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WHOLE BODY COMPOSITION AND BONE MINERAL DENSITY MEASURED BY DUAL-ENERGY X-RAY ABSORPTIOMETRY IN YOUNG SWIMMERS

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Abstract: Height-adjusted indexes that reflect muscularity and fatness have recently gained great momentum in exercise and sports sciences as these indexes are considered to more accurately predict general body composition (BC) status, compared to body mass index. The aim of the study was to compare BC components and height-adjusted indexes between young swimmers and non-athlete controls. Thirty-four young volunteers, consisting of eighteen swimmers (male n=8; female n=10) and sixteen college students serving as a control group (male n=8; female n=8), participated in this study. BC and whole-body bone mineral density (BMD) were measured using DXA and height-normalized indexes of fat mass (FM) and lean mass (LM) were calculated. Two-way (group*sex) ANOVA was used to compare the BC components within and between the groups. No differences in body mass index (BMI), age, and body weight were observed between the groups (p>0.05). Swimmers had greater LM and lean mass index (LMI), and lower total body fat mass percentage (FM%), fat mass index (FMI), and visceral adipose tissue (VAT) (p<0.01) compared to controls. BMD was similar in both groups regardless of sex (p>0.05). Male swimmers had lower FM% and FMI, and higher LM than female swimmers (p<0.001). BMD was correlated with BMI, LM, LMI, appendicular LMI (r=0.47, 0.55, 0.62, 0.60, respectively; p<0.001) and FM% (r=-0.35; p=0.04). Swimmers had higher lean and lower fat mass and VAT compared to inactive college students with similar age. Accordingly, swimming improves BC components; however, it does not seem to increase bone mineral density due to the reduced weight-bearing effect.

Key Words: Swimmers, DXA, fat mass index, lean mass index, visceral adipose tissue

GENÇ YÜZÜCÜLERDE ÇİFT ENERJİ X-RAY ABSORPTIOMETRİYLE ÖLÇÜLEN TÜM VÜCUT BİLEŞİMİ VE KEMİK MİNERAL YOĞUNLUĞU

Öz: Bu araştırmanın amacı genç yüzücüler ve sporcu olmayan kontrol grubu arasında vücut kompozisyonu bileşenleri ve kas ve yağ indekslerini (kas kütle indeksi yağ kütle indeksi) karşılaştırmaktır. Bu çalışmaya 18 yüzücü (erkek n=8; kadın n=10) ve 16 kontrol grubu (erkek n=8; kadın n=8) olmak üzere 34 genç gönüllü katılmıştır. Vücut kompozisyonu ve kemik mineral yoğunluğu, Dual-Enerji X-ray absorbsiyometri kullanılarak belirlenmiştir ve boy uzunluğu ile normalize edilmiş yağ ve kas kütle indeksleri hesaplanmıştır. Gruplar içinde ve gruplar arasında vücut kompozisyonu bileşenlerini karşılaştırmak için iki yönlü ANOVA kullanılmıştır. Gruplar arasında beden kütle indeksi, yaş, vücut ağırlığı açısından fark gözlenmemiştir (p>0.05). Yüzücülerin, kontrol grubuna kıyasla kas kütlesi ve yağsız kütle indeksi daha yüksek; vücut yağ oranı, yağ kütle indeksi ve viseral yağ dokusu daha düşük bulunmuştur (p<0.01). Kemik mineral yoğunluğu, cinsiyetten bağımsız olarak her iki grupta da benzerdir (p>0.05). Erkek yüzücülerin, kadın yüzücülere göre daha düşük vücut yağ oranı ve yağsız kütle indeksine ve daha yüksek kas kütlesine sahip olduğu gözlenmiştir (p<0.001). Kemik mineral yoğunluğu; beden kütle indeksi, kas kütlesi, kas kütle indeksi, apendiküler kas kütle indeksi ile (sırasıyla r=0.47, 0.55, 0.62, 0.60; p<0.001) ve vücut yağ oranı (r=-0.35; p=0.04) ile anlamlı ilişkili bulunmuştur. Yüzücüler, benzer yaştaki aktif olmayan kontrol grubuna kıyasla daha yüksek kas kütlesi ve daha düşük yağ kütlesi ve viseral yağ dokuya sahiptir. Buna göre yüzme, vücut kompozisyonu bileşenlerini iyileştirir, ancak vücut ağırlığını taşıma etkisindeki azalma nedeniyle kemik mineral yoğunluğunda bir değişikliğe yol açmamaktadır.

Anahtar Kelimeler: Yüzücüler, DXA, yağ kütle indeksi, yağsız kütle indeksi, viseral yağ doku

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INTRODUCTION

Assessment of body composition (BC) in athletes has both health and performance implications, and thus has long been a topic of interest in exercise and sport science (Silva, 2019; Yargıç, Kürklü, Celen, & Goktepe, 2020). It is well documented that body size and BC components (such as fat and lean mass) are associated with sports performance (Atakan, 2017; Silva, 2019). Although, in general, low fat mass (FM) and high lean mass (LM) provide a good locomotor basis for athletic performance, the association of sport performance and BC components vary with regard to the nature of the sport. For instance, body fat is detrimental to athletic performance in weight-dependent activities (running, cycling, ice-skating, gymnastics etc.), while it is advantageous in contact sports (American football, wrestling, sumo wrestling etc.). Body fat improves the stability of the body and is beneficial in swimming where body fat increases buoyancy in water and serves as a heat insulator in cold water. Thus, the accurate assessment of BC is of great importance for several reasons: to determine the eligibility of the athlete for the sport and the specific position in that sport, and to monitor the effectiveness of training and nutrition programs. It is essential to determine average and reference values for each BC component in each sport branch with regard to gender, age, competition level, and position in the game where necessary.

