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Skinfold thickness variation and associations with cardiorespiratory fitness in male soccer players of different ages

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Abstract. – OBJECTIVE: The aim of the present study was to examine skinfold thickness (SKF) distribution in youth and adult male soccer players regarding cardiorespiratory fitness (CRF) and the role of age.

PATIENTS AND METHODS: Participants were youth [n=83, age 16.2 (1.0) years, mean (standard deviation)] and adult male soccer players [n=121, 23.2 (4.3) years], who were tested for SKF on 10 anatomical sites and Conconi test was used to assess velocity at maximal oxygen uptake (vVO_2max).

RESULTS: A between-within-subjects analysis of variance revealed a small interaction between the anatomical site and age group on SKF (*p*=0.006, η^2=0.022), where adolescents had larger cheek (+0.7 mm; *p*=0.022; 95% confidence intervals – CI – 0.1, 1.3), triceps (+0.9 mm; *p*=0.017; 95% CI 0.2, 1.6) and calf (+0.9 mm; *p*=0.014; 95% CI 0.2, 1.5) SKF, while adults had larger chin (+0.5 mm; *p*=0.007; 95% CI 0.1, 0.8) SKF, and no difference was observed for the rest of the anatomical sites. No difference between adolescent and adult age groups was observed in average SKF (SKFavg) [9.0 (2.7) *vs.* 9.1 (2.5) mm; difference -0.1 mm; 95% CI, -0.8, 0.6; *p*=0.738]. Compared to adults, adolescents had a lower SKF coefficient of variation (SKFcv) [0.34 (0.10) *vs.* 0.37 (0.09); difference-0.03; 95% CI, -0.06, -0.01; *p*=0.020] and subscapular-to-triceps ration (STR) [1.08 (0.28) *vs.* 1.29 (0.37); difference-0.21; 95% CI, -0.31, -0.12; *p*<0.001]. The largest Pearson moment correlation coefficient between vVO_2max and SKF was shown in the subscapular (r=-0.411; 95% CI, -0.537, -0.284; *p*<0.001) and the smallest in the patellar anatomical site (r=-0.221; 95% CI, -0.356, -0.085; *p*=0.002). In addition, vVO_2max correlated moderately with SKFavg (r=-0.390; 95% CI, -0.517, -0.262; *p*<0.001) and SKFcv (r=-0.334; 95% CI, -0.464, -0.203; *p*<0.001).

CONCLUSIONS: In summary, CRF was related to the thickness of specific SKF and the magnitude of thickness variation by the anatomical site (i.e., the smaller the variation, the better the CRF). Considering the relevance of specific SKF for CRF, their further use would be recommended for monitoring physical fitness in soccer players.

Key Words:
Adiposity, Age groups, Anthropometry, Exercise test, Football, Men.

Introduction

The association of body fat percentage (BF) and cardiorespiratory fitness (CRF) with performance in soccer has been well known since the 1980's when it was observed that male soccer players competing at high-performance levels showed low BF and high CRF[1,2]. Although soccer has evolved since then, the role of BF and CRF remains equally important nowadays[3]. For instance, the total sprint distance covered in a match was related to low BF and high CRF[3]. Moreover, BF has been associated with CRF[4,5], i.e., the lower the BF, the higher the CRF and *vice versa*. Nevertheless, the existing literature on the relationship between BF and CRF concerning the role of BF in the human body[6,7], and the role of fat distribution on CRF has not been examined so far. Fat distribution refers to the pattern of fat being allocated in various anatomical sites of the human body, e.g., arms, legs and trunk[8]. It was shown that fat distribution among arms, legs and trunk changed across a competitive season[8]. So far, fat distribution in soccer players has been studied using dual-energy X-ray absorptiometry (DXA)[8] and bioelectric impedance vector analysis (BIVA)[9].

DXA and BIVA have been acknowledged as more valid assessment methods than skinfold thi-

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ckness (SKF); nevertheless, they also had some drawbacks (e.g., equipment cost). On the other hand, the SKF method has been used widely in soccer to estimate BF[4,10]. SKF provides information concerning local fat distribution in the human body and is also considered an index to determine adiposity since subcutaneous fat reflects the amount of fat present in the adipose tissue[11]. The validity of the SKF method has been confirmed in soccer using DXA as a criterion method[12]. A comparison of beginners and experienced adolescent soccer players indicated larger differences in triceps than in abdominal SKF, with the latter being thinner than the former[10]. A subscapular-to-triceps SKF ratio (STR) has been used widely as an index of truncal to peripheral adiposity in non-athletes considering the relevance of truncal fat for health[13-15].

