Muscle and adjacent subcutaneous fat thicknesses of the gastrocnemius medialis and rectus femoris and the relationship with countermovement jump and v-cut test performance in young elite basketball players

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Article

Keywords: basketball, countermovement jump, muscle thickness, subcutaneous fat, ultrasound, V-cut

Posted Date: June 13th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1721967/v1

Abstract

The countermovement jump (CMJ), the V-cut test, the muscle thickness (MT) and the adjacent subcutaneous fat thickness (SFT) of the gastrocnemius medialis (GM) and rectus femoris (RF) are important physiological indicators for success in basketball. The aims of this study were to obtain normative data regarding CMJ and V-cutperformance and ultrasound measurements, evaluate between-age-category and between-gender differences in these data and examine the relationships between physical tests and ultrasound measurements. The measurements were recorded in a sample of 131 elite basketball players (66 males) who played in three age-categories (U14, U16, or U18).We performed two-way analysis of covariance tests and age-adjusted partial correlation analyses. U16 and U18 males showed better performance in the CMJ and V-cut tests and lower GM and RF SFT compared to the U14 males ($p \leq .001$) and to age-category equivalent female players ($p \leq .001$). Comparisons between the females did not show significant differences in any of the study variables. V-cut and GMSFT variables explained 53.3% of the variation for the CMJ result in males ($p < .01$). This study reports normative data from CMJ and V-cut tests and ultrasound measurements of different age-category male and female elite youth basketball players. Furthermore, it is the first to show the association and predictive role of subcutaneous fat thickness in physical performance.

1. Introduction

Basketball is one of the most popular sports in the world and is an intermittent, high-intensity team sport which puts substantial physical and physiological requirements on elite players. Accordingly, information on players' physical fitness and physiological characteristics can be appropriately utilised by coaches, athletic trainers, physiotherapists and sport physicians when planning daily practice sessions, weekly agendas, or long-term programmes. This information may help increase control over the physical and physiological workloads of players, in turn allowing the effectiveness of training programmes or player screening for selection to be evaluated.[1] This information is also critical in the field of talent detection. Indeed, a recent systematic review reported that anthropometric variables and sprint, flexibility, and agility tests seem to be the primary basis for talent identification in basketball.[2]

In the context of physical fitness, the specific physical tests periodically implemented must be relevant to the physical demands of the sport in question. Two essential physical requirements in basketball are jumping and sprinting with changes of direction (COD).[3] Jumping is part of several defensive (i.e., blocking, rebounding, and stealing) and offensive (i.e., passing, rebounding, and shooting) skills used in the game.[4] Likewise, accelerations and decelerations involving COD are common (i.e., dribbling) and are also repeatedly executed during every basketball game.[5,6] Two physical fitness tests often used to assess vertical jumping and sprinting with COD skills in male and female basketball players are the countermovement jump (CMJ) and the V-cut tests. However, not many studies have reported their normative values in young elite basketball players (CMJ[7–13]; and V-cut[10,14,15]) and fewer still have compared their results between different age-categories and/or genders (CMJ[7,8,11–13]; and V-cut[14,15]). To the best of our knowledge, no normative data in elite basketball players for the CMJ in U16 group males or U14 group females, or for the V-cut in U16 group males and females or U14 group females are available in the academic literature.

Muscle architecture and body fat are also important physiological indicators for success in an extensive range of sports, including basketball. Muscle architecture largely determines muscle strength and power production, which are both necessary components in optimal athletic performance.[16–18] Specifically, muscle strength and power generated by muscles in the lower extremities (e.g., the gastrocnemius medialis [GM] and rectus femoris [RF]) are essential in elite basketball performance, regardless of age or gender.[19] Similarly, body fat (i.e., subcutaneous fat thickness [SFT]) has been shown to be specifically related with performance in basketball.[20] Therefore, accurate means of assessing these physiological indicators are also required for this sport.

Ultrasound (US) of the musculoskeletal system is sufficiently accurate and reproducible to be used routinely in various research fields.[21,22] It is rapid, simple, non-invasive, non-ionising, and cost-effective compared with other imaging techniques.[23] In addition, US is particularly useful for field settings because of its portability. US can be used in a wide variety of people ranging from extremely lean to obese,[24] and has been applied in various groups, including basketball players.[22,25–29] However, to the best of our knowledge, no study has simultaneously reported the US normative values for GM and RF (muscle thickness [MT] and SFT), comparing these results between different age-categories and genders in young elite basketball players.