BC measurement is performed using a variety of different methods such as skinfold testing (SKF), hydrostatic weighing (HW), bioelectrical impedance (BIA) and dual-energy X-ray absorptiometry (DXA) (Cheng et al., 2016; Malina & Geithner, 2011). During the past decade, the measurement of BC using DXA has gained important momentum as the most accurate tool for practitioners and researchers (Nana, Slater, Hopkins, & Burke, 2012). DXA provides a rapid and non-invasive technique to estimate FM and LM, plus bone mineral content (BMC) and density of the total body as well as in regions of interest (e.g., left and right arms and legs, and trunk). In addition, soft LM (SLM), visceral adipose tissue (VAT), and several indexes of fatness and leanness as well as mass distribution ratios can be calculated by using these variables. Several recent reports in athletes including swimmers showed that DXA can be used to track changes in LM and SLM, which are good indicators of body skeletal muscle mass (Carbuhn, Fernandez, Bragg, Green, & Crouse, 2010; Roelofs, Smith-Ryan, Trexler, & Hirsch, 2017).

Swimming, competed at many different levels around the world, is a full-body exercise that involves the generation of propulsive forces sufficient to overcome the effects of water resistance on the body (Moura et al., 2014). Hence, the ability of swimmers to generate this force determines maximal or submaximal performance and depends on several factors including technique, biomechanical parameters, and physical fitness (Mallett, Bellinger, Derave, Osborne, & Minahan, 2021). In turn, physical fitness and performance are associated with BC components such as LM and FM in swimming (Knechtle et al., 2020; Moura et al., 2014; Roelofs et al., 2017; Rossi, Ricci-Vitor, Sabino, Vanderlei, & Freitas, 2014), as well as in other sports (Atakan, 2017; Kosar, 2016; Malina & Geithner, 2011; Turnagol, 2016). In addition, BC affects both swimming speed and the ability to regulate body temperature in cold water, particularly in distance swimmers (Knechtle et al., 2020). In this regard, the outperformance of female swimmers over male swimmers in long-distance swimming is attributed to higher body fat percentage as well as its distribution around the lower body in female swimmers (Knechtle et al., 2020). Furthermore, in adolescent swimmers, height and body fat percentage were associated with the propulsive force of the arm, explaining 22% of the association (Moura et al., 2014). In collegiate distance swimmers, performance improvements within a season were correlated with changes in BMC and LM, indicating that greater increases in LM were correlated with greater improvements in performance (Roelofs et al., 2017). In the published literature, there are discrepancies in the results of studies that compare the BC of swimmers with individuals performing other weight-bearing activities (Barr, 1991; Dave, Subhedar, Mishra, & Sharma, 2016; Ubago-Guisado et al., 2017) and non-athlete controls (Emslander et al., 1998; Scofield & Hecht, 2012). These studies showed that swimmers have lower FM and higher LM compared to the gender and age-matched non-swimmers (Dave et al., 2016; Lozano-Berges et al., 2017; Rossi et al., 2014; Ubago-Guisado et al., 2017). It was also reported that female swimmers possessed higher body fat percentage (BF%) and lower LM than male swimmers (Lozano-Berges et al., 2017; Malina & Geithner, 2011).

Also, as swimming is a not weight-bearing activity, participating in this kind of activity (cycling, swimming) may cause lower bone mineral density (BMD) compared to athletes participating in weight-bearing activities (Abrahin et al., 2016; Emslander et al., 1998; Kosar, 2016; Mudd, Fornetti, & Pivarnik, 2007; Ubago-Guisado et al., 2017; Valente-Dos-Santos et al., 2018) and also compared to their non-athletic peers (Emslander et al., 1998; Scofield & Hecht, 2012; Ubago-Guisado et al., 2017). In the growing literature about BC of swimmers, there is only one study conducted to investigate the associations of lean and FM measures with whole-body BMC and BMD using DXA in female adolescent swimmers (Kosar, 2016). Whole body SLM and body mass index (BMI) are associated with bone health (Maillane-Vanegas et al., 2020). Changes in SLM were found to be the most relevant determinant of BMD accrual in the lower limbs, mainly among adolescents engaged in sports, including swimming (Luiz-de-Marco et al., 2020), independently of FM, so that changes in SLM within a 12-month period explained 54% and 58.5% of all variances of bone accrual in the left and right legs, respectively (Luiz-de-Marco et al., 2020). However, to the best of our knowledge, no study to date was conducted to compare whole BC and BMD among young swimmers and non-athletes using DXA. Thus, the purpose of this study was to compare BC components measured by DXA between young swimmers and age- and BMI-matched non-athlete counterparts.