Although the relationship between CRF and BF in soccer players has been well-known[1,2], less information was available regarding the role of fat distribution estimated by the variation of SKF. Moreover, since it was suggested that BF did not differ by age in soccer[16-19], it would be interesting to verify this observation separately for each anatomical site of SKF or other measures of fat distribution such as STR. Such information might provide practical tools for coaches and fitness trainers working with male soccer players. E.g., with which anatomical SKF site CRF correlates more might aid in effectively monitoring performance indices and focusing on specific SKF anatomical sites. Furthermore, suppose CRF correlates not only with SKF sum but also with SKF variation. In that case, coaches and fitness trainers should consider the SKF variation during body composition assessment in addition to the total score of SKF. Another aspect of practical significance, especially for those working with adolescent soccer players, would be the identification of age-related patterns of SKF distribution in addition to the well-known lack of difference in BF between adolescent and adult soccer players[16-19]. Therefore, the aim of the present study was to examine SKF variation in male soccer players with regards to (a) variation by anatomical site, (b) differences between age groups (adolescents vs. adults), and (c) the relationship with CRF. We hypothesized that (a) the highest SKF would be in anatomical sites reflecting the "apple" pattern of fat deposit in men (i.e., iliac crest and abdominal); (b) no age-related difference would be observed; and (c) the CRF would correlate significantly with anatomical sites with large SKF.

Patients and Methods

Fat distribution in soccer players and its relevance for CRF were examined by a cross-sectional study design. The study and the testing protocols were conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of EPL (1/1-8-2008) date of approval). The reporting of this study considered the STROBE guidelines to enhance the quality and transparency of clinical research[20]. Participants were adolescent [n=83, age 16.2 (1.0) years, mean (standard deviation)] and adult male soccer players [n=121, 23.2 (4.3) years] from the region of Athens. They were recruited through an invitation to soccer clubs in this region. Exclusion criteria were the presence of any illness, injury or other conditions preventing them from exercise training. Inclusion criteria were sex (male), older than 14 years, and regular soccer training participation. Concerning the required sample size for the present study, a power analysis was conducted using G*Power Software[21] (Universität Mannheim, Mannheim, Germany) and considering previous research showing a correlation between estimated maximal oxygen uptake (VO2max) and the sum of SKF 0.34[22]. Based on this analysis, it was found that a sample size of 66 for each age group would be necessary. The training status of participants included three to five training units (depending on the age group, the older the age group, the larger the number of training units) and one official match weekly. Testing procedures were performed on two days separated by one week; day one included an evaluation of body mass, height, and BF evaluated in an exercise physiology laboratory, whereas day two consisted of a graded exercise test (Conconi test) performed in the field.

Testing Procedures

An electronic body mass scale (HD-351; Tanita, Arlington Heights, IL, USA) and a stadiometer (SECA Leicester, UK) measured body mass and body height, respectively, and based on these parameters, body mass index was calculated. SKF was measured using a Harpenden skinfold caliper (Harpenden, West Sussex, UK) on 10 anatomical sites (cheek, chin, pectoral I, triceps, subscapular, abdominal, pectoral II, iliac crest, thigh, and calf) according to Parizkova's methodology described in Eston and Reilly[23]. Chest I refers to the diagonal fold between the anterior axillary line and the nipple. In contrast, pectoral II refers to the vertical SKF in the midaxillary line at the level of the xiphoid process. These anatomical sites have been used widely in children, adolescents and adults[24-27]. The CRF was assessed using Conconi protocol[28], a field incremental running test with starting speed 9 $km.h^{-1}$, which increased by 0.3-0.7 $km.h^{-1}$ every 200 m until volitional exhaustion, and the end speed was recorded as velocity at VO_2max (vVO_2max). Heart rate was continuously monitored during this test by Team2 Pro (Polar Electro Oy, Kempele, Finland) and the end HR was noted as HRmax. Test-retest intraclass correlation coefficient (ICC) for SKF was 0.989, whereas inter-rater ICC was 0.999 in women and men of different fitness level[29]. Based on published data[30], we calculated an ICC of 0.845 for vVO_2max. The Conconi protocol has been widely used in the recent literature[31-34]. For instance, it was used to evaluate the effectiveness of high-intensity interval training in physically active men[31] and diet in male runners[32], to track CRF in conscripts[33] and to study methodological aspects such as pacing adherence[34]. Considering the criticism of the Conconi protocol to evaluate the anaerobic threshold[30,35,36], we did not consider the analysis of the deflection point between HR and running speed and used this test to evaluate only vVO_2max. Furthermore, SKF has also been used in the recent literature to evaluate BF in soccer players[37-40].