Considering all the above, the aims of the present study were to (1) obtain normative data from physical tests [CMJ and V-cut] and ultrasound measurements [MT and the adjacent SFT of the GM and RF] of different age-category male and female elite youth basketball players; (2) evaluate possible between-age-category (U14, U16, and U18) and between-gender (male or female) differences in all these data; and (3) examine the relationships between physical and US measurements and determine the combination of variables that most accurately predict the abilities of jumping and sprinting with COD in males and females.

2. Materials And Methods

2.1 Participants

The current cross-sectional study enrolled a total of 131 elite basketball players (66 male and 65 female) aged 12–18 years who were divided into three age categories: U14 (12/13/14-years-old), U16 (15/16-years-old), and U18 (17/18-years-old). All the players belonged to the same top-level Spanish men's and women's basketball club. To be eligible for inclusion, all participants had to be included on an active federated list and free from any musculoskeletal injuries (or sequelae that could interfere with testing) at the time of data collection. All the players were informed about the aims, benefits, and procedures involved in this research project, as well as the possibility of withdrawing from the study at any moment without providing an explanation; written informed consent was obtained from each participant (or from their guardians if they were aged under 18 years). The study was approved by the Ethics Committee for Biomedical Research at the University Cardenal Herrera-CEU in Valencia (Spain) and adhered to the recommendations of the Declaration of Helsinki.

2.2 Procedure

All the measurements (anthropometric/US and physical) were taken during the regular playing season in the month of April 2021 on two days of the same week. The first evaluation session involved the anthropometric and US measurements and the physical fitness tests were performed in the second session. The week prior to the measurements, players were informed not to consume any stimulants (e.g., caffeine) from the morning of the testing day, not to eat in the 2 hours prior to testing, maintain their nutritional habits 2 days before the tests, and avoid any vigorous exercise 48 h before the physical testing session.

First, the anthropometric variables were measured while the athletes were in their underwear or tight sports clothes and without shoes, immediately before US images were captured. Mass (kg) and height (cm) measurements were recorded to the nearest decimal point using a SECA 769 scale and SECA 220 stadiometer (both CE 0123, Hamburg, Germany). The body mass index (BMI) of the participants was calculated using the formula mass/height^2 (kg/cm^2).

Second, US images were acquired with a SONOIQ YOUKEY Q7 wireless mobile US system using a linear probe head (model L11-4Ks) with a frequency of 7.5 MHz and frequency range of 6–11 MHz for musculoskeletal (MSK) applications (WuHan Youkey Bio-Medical Electronics Co. Ltd.), as shown in (Fig. 1). This extra lightweight (160 g) US device was chosen because of the wireless connection between the probe and any mobile screen, tablet, or mobile phone, making it versatile for performing measurements in non-clinical environments. A Samsung Galaxy Tab A tablet (2016) capable of storing the US images and posterior processing was used as a screening device.

All the imaging was performed by one researcher (S.G.), an experienced physiotherapist trained in rehabilitative US imaging with more than 15 years of experience. The images were taken from the participant's dominant lower limb on the RF (Fig. 2) and GM muscles (Fig. 3). Enough gel and sufficient pressure was applied to avoid interference with the actual thickness of the muscle being evaluated. One experienced biomedical engineer (S.N.) with extensive training in medical US imaging and an ample knowledge of anatomy was responsible for performing the muscle segmentations and measuring the selected regions of interest in the SFT and muscle bellies. Fiji, an open-source project and GNU general public license tool[30] was used to process and analyse the US images.

To evaluate the RF, acquisition was performed with the patient in the supine position and the leg in extension. The measured site was the midpoint between the upper edge of the patella and the anterosuperior iliac spine, taken with the athlete sitting and with a flexion of 90° in the hip, knee, and ankle. To take the longitudinal US image the transducer was placed parallel to the longitudinal axis of the RF. Assessment of the GM was performed with the patient in prone position with the leg in semiflexion supporting the instep of the foot on a standard medical roller. The measurement was acquired from the proximal third, between the internal malleolus of the ankle and the knee fold, also with the athlete sitting and with a flexion of 90° in the hip, knee, and ankle. The longitudinal US image was recorded by placing the probe parallel to the longitudinal axis of the GM.