METHODS

Research Group

This study included 34 young volunteers (aged 19.7±0.9 years) consisting of 18 swimmers (male: 8, female: 10), and 16 non-athlete volunteers (male: 8, female: 8) who served as control group. Swimmers had at least 12 years of swimming training with a frequency of 5 days per week and competed in four swimming styles or strokes including freestyle, backstroke, breaststroke, and butterfly across a range of distances (50 m, 100 m, 200 m, 400 m), and volunteered to participate in the present study. The control group was composed of age-, sex- and BMI-matched counterparts of swimmers, who did not participate in regular physical activity during the last 6 months. Participants were told not to take any medication, coffee or alcohol and not to be physically active at least 48 hrs preceding the test day. The experiments were performed in accordance with the ethical standards of the Helsinki Declaration and participants signed an informed consent form. Approval for this study was obtained from the Non-Interventional Clinical Research Ethics Board of Hacettepe University (Approval no: 2021/03-32).

Data Collection Tools

Body height was measured using a wall stadiometer (Holtain stadiometer, UK) to the nearest 0.1 cm and body weight was measured with a scale (Tanita TBF-401A, Germany) to the nearest 0.1 kg. Whole BC and BMD were measured by a narrow fan bean (4.5°) DXA scanner (Lunar Prodigy Pro; GE Healthcare, Madison, WI, USA) using total body scan mode. The data were analysed with GE Encore v14.1 software. The scanning mode was automatically selected by the DXA device according to body size. The DXA equipment was calibrated daily as per the manufacturer's suggestions. The reliability and validity of DXA to determine BC were established (Nana et al., 2012). Prior to DXA measurements, participants were asked to remove any metal objects that would interfere with testing. A technician assisted the participants in proper positioning to obtain the most accurate measurement based on the manufacturer's guidelines. All scans and analyses were performed by the same trained and experienced staff. Briefly, after removing shoes, the participant's body was centred using a centreline on the scanner table as a reference to align the subject. Participants' hands were placed on the side with thumbs up, palms facing legs and arms alongside the participant's body so that they were in mid-prone position with a standardized gap (1 cm) between the palms and the trunk. Finally, the head was adjusted to 3 cm below the horizontal line on the table pad and Velcro straps were used to secure the participant's knees and feet to prevent movement during the measurement. Participants were instructed to remain still throughout the scanning procedure. The laboratory precision error for regional analysis of the whole body scan, as defined by the coefficient of variation (CV) for repeated measurements in 12 young volunteers who did not participate in this study, was 2.09, 1.17, 0.75, and 0.18 for FM, body weight, LM and BMD of the whole body, respectively.

BC variables chosen for further analysis consisted of FM percentage (FM%), FM (kg), FM index (FMI), percentage of LM (LM%), LM (kg), LM index (LMI), appendicular LMI, and visceral fat volume (g). Height-adjusted indexes were calculated as follows: BMI [weight (kg)/height^2 (m)], FMI [FM (kg)/height^2 (m)], LMI [LM (kg)/height^2 (m)], and appendicular LMI [LM (arms and legs) (kg)/height^2 (m)] (Schutz, Kyle, & Pichard, 2002; VanItallie, Yang, Heymsfield, Funk, & Boileau, 1990). Total body BMD (g/cm^2) and BMD z-score were included in this study as bone mass measures.

Data Analysis

Two-way analysis of variance (2 (sex: male vs female) x 2 (group: swimmers vs control)) was used to compare means for BC components by group and sex (SPSS, Inc. Chicago, IL, USA). The significance level was set to $p<0.05$. Descriptive statistics and results are presented as mean ± standard deviation (SD). Pearson's product moment correlation coefficients were calculated to determine if there was a significant association between BC variables and bone mineral density.

RESULTS

The descriptive characteristics of male and female swimmers and non-athletes are presented in Table 1. Statistical analysis revealed that swimmers and non-athletes were similar in age, body weight, height, and BMI ($p>0.05$; Table 1), regardless of sex.

Table 1: Body composition and bone mineral density variables of swimmers and controls

	Swimmers (n=18)		Non-Athletes (n=16)	
	Males (n=8)	**Females (n=10)**	**Males (n=8)**	**Females (n=8)**
Age (yrs)	20.8 ± 1.3	19.2 ± 0.7	19.6 ± 0.5	19.3 ± 1.1
Height (cm)	177.1 ± 3.3	164.5 ± 3.3	173.6 ± 3.6	163.4 ± 3.8
Weight (kg)	68.6 ± 3.1	56.8 ± 6.2	67.0 ± 4.7	60.7 ± 3.5
BMI (kg/m^2)	21.8 ± 0.8	20.9 ± 2.2	22.2 ± 2.1	22.7 ± 1.5
DXA body mass (kg)	69.4 ± 3.2	57.4 ± 6.2	67.0 ± 4.7	61.4 ± 3.4
LM (kg)	54.7 ± 3.0	36.5 ± 2.6	50.6 ± 3.4	36.0 ± 2.1
LM (%)	78.8 ± 2.5	63.9 ± 5.2	74.7 ± 4.1	58.6 ± 2.9
LMI (kg/m^2)	17.4 ± 0.9	13.7 ± 0.8	16.7 ± 1.3	13.4 ± 0.69
App. LMI (kg/m^2)	7.9 ± 0.3	5.7 ± 0.4	7.7 ± 0.6	5.8 ± 0.3
FM (kg)	11.9 ± 1.9	18.8 ± 4.7	14.7 ± 3.5	23.3 ± 2.7
FM (%)	17.1 ± 2.4	32.2 ± 5.4	21.5 ± 4.2	37.9 ± 3.1
FMI (kg/m^2)	3.8 ± 0.6	6.9 ± 1.7	4.9 ± 1.3	8.7 ± 1.2
BMC (g)	2.872 ± 233.8	2.204 ± 163.4	2.634 ± 255.4	2.164 ± 227.7
BMD (g/cm^2)	1.24 ± 0.09	1.11 ± 0.09	1.15 ± 0.09	1.08 ± 0.09
Z-scores	0.82 ± 0.95	0.47 ± 1.00	-0.17 ± 0.97	0.02 ± 1.22