Statistical Analysis

The average value of SKF (SKFavg) and the coefficient of variation (CV) were calculated for the SKF of all anatomical sites (SKFcv). A repeated-measures analysis of variance (ANOVA) examined differences in SKF among anatomical sites. Eta square (η^2) estimated the magnitude of effect size and was categorized as small ($0.010<\eta^2\leq 0.059$), medium ($0.059<\eta^2\leq0.138$) and large ($\eta^2>0.138$)[41]. The repeated-measures ANOVA was used – instead of one-way ANOVA – considering that the same participants were measured more than once on the same dependent variable (SKF). A between-within subjects ANOVA tested the interaction of the age group with the anatomical sites on SKF. For each anatomical site, an independent *t*-test compared adolescents and adults. The Pearson moment correlation coefficient r examined the relationship between vVO_2max and SKF. The statistical tests were conducted on IBM SPSS v.26.0 (IBM, Armonk, NY, USA) and GraphPad Prism v.7.0 (GraphPad Software, San Diego, CA, USA). The Alpha level was set at 0.05.

Results

Anthropometric Characteristics, Skinfold Thickness and Cardiorespiratory Fitness of Participants

The anthropometric characteristics, SKF and CRF of the participants, and their variation by age group can be seen in Table I. No difference between age groups was observed in vVO_2max (+0.2 $km.h^{-1}$; 95% confidence intervals, CI, -0.3, 0.7; $p=0.462$) and SKFavg (-0.1 mm; 95% CI, -0.8, 0.6; $p=0.738$). Compared to adults, adolescents had a higher HRmax (+3.6 bpm; 95% CI, 1.1, 6.2; $p=0.005$), were younger (-7.0 years; 95% CI, -7.9, -6.0; $p<0.001$), lighter (-7.4 kg; 95% CI -9.7, -5.2; $p<0.001$), shorter (-3.0 cm; 95% CI, -4.9, -1.1; $p=0.001$), had a lower BMI (-1.6 $kg.m^{-2}$;

Table I. Anthropometric characteristics, skinfold thickness and cardiorespiratory fitness of participants.

Parameter	Total (n=204)	Adolescents (n=83)	Adults (n=121)	*p*-value
Age (years)	20.3±4.8	16.2±1.0	23.2±4.3	<0.001*
Body mass (kg)	71.6±8.8	67.2±8.2	74.6±7.9	<0.001*
Height (cm)	177.4±6.6	175.6±6.8	178.6±6.3	0.001*
BMI ($kg.m^{-2}$)	22.7±2.2	21.8±2.1	23.4±1.9	<0.001*
vVO_2max ($km.h^{-1}$)	15.9±1.7	16.0±1.8	15.8±1.6	0.462
HRmax (bpm)	197.5±9.1	199.7±7.1	196.0±10.1	0.005*
SKFavg (mm)	9.1±2.6	9.0±2.7	9.1±2.5	0.738
SKFcv	0.36±0.10	0.34±0.10	0.37±0.09	0.020*
STR	1.21±0.35	1.08±0.28	1.29±0.37	<0.001*

BMI, body mass index; vVO_2max, the velocity at maximal oxygen uptake; HRmax, maximal heart rate; SKFavg, average skinfold thickness of 10 anatomical sites; SKFcv, coefficient of variation of skinfold thickness of 10 anatomical sites; STR, subscapular to triceps skinfold thickness ratio. Values are presented as means±standard deviations. The symbol * denotes significant difference between age groups at $p<0.05$.

95% CI, -2.2, -1.0; $p<0.001$), SKFcv (-0.03; 95% CI, -0.06, -0.01; $p=0.020$) and a lower STR (-0.21; 95% CI, -0.31, -0.12; $p<0.001$).