In the second session, two experienced athletic trainers (P.C. and B.R.) implemented the CMJ and then the V-cut physical tests. All measurements were conducted indoors on a basketball court at the same time of day (6:00–8:00 p.m.) and under approximately the same environmental conditions (22–24 ºC). A standardized 10-min warm-up consisting of jogging, dynamic stretching, lower and upper limb strength exercises, submaximal plyometric exercises, and submaximal intermittent running with changes in direction was performed prior to the tests. No familiarisation phase was for the evaluation tests was required because all the players had already performed them 3 times during the season.

CMJ heights were assessed using a Din-A2 contact platform (420 × 594 mm) and Chronojump software (Boscosystem®, Barcelona, Spain). All players performed three jumps, with a recovery period of two minutes. The start and end position was an upright, hip-wide standing position, with hands placed on the hips. Upon instruction, the player lowered their centre of mass by bending the knees to a self-selected level, and immediately after reaching the lowest position, they jumped vertically as high as possible. Each trial was validated by a visual inspection to ensure that each landing was devoid of leg flexion, and players were instructed to keep their hands on their hips to prevent arm swings. The highest jump height was used for the subsequent analysis. Because of its importance in a variety of sports, the CMJ is possibly the most common assessment test implemented to measure lower body-ballistic performance.[31]

In the V-cut test, players performed a 25-m (5 × 5) sprint with four 45° direction changes, each for 5 m. Marks and cones (0.7 m apart) were placed on the floor to indicate when the participants should change direction. For the trial to be valid, players had to pass the line marked on the floor, with one foot remaining completely on the floor at every turn. Two trials were completed with a three-minute rest period between each trial. The time taken for each test was recorded to the nearest two decimal points using an electronic timing gate (Microgate SARL, Bolzano, Italy) and the fastest trial was retained for further analyses. This test has previously demonstrated good reliability and validity for assessing the ability of young basketball players to change direction.[14]

2.3 Statistical analysis

Compliance with the assumption of normality was checked for each dependent variable using the Kolmogorov–Smirnov test. To analyse the effect of gender (male and female) and age-category (U14, U16, and U18) on the outcome measures (CMJ, V-cut, GM-SFT, GM-MT, RF-SFT, and RF-MT), two-way analysis of covariance (ANCOVA) tests were performed with gender and age-category as factors, adjusting the analysis for BMI. A post hoc Bonferroni test was used to identify specific between-group differences when a significant interaction was detected. Partial eta-squared (ηp^2) effect sizes were calculated such that 0.01 < 0.06, 0.06 < 0.14, and ≥ 0.14 corresponded to small, medium, or large effect sizes, respectively.[32]

Because the two-way ANCOVA tests showed significant interactions between gender and age-category, age-adjusted partial correlation analyses were performed separately for males and females to examine associations between the variables. The magnitude of the Pearson correlation was interpreted according to the suggestions by Hopkins et al. where 0.0–0.1 = trivial; 0.1–0.3 = small; 0.3–0.5 = moderate; 0.5–0.7 = large; 0.7–0.9 = very large, and 0.9–1 = almost perfect.[33] In addition, forward stepwise regression was used to determine the combination of variables that most accurately predicted CMJ and V-cut in males and females. The statistical analyses were performed using SPSS software (v.18.0) for Windows (SPSS Inc., Chicago, IL.). All the statistical tests were two-tailed with the critical *P*-value for significance set to < 0.05.

3. Results

The descriptive analysis of age, height, weight, BMI, and training practice in the different groups is detailed in “Table 1”. The two-way ANCOVA tests showed significant interactions (gender × age-category) for CMJ, V-cut, GM-SFT, GM-MT, and RF-SFT ($p < .01$; Table 2); in contrast, there was no significant interaction for RF-MT. The results of the post-hoc between-gender and between age-category pairwise comparisons are shown in “Tables 2 and 3”, respectively.

