Aadress: Sõnajala 13, 61709, Tartumaa
Telefon: +372 5263535
E-mail: maritsalus@nooruse.ee, marit.salus@ut.ee

Haridus: Tartu Ülikool, *MS*c, 2009

Keeled: eesti keel, inglise keel, vene keel

Haridustee:

2018–2023	Doktoriõpe, Tartu Ülikooli kehakultuuriteaduskond, Eesti
2005–2009	Magistriõpe, Tartu Ülikooli kehakultuuriteaduskond, Eesti
2001–2005	Bakalaureuseõpe, Tartu Ülikooli kehakultuuriteaduskond, Eesti
1990–2001	Miina Härma Gümnaasium, Tartu, Eesti

Töökogemus:

2019–	Füsioterapeudi õppekava lektor, Tartu Tervishoiu Kõrgkool, Eesti
2017–2019	Massööri õppekava juhtivõpetaja, Tartu Tervishoiu Kõrgkool, Eesti
2011–2017	Rehabilitatsiooni osakonna juht/füsioterapeut, Dorpat Tervis OÜ, Eesti
2008–2018	Fitnessi treener, Tartu Ülikooli Fitness-klubi, Eesti
2005–2009	Füsioterapeut-massöör, Tartu Ülikooli Akadeemiline Spordiklubi, Eesti

DISSERTATIONES KINESIOLOGIAE UNIVERSITATIS TARTUENSIS

1. **Lennart Raudsepp.** Physical activity, somatic characteristics, fitness and motor skill development in prepubertal children. Tartu, 1996, 138 p.
2. **Vello Hein.** Joint mobility in trunk forward flexion: methods and evaluation. Tartu, 1998, 107 p.
3. **Leila Oja.** Physical development and school readiness of children in transition from preschool to school. Tartu, 2002, 147 p.
4. **Helena Gapeyeva.** Knee extensor muscle function after arthroscopic partial meniscectomy. Tartu, 2002, 113 p.
5. **Roomet Viira.** Physical activity, ecological system model determinants and physical self-perception profile in early adolescence. Tartu, 2003, 167 p.
6. **Ando Pehme.** Effect of mechanical loading and ageing on myosin heavy chain turnover rate in fast-twitch skeletal muscle. Tartu, 2004, 121 p.
7. **Priit Kaasik.** Composition and turnover of myofibrillar proteins in volume – overtrained and glucocorticoid caused myopathic skeletal muscle. Tartu, 2004, 123 p.
8. **Jarek Mäestu.** The perceived recovery-stress state and selected hormonal markers of training stress in highly trained male rowers. Tartu, 2004, 109 p.
9. **Karin Alev.** Difference between myosin light and heavy chain isoforms patterns in fast- and slow-twitch skeletal muscle: effect of endurance training. Tartu, 2005, 117 p.
10. **Kristjan Kais.** Precompetitive state anxiety, self-confidence and ahtletic performance in volleyball and basketball players. Tartu, 2005, 99 p.
11. **Aire Leppik.** Changes in anthropometry, somatotype and body composition during puberty: a longitudinal study. Tartu, 2005, 161 p.
12. **Jaan Ereline.** Contractile properties of human skeletal muscles: Association with sports training, fatigue and posttetanic potentiation. Tartu, 2006, 133 p.
13. **Andre Koka.** The role of perceived teacher feedback and perceived learning environment on intrinsic motivation in physical education. Tartu, 2006, 137 p.
14. **Priit Purge.** Performance, mood state and selected hormonal parameters during the rowing season in elite male rowers. Tartu, 2006, 101 p.
15. **Saima Kuu.** Age-related contractile changes in plantarflexor muscles in women: associations with postactivation potentiation and recreational physical activity. Tartu, 2006, 101 p.
16. **Raivo Puhke.** Adaptive changes of myosin isoforms in response to long-term strength training in skeletal muscle of middle-aged persons. Tartu, 2006, 99 p.
17. **Eva-Maria Riso.** The effect of glucocorticoid myopathy, unloading and reloading on the skeletal muscle contractile apparatus and extracellular matrix. Tartu, 2007, 114 p.