Anatomical Site and Age Group

A large main effect of the anatomical site on SKF was observed ($p<0.001$, $\eta^2=0.551$) with the abdomen [13.8 (6.2) mm, mean (standard deviation)] and iliac crest [13.9 (6.3) mm] being the largest, and chin the lowest [5.2 (1.2) mm] (Figure 1). No main effect of age group on SKF was shown ($p=0.738$, $\eta^2=0.001$). A small interaction between the anatomical site and age group on SKF was found ($p=0.006$, $\eta^2=0.022$), where adolescents had larger cheek (+0.7 mm; $p=0.022$; 95% confidence intervals – CI – 0.1, 1.3), triceps (+0.9 mm; $p=0.017$; 95% CI 0.2, 1.6) and calf (+0.9 mm; $p=0.014$; 95% CI 0.2, 1.5) SKF, while adults had larger chin (+0.5 mm; $p=0.007$; 95% CI 0.1, 0.8) SKF, and no difference was observed for the rest of the anatomical sites.

Correlational Analysis of vVO_2max vs. Anatomical Sites by Age Group

In the total sample, the correlation analysis of vVO_2max with the SKF of anatomical sites showed small (chin, triceps, patellar, and calf) to moderate (subscapular, pectoral I, pectoral II, abdominal, and iliac crest) correlations for all anatomical sites except for the cheek (Figure 2). In this sample, the largest correlation was observed in subscapular and the smallest in patellar SKF. When age groups were considered, vVO_2max did not correlate with SKF of the cheek (adolescents and adults), triceps (adults), patellar (adolescents) and calf (adults) ($p>0.05$) (Table II). The largest correlation was observed in the subscapular site for adolescents and the abdominal site for adults, whereas the smallest was shown in the chin and pectoral II sites, respectively. In addition, vVO_2max correlated moderately with SKFavg (r=-0.390; 95% CI, -0.517, -0.262; $p<0.001$) and SKFcv (r=-0.334; 95% CI, -0.464, -0.203; $p<0.001$) in the total sample, r=-0.470 (95% CI, -0.669, -0.276; $p<0.001$) and r=-0.351 (95% CI, -0.562, -0.145; $p=0.001$), respectively, in adolescents, and r=-0.321 (95% CI, -0.489, -0.148) and r=-0.312 (95% CI, -0.492, -0.142; $p<0.001$), respectively, in adults. There was a small correlation between vVO_2max and STR in adults (r=-0.183; 95% CI, -0.345, -0.005; $p=0.044$), but not in the total sample (r=-0.136; 95% CI, -0.257, 0.020; $p=0.053$) and adolescents (r=-0.034; 95% CI, -0.272, 0.200; $p=0.761$).

Discussion

The main findings of the present study were that (a) age groups did not differ for CRF and overall subcutaneous adiposity (SKFavg), (b)