App: Appendicular, **BMI:** Body mass index, **LM:** Lean mass, LMI: Lean mass index, **FM:** Fat mass, **FMI:** Fat mass index, **BMC:** Bone mineral content, **BMD:** Bone mineral density. Mean ± SD.

Significant main effects of group were noted for LM ($F_{(1,34)}$ = 5.887, p = 0.021, η^2 = 0.164), LM% ($F_{(1,34)}$ = 11.890, p = 0.002, η^2 = 0.284), FM ($F_{(1,34)}$ = 9.339, p = 0.005, η^2 = 0.237), FM% ($F_{(1,34)}$ = 12.814, p = 0.001, η^2 = 0.299), FMI ($F_{(1,34)}$ = 10.394, p = 0.003, η^2 = 0.257) and estimated VAT ($F_{(1,34)}$ = 11.664, p = 0.002, η^2 = 0.287), (Fig. 1A-F). This indicates that swimmers had greater LM, LM%, and lower FM, FM%, FMI and VAT than controls. However, there was no significant group effect for LMI, appendicular LMI, BMC, BMD or z-scores of BMD, showing that swimmers and controls were similar with respect to these variables (p>0.05, Table 1).

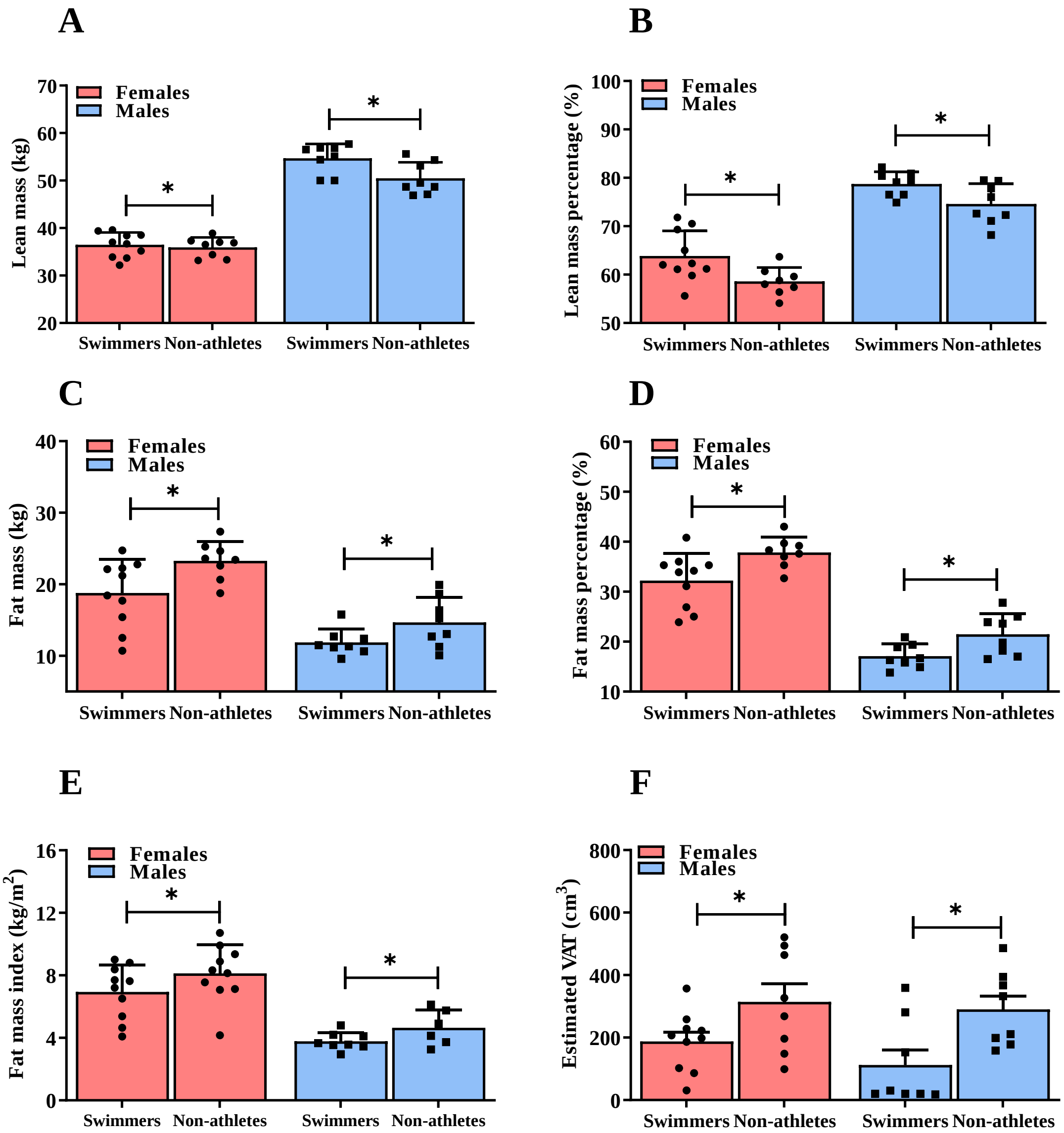

Figure 1. Difference in lean mass (A), lean mass percentage (B), fat mass (C), fat mass percentage (D), fat mass index (E) and estimated visceral adipose tissue (F) in swimmers and non-athletes. *p<0.05 significant difference between the groups. VAT; visceral adipose tissue. Mean ± SD.