Table 1
Participant characteristics

Age-category	Gender	*N*	Age (y)	Height (cm)	Weight (kg)	BMI (kg/m^2)	Training practice (h/week)
U14	*Male*	28	13.2 (0.8)	179.8 (9.0)	67.0 (10.9)	19.8 (4.4)	6h (4.5h technical/tactical sessions + 1.5h physical sessions) + 1 match.
	*Fe*male	31	13.4 (0.8)	171.5 (7.4)	63.8 (10.0)	21.5 (1.8)	
U16	*Male*	21	15.3 (0.5)	190.3 (8.4)	82.1 (12.9)	22.6 (2.3)	9h (6h technical/tactical sessions + 3h physical sessions) + 1 match.
	Female	19	15.6 (0.5)	172.6 (5.4)	64.8 (6.7)	21.7 (1.7)	
U18	*Male*	17	17.2 (0.4)	191.4 (6.9)	81.2 (8.1)	22.2 (1.7)	9h (6h technical/tactical sessions + 3h physical sessions) + 1 match.
	Female	15	17.3 (0.5)	176.9 (5.8)	71.2 (6.9)	22.7 (1.6)	

Data are presented as mean ± *SD*

Abbreviation: BMI = body mass index.

Table 2
Comparisons between gender (male vs. female).

Variables	Age-category	Mean (*SD*)		Difference (95% CI)	Partial eta^2	*p* value	ANOVA effects (*p* value)		
		Male (n = 66)	**Female (n = 65)**				**Group**	**Gender**	**Group × Gender**
CMJ (cm)	*U14*	25.0 (4.2)	22.0 (3.4)	3.0 (0.6 to 5.4)	.054	.014*	< .001	< .001	.003
	U16	32.1 (5.9)	23.4 (3.6)	8.7 (6.0 to 11.4)	.229	< .001**			
	U18	32.7 (3.6)	24.1 (5.0)	8.6 (5.2 to 11.9)	.185	< .001**			
V-cut (s)	*U14*	7.27 (0.40)	7.40 (0.24)	−0.13 (−0.30 to 0.04)	.019	.132	< .001	< .001	< .001
	U16	6.70 (0.34)	7.34 (0.27)	−0.64 (−0.85 to −0.43)	.239	< .001**			
	U18	6.61 (0.27)	7.26 (0.46)	−0.65 (−0.88 to −0.41)	.199	< .001**			
GM-SFT (cm)	*U14*	0.54 (0.15)	0.58 (0.13)	−0.04 (−0.12 to −0.03)	.014	.242	.019	< .001	< .001
	U16	0.37 (0.20)	0.67 (0.10)	−0.30 (−0.39 to −0.21)	.302	< .001**			
	U18	0.36 (0.09)	0.56 (0.18)	−0.20 (−0.31 to −0.10)	.126	< .001**			
GM-MT (cm)	*U14*	1.73 (0.26)	1.66 (0.29)	0.07 (−0.09 to 0.23)	.007	.405	.904	.965	.007
	U16	1.81 (0.27)	1.61 (0.29)	0.20 (0.01 to 0.39)	.040	.043*			
	U18	1.54 (0.37)	1.81 (0.33)	−0.27 (−0.50 to −0.05)	.054	.019*			
RF-SFT (cm)	*U14*	0.71 (0.22)	0.87 (0.26)	−0.16 (−0.27 to −0.05)	.073	.006	.055	< .001	< .001

Results of the Bonferroni post-hoc test: *$p \leq 0.05$; **$p \leq 0.01$.

Abbreviations: CMJ = countermovement jump; GM = gastrocnemius medialis muscle; MT = muscular thickness; SFT = subcutaneous fat thickness; RF = rectus femoris muscle.

	U16	0.44 (0.20)	0.95 (0.17)	−0.51 (−0.65 to −0.39)	.373	< .001**			
	U18	0.45 (0.19)	0.92 (0.30)	−0.47 (−0.63 to −0.31)	.258	< .001**			
RF-MT (cm)	*U14*	1.50 (0.31)	1.57 (0.28)	−0.07 (−0.26 to 0.14)	-	-	.033	.438	.716
	U16	1.52 (0.48)	1.50 (0.31)	0.02 (−0.21 to 0.26)	-	-			
	U18	1.68 (0.34)	1.80 (0.46)	−0.12 (−0.40 to 0.16)	-	-			

Results of the Bonferroni post-hoc test: $*p \leq 0.05$; $**p \leq 0.01$.

Abbreviations: CMJ = countermovement jump; GM = gastrocnemius medialis muscle; MT = muscular thickness; SFT = subcutaneous fat thickness; RF = rectus femoris muscle.