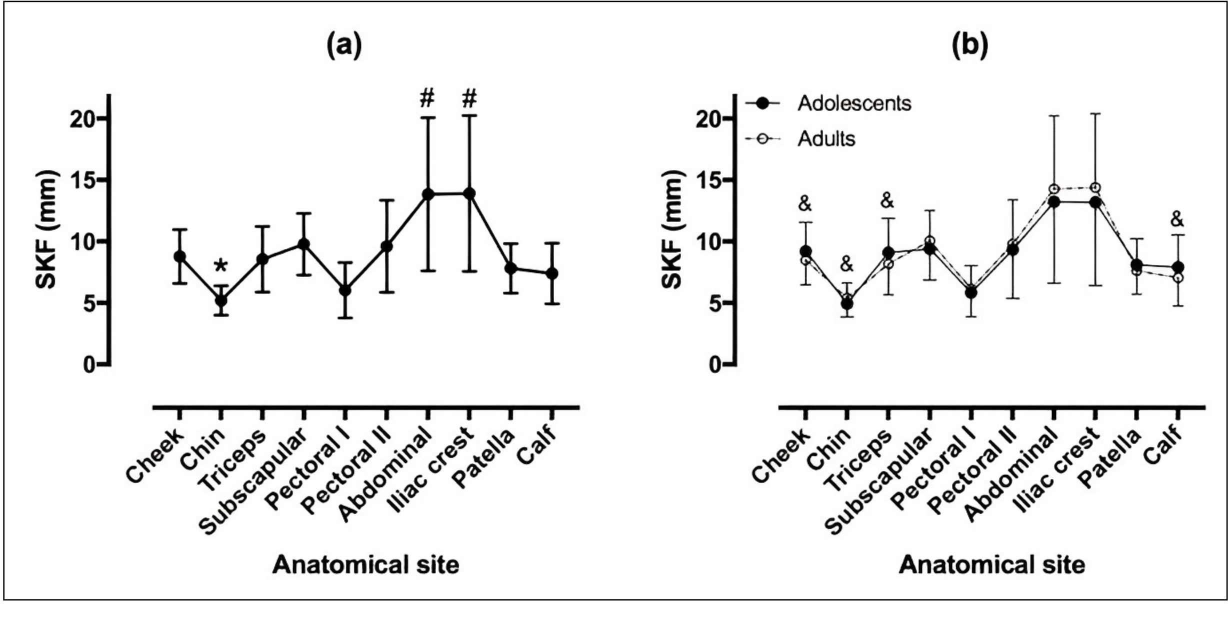

Figure 1. Variation of skinfold thickness by the anatomical site in all participants (**a**) and age groups (**b**). SKF, skinfold thickness; *the smallest SKF, # the largest SKF, & difference between age groups at $p<0.05$.