We found significant main effects of sex for FM ($F_{(1,34)}$ = 42.564, p = 0.001, η^2 = 0.587), FM% ($F_{(1,34)}$ = 127.435, p = 0.001, η^2 = 0.809), FMI ($F_{(1,34)}$ = 59.575, p = 0.001, η^2 = 0.665), LM ($F_{(1,34)}$ = 288.793, p = 0.001, η^2 = 0.906), LM% ($F_{(1,34)}$ = 128.944, p = 0.001, η^2 = 0.811), LMI ($F_{(1,34)}$ = 133.419, p = 0.001, η^2 = 0.816), appendicular LMI ($F_{(1,34)}$ = 289.904, p = 0.001, η^2 = 0.906), BMC ($F_{(1,34)}$ = 56.672, p = 0.001, η^2 = 0.654), and BMD ($F_{(1,34)}$ = 10.311, p = 0.003, η^2 = 0.256). This indicates that males had higher LM, LM%, LMI, appendicular LMI, and lower FM, FM % and FMI compared to females (Fig. 2A-2I). There was no main effect of sex on either VAT ($F_{(1,34)}$ = 1.213, p = 0.280, η^2 = 0.040) or BMD z-scores ($F_{(1,34)}$ = 0.046, p = 0.831, η^2 = 0.002), suggesting that these variables were similar between males and females. No interaction of sex and group was noted for any of the variables measured (p>0.05).