Table 3
Comparisons between age-category (U14/U16/U18).

Variables	Gender	U14 minus U16		U14 minus U18		U16 minus U18	
		Difference (95% CI)	p-**value**	**Difference (95% CI)**	p-**value**	**Difference (95% CI)**	p-**value**
CMJ (cm)	*Male*	−7.1 (−10.3 to − 3.9)	< .001**	−7.7 (−11.2 to − 4.2)	< .001**	−0.6 (−4.2 to 3.0)	1.000
	Female	−1.4 (−4.5 to 1.7)	.796	−2.1 (−5.7 to 1.6)	.484	−0.7 (−4.6 to 3.2)	1.000
V-cut (s)	*Male*	0.57 (0.32 to 0.81)	< .001**	0.66 (0.40 to 0.91)	< .001**	0.09 (−0.18 to 0.36)	1.000
	Female	0.06 (−0.17 to 0.28)	1.000	0.14 (−0.11 to 0.39)	.532	0.08 (−0.19 to 0.36)	1.000
GM-SFT (cm)	*Male*	0.17 (0.07 to 0.27)	< .001**	0.18 (0.07 to 0.29)	< .001**	0.01 (−0.10 to 0.12)	1.000
	Female	−0.09 (−0.19 to 0.02)	.129	0.02 (−0.11 to 0.14)	1.000	0.11 (−0.03 to 0.24)	.160
GM-MT (cm)	*Male*	−0.08 (−0.30 to 0.14)	1.000	0.19 (−0.04 to 0.41)	.150	0.27 (0.03 to 0.50)	.021*
	Female	0.05 (−0.17 to 0.27)	1.000	−0.15 (−0.41 to 0.10)	.446	−0.20 (−0.47 to 0.07)	.230
RF-SFT (cm)	*Male*	0.27 (0.12 to 0.42)	< .001**	0.26 (0.10 to 0.42)	.001**	−0.01 (−0.18 to 0.15)	1.000
	Female	−0.08 (−0.24 to 0.07)	.494	−0.05 (−0.23 to 0.13)	1.000	−0.03 (−0.16 to 0.23)	1.000
RF-MT (cm)	*Male*	−0.02 (−0.29 to 0.25)	-	−0.18 (−0.45 to 0.11)	-	−0.16 (−0.45 to 0.14)	-
	Female	0.07 (−0.20 to 0.34)	-	−0.23 (−0.55 to 0.08)	-	−0.30 (−0.64 to 0.04)	-

Results of the Bonferroni post-hoc test: *$p \leq 0.05$; **$p \leq 0.01$.

Abbreviations: CMJ = countermovement jump; GM = gastrocnemius medialis muscle; MT = muscular thickness; SFT = subcutaneous fat thickness; RF = rectus femoris muscle.

Regarding gender, U16 and U18 males showed better performance in the CMJ and V-cut tests and less GM-SFT and RF-SFT compared to age-category equivalent females ($p < .001$), with moderate to large effect sizes ($\eta p^2 > .12$). In contrast, there were no significant between-gender differences in the U14 age-category groups for V-cut, GM-SFT, and GM-MT, and the differences in CMJ and RF-SFT were smaller, with small to moderate effect sizes. Regarding age-category comparisons, the males in the older age categories (U16 and U18) performed better in the CMJ and V-cut tests and showed less GM-SFT and RF-SFT compared to the youngest group (U14; $p \leq .001$). Interestingly, comparisons with females of different age categories did not show any significant differences for any of the studied variables.

Associations between physical (CMJ and V-cut) and US (GM-SFT, GM-MT, RF-SFT, and RF-MT) variables are summarised in Table 4. In males, the CMJ showed a significant negative and moderate association with V-cut, GM-SFT, and RF-SFT. Stepwise multiple regression analysis in males revealed that the V-cut was a significant and independent predictor for CMJ (AdjR^2 = .470, β = −.693, p < .01; model 1), explaining 47% of the variation in the CMJ (Table 5). Model 2 included the GM-SFT to the V-cut and explained 53.3% of the variation. In females, the CMJ showed a significant negative and small to moderate association with V-cut and RF-SFT, while the V-cut showed a significant positive and moderate association with RF-SFT. Stepwise multiple regression analysis revealed that the RF-MT was a significant and independent predictor for CMJ (AdjR^2 = .079, β = .313, p < .05), explaining 7.9% of the variation in the CMJ (model 1). Model 3 included the V-cut and the GM-MT to the RF-MT and explained 24.7% of this variation.