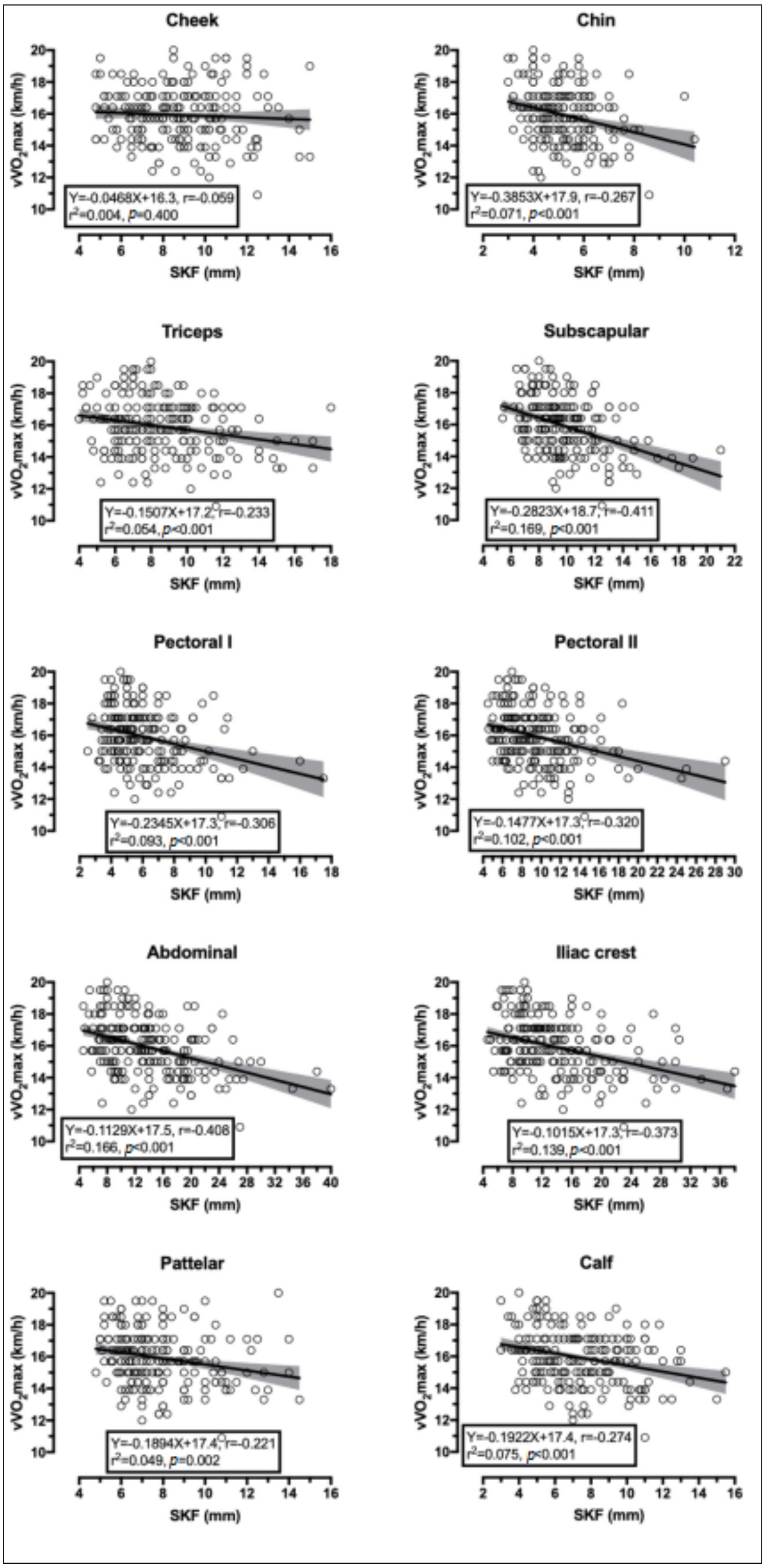

Figure 2. Correlation of cardiorespiratory fitness (velocity at maximal oxygen uptake, vVO_2max) with skinfold thickness by anatomical site. The line represents the best-fit one of linear regression. The goodness of fit is shown by r^2.

Table II. Correlation between cardiorespiratory fitness (velocity at maximal oxygen uptake) and skinfold thickness by anatomical site and age group.

	Age group			
	Adolescents		Adults	
Anatomical site	r	p	r	p
IIEF Cheek	0.041	0.713	-0.168	0.066
Chin	-0.246	0.025	-0.277	0.022
Triceps	-0.417	<0.001	-0.099	0.282
Subscapular	-0.487	<0.001	-0.348	<0.001
Pectoral I	-0.346	0.001	-0.273	0.002
Pectoral II	-0.439	<0.001	-0.216	0.017
Abdominal	-0.436	<0.001	-0.380	<0.001
Iliac crest	-0.473	<0.001	-0.281	0.002
Patellar	-0.215	0.051	-0.240	0.008
Calf	-0.458	<0.001	-0.138	0.132

adolescents had smaller SKFcv, STR than adults, (c) adolescents had larger cheek, triceps and calf SKF, and smaller chin SKF than adults, (d) CRF was related with the SKF of anatomical sites with small (chin, triceps, patellar, and calf) to moderate (subscapular, pectoral I, pectoral II, abdominal and iliac crest) correlations for all anatomical sites except for the cheek, (e) the magnitude of these correlations varied by age group.

SKF by Age Groups

The lack of differences between age groups for most anatomical sites was in agreement with the existing literature[16-19]. A review[16] on this topic showed no association between BF and age. No difference in BF assessed by BIA method between age groups (10, 12, and 14 years) was found previously[17]. Moreover, no difference in BF estimated by the SKF method was shown among under-14, under-16 and under-18 groups (SKF)[18] or from under-12 to under-21 and senior group[19]. Exceptionally, a study[42] observed lower BF assessed by the SKF method in the senior group and under-23 compared to the under-16 and under-19 group, a discrepancy that might be attributed to the potential role of performance level (the higher the performance level, the lower the BF)[16]. It is noteworthy that from 7 to 32 years, CRF (physical working capacity at heart rate 170 bpm) has been shown to increase[19]. Interestingly, although previous studies[16-19] and the present one did not observe age-related differences in BF, the sum of SKF or SKFavg, we found age-related differences in cheek, chin, triceps and calf SKF, SKFcv and STR, indicating a different pattern of fat distribution between adolescent and adult soccer players. For instance, a proportionally higher subscapular SKF than the triceps was observed in adults than in adolescents, which reflected the tendency to increase fat deposits in the trunk for adolescents. This observation was in line with previous research[43] indicating a redistribution of subcutaneous fat from the extremities to trunk during adolescence, especially in the lower parts of the trunk.