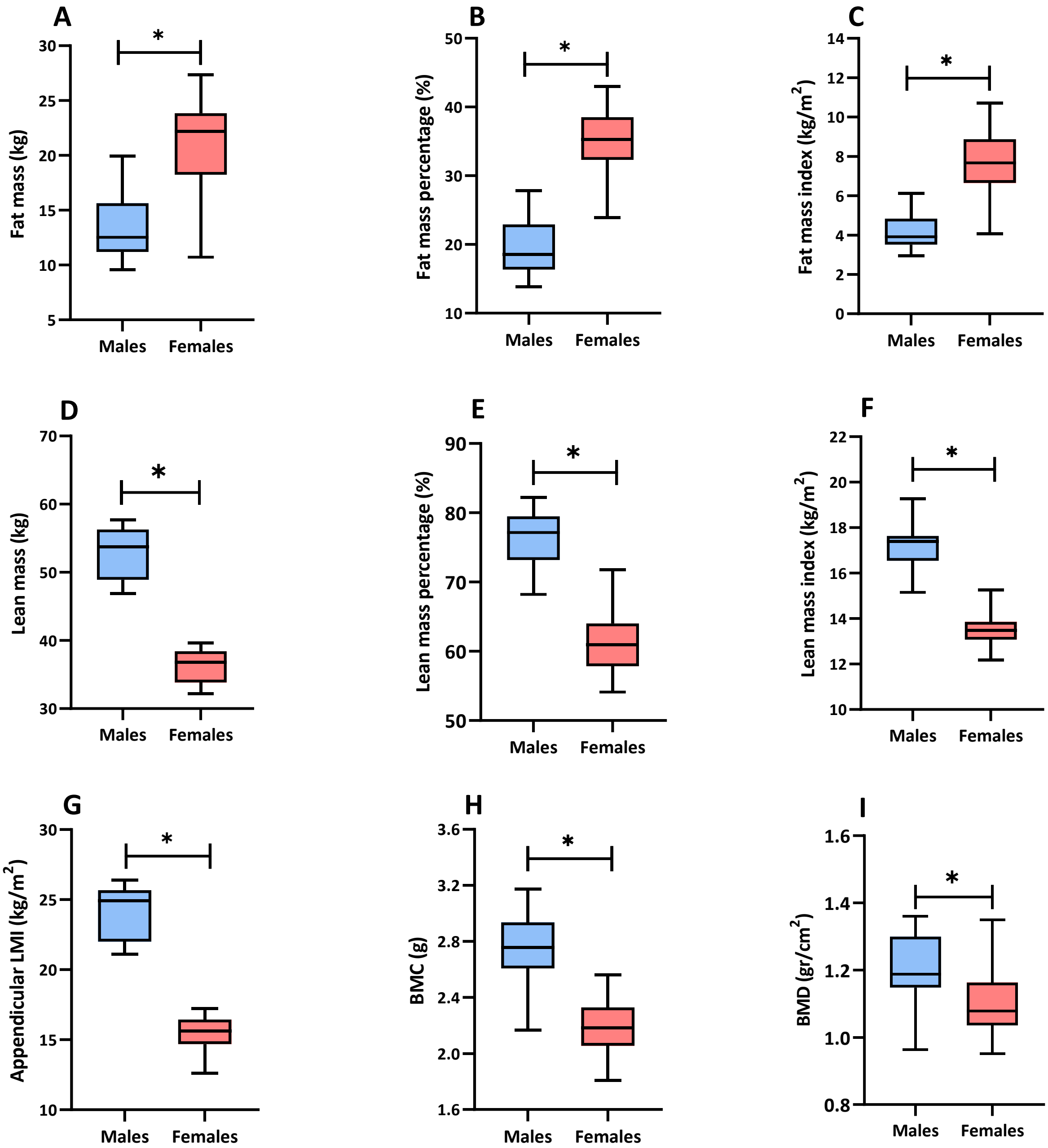

Figure 2. Box and whisker plot of difference between males and females in fat mass (A), fat mass percentage (B), fat mass index (C), lean mass (D), lean mass percentage (E), lean mass index (F) appendicular lean mass index (G), bone mineral content (H) and bone mineral density (I). *p<0.05 significant difference between genders. VAT; visceral adipose tissue, LMI; lean mass index, BMC; bone mineral content, BMD; bone mineral density. The bottom and top of the box represent the minimum and maximum values, respectively; the band inside the box represent the median.

When swimmers and controls are combined into one group, BMD was positively associated with BMI (r=0.47; p=0.005, Fig. 3A), LM (r=0.55; p=0.001, Fig. 3B), LMI (r=0.62; p<0.001, Fig. 3C), and appendicular LMI (r=0.60; p<0.001, Fig. 3D) and negatively associated with FM% (r= -0.35; p=0.04, Fig. 3E).

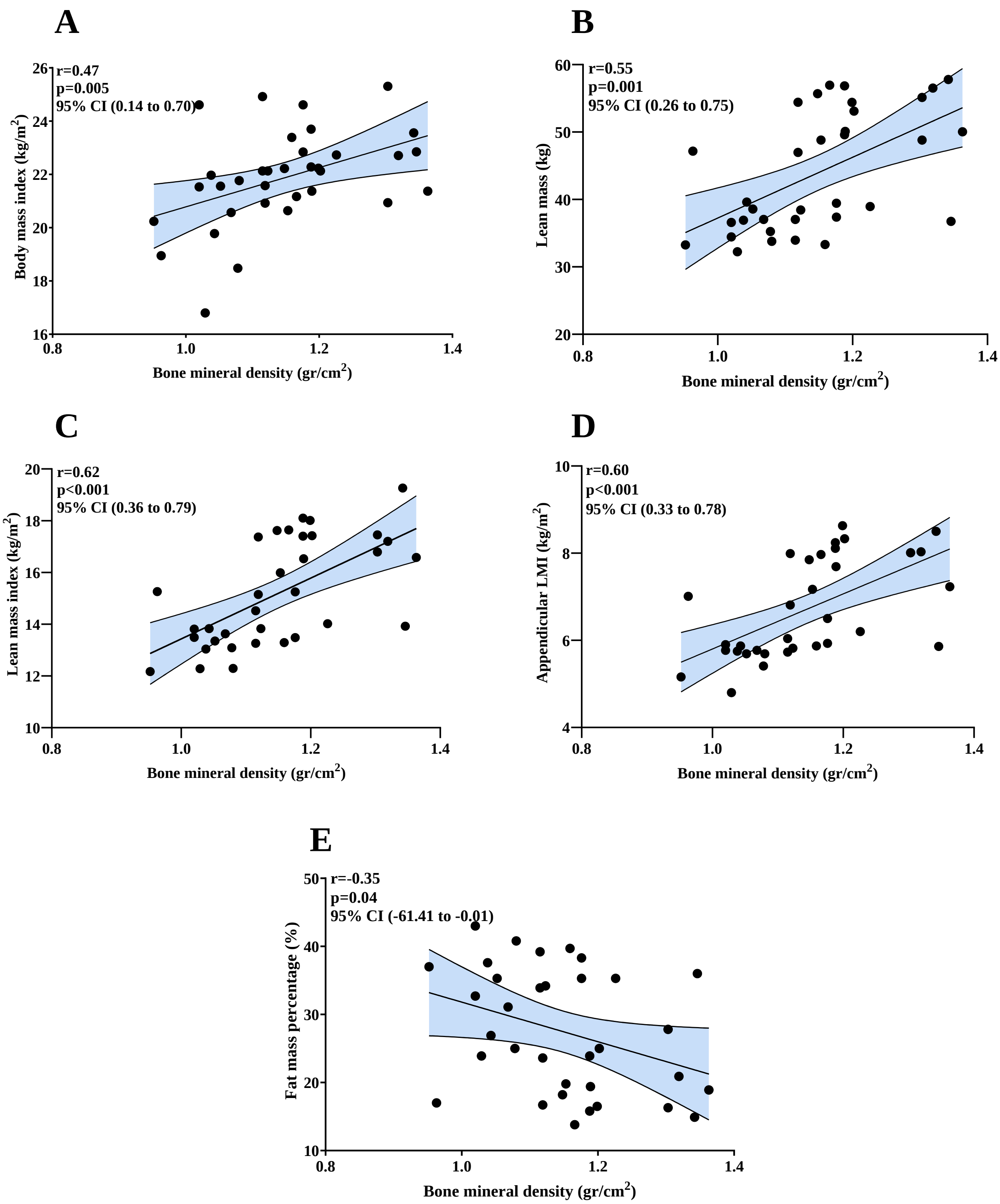

Figure 3. Association of bone mineral density with body mass index (A), lean mass (B), lean mass index (C), appendicular lean mass index (D), fat mass percentage (E). LMI; lean mass index, CI; confidence interval.