18. **Terje Sööt.** Bone mineral values in young females with different physical activity patterns: association with body composition, leg strength and selected hormonal parameters. Tartu, 2007, 94 p.
19. **Karin Tammik.** Neuromuscular function in children with spastic diplegic cerebral palsy. Tartu, 2007, 102 p.
20. **Meeli Saar.** The relationships between anthropometry, physical activity and motor ability in 10–17-year-olds. Tartu, 2008, 96 p.
21. **Triin Pomerants.** Ghrelin concentration in boys at different pubertal stages: relationships with growth factors, bone mineral density and physical activity. Tartu, 2008, 80 p.
22. **Tatjana Kums.** Musculo-skeletal function in young gymnasts: association with training loads and low-back pain. Tartu, 2008, 128 p.
23. **Maret Pihu.** The components of social-cognitive models of motivation in predicting physical activity behaviour among school students. Tartu, 2009, 116 p.
24. **Peep Päll.** Physical activity and motor skill development in children. Tartu, 2009, 102 p.
25. **Milvi Visnapuu.** Relationships of anthropometrical characteristics with basic and specific motor abilities in young handball players. Tartu, 2009, 114 p.
26. **Rita Gruodytė.** Relationships between bone parameters, jumping height and hormonal indices in adolescent female athletes. Tartu, 2010, 82 p.
27. **Ragnar Viir.** The effect of different body positions and of water immersion on the mechanical characteristics of passive skeletal muscle. Tartu, 2010, 142 p.
28. **Iti Müürsepp.** Sensorimotor and social functioning in children with developmental speech and language disorders. Tartu, 2011, 90 p.
29. **Ege Johanson.** Back extensor muscle fatigability and postural control in people with low back pain. Tartu, 2011, 106 p.
30. **Evelin Lätt.** Selected anthropometrical, physiological and biomechanical parameters as predictors of swimming performance in young swimmers. Tartu, 2011, 90 p.
31. **Raul Rämson.** Adaptation of selected blood biochemical stress and energy turnover markers to different training regimens in highly trained male rowers. Tartu, 2011, 84 p.
32. **Helen Jõesaar.** The effects of perceived peer motivational climate, autonomy support from coach, basic need satisfaction, and intrinsic motivation on persistence in sport. Tartu, 2012, 108 p.
33. **Sille Vaiksaar.** Effect of menstrual cycle phase and oral contraceptive use on selected performance parameters in female rowers. Tartu, 2012, 86 p.
34. **Anna-Liisa Parm.** Bone mineralization in rhythmic gymnasts before puberty: associations with selected anthropometrical, body compositional and hormonal parameters. Tartu, 2012, 96 p.

35. **Jelena Sokk.** Shoulder function in patients with frozen shoulder syndrome: the effect of conservative treatment and manipulation under general anaesthesia. Tartu, 2012, 125 p.
36. **Helena Liiv**. Anthropometry, body composition and aerobic capacity in elite DanceSport athletes compared with ballet and contemporary dancers. Tartu, 2014, 80 p.
37. **Liina Remmel**. Relationships between inflammatory markers, body composition, bone health and cardiorespiratory fitness in 10- to 11-year old overweight and normal weight boys. Tartu, 2014, 94 p.
38. **Doris Vahtrik.** Leg muscle function in relation to gait and standing balance following total knee arthroplasty in women. Tartu, 2014, 105 p.
39. **Artūrs Ivuškāns.** Bone mineral parameters in 11–13-year-old boys: associations with body composition and physical activity. Tartu, 2014, 95 p.
40. **Antonio Cicchella.** Relationships of multifunctional hormone leptin with anthropometry, aerobic capacity and physical activity in peripubertal boys. Tartu, 2014, 87 p.
41. **Martin Mooses**. Anthropometric and physiological determinants of running economy and performance from Estonian recreational to Kenyan national level distance runners. Tartu, 2014, 94 p.
42. **Triin Rääsk.** Subjectively and objectively measured physical activity and its relationships with overweight and obesity in adolescent boys. Tartu, 2016, 124 p.
43. **Donvina Vaitkevičiūtė.** Bone mineralization in boys during puberty: associations with body composition, physical activity and selected bone and adipose tissue biochemical markers. Tartu, 2016, 92 p.
44. **Kerli Mooses**. Physical activity and sedentary time of 7–13 year-old Estonian students in different school day segments and compliance with physical activity recommendations. Tartu, 2017, 84 p.
45. **Eva Mengel.** Longitudinal changes in bone mineral characteristics in boys with obesity and with different body mass index gain during pubertal maturation: associations with body composition and inflammatory biomarkers. Tartu, 2018, 113 p.
46. **Martin Aedma.** Assessment of the impact of selected dietary supplements on upper-body anaerobic power in wrestlers in simulated competition-day conditions. Tartu, 2018, 112 p.
47. **Henri Tilga.** Effects of perceived autonomy-supportive and controlling behaviour from physical education teachers on students' psychological needs and health-related quality of life. Tartu, 2019, 135 p.
48. **Anni Rava.** Associations between body composition, mobility and blood inflammatory biomarkers with physical activity in healthy older women. Tartu, 2019, 94 p.
49. **Silva Suvi**. Assessment of the impact of selected dietary supplements on endurance ability in high-temperature environments. Tartu, 2019, 121 p.
50. **Pärt Prommik.** Hip fracture rehabilitation during 2009–2017 in Estonia. Tartu, 2021, 147 p.

51. **Hanna Kalajas-Tilga**. Trans-contextual model of motivation predicting change in physical activity among Estonian school students. Tartu, 2022, 118 p.
52. **Rasmus Pind.** Quantification of internal training load and its use in different practical training applications. Tartu, 2022, 108 p.
53. **Dmitri Valiulin.** Effect of high-intensity priming added to common warm-up on performance among endurance athletes. Tartu, 2022, 103 p.
54. **Janno Jürgenson**. Effect of 12-week strength training and a competitive half-marathon run on arterial stiffness and blood biochemistry in well-trained male athletes. Tartu, 2022, 105 p.
55. **Mati Arend.** Effects of specific inspiratory muscle warm-up on maximal inspiratory pressure, rowing performance, and VO_2 kinetics. Tartu, 2022, 91 p.
56. **Martin Argus**. Musculoskeletal disorders in relation to work-related factors, physical activity, functional characteristics, and COVID-19 lockdown among office workers. Tartu, 2023, 109 p.
57. **Kadri Medijainen**. Effects of disease-specific physiotherapy on functional performance in patients with mild-to-moderate Parkinson's disease. Tartu, 2023, 103 p.