Correlation of Cardiorespiratory Fitness with Anatomical Sites' Skinfold Thickness by Age

A negative relationship was observed between vVO_2max and most of the anatomical sites' SKF, i.e., the faster the vVO_2max, the lower the SKF. This relationship might be attributed to the cause-effect relationship between CRF training and BF. It has been well known that CRF training improved CRF and the rate of improvement depended on the amount of CRF training which amounted to an increase of VO_2max in circumpubertal swimmers[44]. This relationship has also been verified in clinical groups, where CRF training increased VO_2max or VO_2peak in middle-aged women[45], patients with type 2 diabetes mellitus[46] and chronic heart failure with mild to moderate symptoms[47]. In addition to the beneficial role of CRF training for CRF, CRF training resulted in BF management. For instance, it has been shown that CRF exercise of 10 metabolic equivalents often resulted in a visceral fat decrease and that exercise intensity affected the speed of the visceral fat decrease[48]. In this context, CRF training has been considered a cornerstone of programs aiming to decrease visceral fat[49]. In elite youth soccer during the pre-season period, the improvement in CRF was positively related to the exercise intensity of CRF training[50]. The beneficial role of CRF training on BF and CRF has been shown by studying the role of detraining. For instance, 15 weeks of an absence of organized training in youth soccer players resulted in increased BF and decreased CRF[51]. Also, a training break caused by the COVID-19 restrictions decreased CRF in young soccer players[52]. Based on the abovementioned studies, it was concluded that the inverse relationship of CRF with SKF was in line with the existing literature. Nevertheless, a novel finding was that vVO_2max mainly correlated with the central and less with peripheral anatomical sites' SKF. It should be noted that the central anatomical sites presented the largest SKF and a similar pattern as previously reported in marathon runners[53]. Previous research[54] suggested that CRF training would exert a larger effect on central than peripheral SKF. Thus, the larger correlation of $vVO_2max$with central SKF might confirm that the CRF training-induced changes in BF should be assumed to locate on central anatomical sites.

Practical Applications, Limitations and Implications for Future Research

The assessment of SKF in soccer has a wide range of applications, including profiling and testing soccer players in light of the relationship of SKF with performance measures. For instance, triceps SKF was used to calculate somatotype, specifically the endomorphy component, according to the Heath-Carter method[55], which shows that the larger the triceps SKF, the larger the endomorphy. Mid-thigh SKF was a predictor of lower-limbs appendicular muscle mass[56], the larger the mid-thigh SKF, the smaller the lower-limbs appendicular muscle mass. Regarding monitoring the body composition, SKF tracked changes in fat-free mass and BF throughout a season in soccer players[57] and through a 10-week competitive period in referees[58,59]. SKF might differentiate among playing positions with larger values observed in goalkeepers[60,61], and between selected and non-selected players[62]. Interestingly, its role might vary by age, e.g., SKF was the primary predictor of 15-m sprint and countermovement jump in under 12 years, but not in 12-13 years[63]. Nevertheless, the distribution of SKF among anatomical sites was not well studied previously, highlighting our research's novelty.

Limitations

A limitation of the present study was that it did not consider the role of performance level, whereas it has been well known that BF differentiated soccer players by performance level, with high-level soccer players presenting lower BF than their lower-level counterparts[16]. Thus, it would be interesting for future studies to investigate the variation of SKF by anatomical site, considering the role of performance level. Moreover, considering the differences between BF[64] and CRF[65] assessment methods, the findings should be generalized and compared with caution.

Conclusions

In summary, CRF was related to the thickness of specific SKF and the magnitude of thickness variation by the anatomical site (i.e., the smaller the variation, the better the CRF). These findings had relevance for exercise testing and training and might be used by professionals working with adolescent and adult soccer players.

Authors' Contributions

Conceptualization, P.N. and B.K.; methodology, P.N. and B.K.; software, P.N. and B.K.; validation, P.N. and B.K.; formal analysis, P.N. and B.K.; investigation, P.N. and B.K.; resources, P.N. and B.K.; data curation, P.N. and B.K.; writing—original draft preparation, P.N. and B.K.; writing—review and editing, P.N., K.W. and B.K.; visualization, P.N. and B.K.; supervision, P.N.; project administration, P.N. All authors have read and agreed to the published version of the manuscript.

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Ethics Approval

The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of EPL (1/1-8-2008).

Informed Consent

Informed consent was obtained from all subjects involved in the study. In the case of under-age, i.e., the adolescent participants, the informed consent was provided by their parents or guardians.

Availability of Data and Materials

All data are available from the corresponding author upon reasonable request.

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Conflicts of Interest

The authors declare no conflict of interest.

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