DISCUSSION

This study compared the body composition of swimmers with non-athlete controls and reported the height-adjusted indexes of FM and LM measured by DXA. The findings of the present study demonstrated that male and female swimmers have greater LM, and lower FM and VAT than age- and BMI-matched non-athlete controls. Also, male swimmers had greater LM and lower FM compared to female swimmers. BMD was similar between swimmers and non-athletes. Finally, BMD was positively correlated with BMI, LM, LMI, and appendicular LMI, and negatively associated with FM%.

Since BC is accepted as one of the key factors substantially contributing to optimal performance (Rossi et al., 2014), accurate measurement of BC is an important issue in sport science. In sports, regardless of the training period, FM and LM are considered to be the essential components for improving performance (lChalencon et al., 2012). As expected, various alterations in BC were observed in various studies of swimmers due to the specific nature of the sport and the characteristics of training, as well as exposure to an aquatic environment (Gomez-Bruton, Gonzalez-Aguero, Gomez-Cabello, Casajus, & Vicente-Rodriguez, 2013). Although FM may partially provide more buoyancy in water, increased body volume due to excess FM may increase water resistance and drag. Thus, the effort required to pull the body through the water increases, slowing swimming speed considerably, particularly when combined with low LM (Ilka, 1994). For swimmers, therefore, ideal BC that includes the appropriate amount of FM and LM is of the utmost importance for optimal performance (Rossi et al., 2014). Overall BC, BMC and BMD values of both male and female swimmers in the present study were similar to previously reported values for swimmers (Santos et al., 2014). However, body fat percentage of female swimmers in the present study was high (32.2%) compared to previous reports (12.5%) (Santos et al., 2014). In addition, FMI (male: 3.8±0.6 kg/m2 and female: 6.9±1.7 kg/m2), LMI (male: 17.4±0.9 kg/m2 and female: 13.7±0.8 kg/m2), and appendicular LMI (male: 7.9±0.3 kg/m2 and female: 5.7±0.4 kg/m2) values in our study were similar to previously reported values (Santos et al., 2014).

The findings of this study revealed that swimmers had greater LM and indexes of muscularity than controls who had greater FM, fatness indexes and VAT than swimmers, which is consistent with the findings of previous studies (Barr, 1991; Dave et al., 2016; Kosar, 2016; Lukaski, B.S. Hoverson, S.K. Gallagher, & Bolonchuk., 1990; Rossi et al., 2014). This difference observed between swimmers and non-athletes can be partially attributed to the results of organized training, which benefits muscle maintenance as well as decreases FM in swimmers. A recent systematic review and meta-analysis reported that long-term swim training offers robust beneficial effects on BC with significantly reduced FM% and increased LM in swimmers compared to controls (Lahart & Metsios, 2018). In addition, physical activity is known to affect adipose tissue both acutely and in the longer term; as such, even a single bout of exercise increases adipose tissue blood flow and fat mobilization, resulting in delivery of fatty acids to other tissues, skeletal muscles in particular, (Thompson, Karpe, Lafontan, & Frayn, 2012) and reduces dietary fat storage in adipose tissue. Chronic exercise training changes adipose tissue physiology by enhancing fat mobilization during exercise and physical activity-induced sympathetic activation was reported to significantly reduce VAT in obese and non-obese individuals (Ross et al., 2000). A meta-analysis study by Ohkawara reported that at least 10 METs·h per week aerobic exercise is required to observe a significant reduction in VAT (Ohkawara, Tanaka, Miyachi, Ishikawa-Takata, & Tabata, 2007). More recently, Vissers et al. reviewed fifteen articles to describe the overall effect of exercise on VAT and concluded that even twelve weeks of aerobic exercise is a potent stimulus to reduce VAT more than 30 cm2 in women and more than 40 cm^2 in men (Vissers et al., 2013). The findings of these meta-analyses show that regular exercise has beneficial health effects on FM and VAT, explaining the differences in FM and VAT observed between swimmers with 12 years of swimming training and non-athletes in the present study.

In the present study, we also found greater FM% and fatness indexes in female swimmers compared with male swimmers, which is in line with the findings of previous studies comparing BC components between young male and female competitive swimmers (Avlonitou, Georgiou, Douskas, & Louizi, 1997; Dave et al., 2016). Substantial factors favouring early fat accumulation in females may be due to the gender difference in the adipocyte-derived hormone leptin, which was reported to be up to 4 times higher in women than in men (Marta Garaulet, Francisca PeÂrez-Llamas, Teodomiro Fuente, Salvador Zamora, & Tebar, 2000) and is associated with adiposity (Hassink et al., 1996; Nindl, Scoville, Sheehan, Leone, & Mello, 2002). Also, hormones associated with childbirth and breastfeeding are other major factors causing high fat storage in females. Alternatively, it is known that women tend to consume more fat, saturated fat, carbohydrates, and protein than men as a percentage of total energy. All of these factors can explain the higher FM in female swimmers compared to male swimmers (Nasreddine et al., 2020). However, as we did not check the energy intake of the participants, which would have contributed the study in discussing the effects of nutrition intake on FM, further carefully designed studies considering the energy intake of swimmers are warranted for this assumption.