Table 4
Pearson correlation coefficients for males and females (adjusted for age).

	Males				
	V-cut	**GM-SFT**	**GM-MT**	**RF-SFT**	**RF-MT**
CMJ	−0.423**	−0.419**	−0.044	−0.350*	0.108
V-cut	1	0.232	0.078	0.125	−0.008
GM-SFT		1	0.152	0.786**	0.109
GM-MT			1	0.141	−0.054
RF-SFT				1	−0.067
RF-MT					1
	Females				
	V-cut	**GM-SFT**	**GM-MT**	**RF-SFT**	**RF-MT**
CMJ	−0.293*	−0.134	−0.086	−0.313*	0.261
V-cut	1	0.123	−0.092	0.354*	0.166
GM-SFT		1	0.076	0.527**	−0.156
GM-MT			1	0.187	0.408**
RF-SFT				1	0.202
RF-MT					1

Abbreviations: CMJ = countermovement jump; GM = gastrocnemius medialis muscle; MT = muscular thickness; SFT = subcutaneous fat thickness; RF = rectus femoris muscle.

Table 5
Multiple stepwise linear regression analyses with the CMJ and V-cut as dependent variables in male and female.

	Independent variables	R^2	Adjusted R^2	R^2 change	Standardised β coefficient
Male		**CMJ**			
	Model 1	.480	.470	.480	
	V-cut				−.693**
	Model 2	.550	.533	.070	
	V-cut				−.581**
	GM-SFT				−.288**
		V-cut			
	Model 1	.480	.470	.480	
	CMJ				−.693**
Female		**CMJ**			
	Model 1	.098	.079	.098	
	RF-MT				.313*
	Model 2	.224	.191	.126	
	RF-MT				.358**
	V-cut				−.358**
	Model 3	.293	.247	.069	
	RF-MT				.492**
	V-cut				−.407**
	GM-MT				−.296*
		V-cut			
	Model 1	.098	.079	.098	
	CMJ				−.313*

Abbreviations: CMJ = countermovement jump; GM = gastrocnemius medialis muscle; MT = muscular thickness; SFT = subcutaneous fat thickness; RF = rectus femoris muscle.

4. Discussion

The aims of the present cross-sectional study were threefold: (1) to obtain normative data from the CMJ and V-cut tests as well as US measurements of different age-category elite youth male and female basketball players; (2) to evaluate the presence of between-age-category and between-gender differences in all these data; and (3) to examine the relationships between physical tests and US measurements. All this information will help coaches, athletic trainers, physiotherapists, and sport physicians to monitor the physical and physiological workloads of players and in turn, to select players and assess the effectiveness of training programmes. Moreover, even though different age groups often play in the same category, numerous differences in morphological growth and physiological development are evident during maturation.[28,34–36] Thus, training youth athletes or selecting talent requires careful consideration. In fact, maturity-associated factors must be accounted for not only in terms of training load and physical performance, but also for injury risk.[37]

Regarding the normative data, the results we obtained in the CMJ tests agreed with those from previous studies.[7,8] In this sense, in a study with 112 males (17.2 ± 2.3 y, 189.0 ± 8.4 cm, 81.0 ± 12.6 kg) and 58 females (16.7 ± 1.6 y, 175.2 ± 5.6 cm, 70.2 ± 11.2 kg), Kozinc et al.[7] reported CMJ mean heights for young competitive basketball players that were almost equal to our equivalent U18 age-category groups (32.5 ± 4.8 vs. 32.7 ± 3.6 cm in males, and 24.2 ± 3.4 vs. 24.1 ± 5.0 cm in females).[7] In another study, this author reported similar heights in a comparable sample: 31.0 ± 5.0 cm in 105 U18 male competitive basketball players with a mean 7.1 years of training approximately 6 sessions per week and 24.0 ± 4.0 cm in 60 U18 female competitive basketball players with a mean 6.7 years of training approximately 5 sessions per week.[8]