Swimming is known to be a non-weight-bearing aerobic activity that was reported not to be associated with improvements in bone health and BMD (Kirk L. & Suzanne, 2012). The development of a functionally and mechanically appropriate bone structure is greatly dependent on loading of the skeleton (Hind, Gannon, Whatley, Cooke, & Truscott, 2012). However, the loading associated with swimming is based on muscular contractions against water resistance which may not be a potent stimulus to elicit positive bone response (Hind et al., 2012). Accordingly, athletes who engage in sports requiring high impact loading have greater peak force and greater peak strain on bone, which in turn result in a greater osteogenic response (Carbuhn et al., 2010; Valente-Dos-Santos et al., 2018). Indeed, a study supporting this notion showed that youth female volleyball players had moderately higher levels of BMD of the lower limbs compared to swimmers (Valente-Dos-Santos et al., 2018). In the present study, we did not find significant difference in BMD between swimmers and non-athletes, which is consistent with previous studies reporting similar BMD in male and female swimmers compared to non-athlete counterparts (Abrahin et al., 2016; Emslander et al., 1998), and lower BMD in swimmers than other athletes (Hind et al., 2012). However, a study by Lima et al. reported higher BMD in swimmers than the control group (Lima, De Falco, Baima, Carazzato, & Pereira, 2001) and this difference was explained by the difference in body weight between the groups.

As a non-pharmacological approach, physical activity is known to be an effective intervention to promote BMD, the impact of which is greatly dependent on the type, intensity, frequency, and duration of exercise. However, given the lack of weight-bearing impact, unsurprisingly swimming doesn't seem to improve bone density compared to non-athlete controls (Abrahin et al., 2016; Akgül, Kanbur, Cinemre, Karabulut, & Derman, 2015). In addition, we found that BMD was positively correlated with BMI, LM, and indexes of LM and negatively correlated with FM%. These findings are similar to the findings of previous research that documented LM as an independent predictor of both regional and total BMD in different athletes including gymnasts, non-weight-bearing elite swimmers and cyclists as well as non-athlete controls (Borgard & McDermott, 2010; Lima et al., 2001; Vlachopoulos et al., 2017). Furthermore, Lima et al. showed a strong correlation between BMD and body weight ($r = 0.92$), LM ($r = 0.92$) and BMI ($r = 0.76$), with an insignificant negative correlation ($r = -0.42$) between FM% and BMD in adolescent swimmers and water polo athletes (Lima et al., 2001). Similarly, compelling evidence shows that BMD is positively and negatively associated with

LM and FM, respectively (Andreoli, Celi, Volpe, Sorge, & Tarantino, 2012; Zhu et al., 2017). This association of BMD with LM and FM may be explained by the fact that bone tissue is sensitive to various mechanical stimuli, especially caused by gravity and muscular contractions.

It is well documented that the negative impact of excess body fat on bone metabolism is partially dependent on the association between increased FM, pro-inflammatory cytokines and reduced serum insulin-like growth factor I levels, causing bone resorption and reduced bone formation (Braun & Schett, 2012; Bredella et al., 2011). Moreover, the changes in cytokine secretion with increased adiposity, such as increased leptin and decreased adiponectin, may affect bone formation (Cao, 2011). Also, excess level of FM was linked to lower vitamin D status (Bolland, Grey, Ames, Mason, et al., 2006) and increased parathyroid hormone concentration (Bolland, Grey, Ames, Horne, et al., 2006), both of which are known to exert a profound impact on BMD.

The limitations of this study are the lack of dietary information, injury histories, detailed menstrual histories, genetic information, and hormonal status. Further studies that consider these factors may provide further information. In addition, we recruited 34 participants (18 swimmers and 16 non-athletes); therefore, the findings of the study cannot be generalized due to the small sample size. Similar studies with larger sample sizes are needed to elucidate the differences in BC of swimmers and non-athletes. The study also has several strengths. First, this study is one of the limited studies reporting height-normalized indexes of LM and FM in swimmers. Second, DXA was the method of choice among the different methods available for BC assessment in the current study, which is superior to any two compartment BC testing techniques because of its ability to directly measure the density of three body compartments including LM, FM, and BMC.

CONCLUSION

In summary, the present study demonstrated that male and female swimmers have greater LM and lower FM and VAT compared with non-athletes of similar age and BMI, whilst male swimmers had higher LM and lower FM than female swimmers. BMD is positively associated with BMI and LMI, and is negatively associated with FM, showing that excess FM without an accompanying increase in LM may be deleterious to bone health in swimmers. Given that changes in body composition parameters, specifically FM and LM can exert profound effects on physical performance and health, particularly bone health, trainers should closely consider monitoring the body composition of their athletes. From this point of view, maintaining a healthy diet program during their training period is likely to be a pivotal approach for optimal body composition. To this end, sports dietetics should assist coaches in making meaningful and accurate diet and body composition assessments. Additionally, since the findings of the present study showed that swimming does not enhance bone mineral density compared to non-athlete controls, sports scientists and coaches should consider combining weight-bearing exercise regimens with swimming training programs to improve bone mineral density.

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