Boutera et al.[9] studied the effects of combined balance and plyometric training on CMJ performance in 26 young (16.5 ± 0.5 y), female, regional-level basketball players and reported baseline heights of 25–27 cm. This was similar to those from our equivalent U16 and U18 age-category groups (23.4 and 24.1 cm, respectively) and the small differences could be partially attributed to different BMIs (< 20 vs. > 21.5 kg/m^2 in our study). Gonzalo-Skok et al.[10] studied the influence of force-vector and force application plyometric training in 20 young (13.2 ± 0.7 y), elite (Spanish Basketball National League), male basketball players and showed baseline CMJ heights of 31–33 cm. This was higher than our equivalent U14 age-category group (25.0 ± 4.2 cm), perhaps partly because of anthropometric differences, with our sample being a mean 6.9 cm taller and 8 kg heavier than their cohort. Of note, both studies collected data at the same time of the season—after 7 months of regular competition.

Fewer studies reported normative values for the V-cut in young elite basketball players.[10,15] The aforementioned study by Gonzalo-Skok et al.[10] showed mean V-cut times of 7.25–7.37 s, which is congruent with our findings in the equivalent U14 group (7.27 ± 0.40 s). Baena-Raya et al.[15] evaluated the gender-specific associations of the mechanical variables related to the horizontal force-velocity profile using different COD tests in 23 women (aged 23.6 ± 5.1 y, range 16–36 y, competing in the Spanish League second division) and 48 men (aged 20.3 ± 3.8 y, range 16–30 y, competing in the same League or at an elite level). These authors showed V-cut times close to those obtained in our U16 and U18 groups (7.31 ± 0.52 s in women and 6.75 ± 0.56 s in men). We did not find normative data for elite basketball players in the academic literature corresponding to the CMJ in males in the U16 group or females in the U14 group, or corresponding to the V-cut in males and females of the U16 group or females of the U14 group.

To control the possible effect of the different maturation rhythms of the players of each age-category and gender, as well as the consequent anthropometric differences derived from it, the ANCOVA analyses were adjusted for BMI. Effectively, the maturation process does not occur at the same chronological age for all individuals. Peak growth in the 10th to the 90th age percentiles spans approximately 4.5 years[38] and so the use of adjusted measures (i.e., to BMI) is advisable when comparing physical fitness variables (e.g., CMJ and V-cut). It also appears as though body mass plays a critical role in jump performance and is associated with improved peak power in adolescent boys and girls.[39] Furthermore, basketball is a competitive sport that involves body contact and so an athlete's height and weight are important when evaluating performance, which can further differ according to the athlete's court position.[40]

In our study, the between-gender comparison showed better CMJ and V-cut performances in males, with significant differences and large effect sizes in the U16 and U18 groups. This concurs with previous studies also reporting gender differences in the CMJ height for U18[7,8] and U16 and U18[12,13] basketball players and in the V-cut times of older players (16–30 y in men and 16–36 y in women).[15] In the same vein, Rice et al.[11] compared force and power time-curve variables for the CMJ between Division I strength-matched male and female basketball athletes (*n* = 21, 8 males and 13 females aged 19.7 ± 1.39 y) and found that males jumped significantly higher than females. The magnitude of the difference was similar to our findings (25% vs. 27% and 26% in our U16 and U18 groups, respectively). These authors concluded that impulse power during the eccentric phase and peak power during the concentric phase was significantly greater in males than females, both in absolute and relative terms. The smaller differences found in the between-gender comparisons in our U14 groups (which did not reach statistical significance in the V-cut test) could be partly explained by the natural variation in biological maturation rates between adolescent males and females. Males typically have longer, hormonally-stimulated prepuberal growth periods with greater peak height and body mass velocity curves.[34] Females tend to reach their peak height velocity at about 12 years and a height plateau by 15 years, while males peak at 14 years and often have not yet reached a growth plateau at 18 years.[35]

Regarding the between age-category pairwise comparisons, our results in males showed significantly better CMJ and V-cut performances in the U18 and U16 groups compared with the U14 group. These results are congruent with those from the study by Kellis et al.[13], who evaluated the jumping ability (including the CMJ) of male basketball players according to their chronological age and found differences between the U16/U18 and the U13 groups. These authors speculated that one factor that may cause these discrepancies is the characteristic low levels of testosterone at this age (U13) which would result in reduced muscular strength. These results are reinforced by an earlier study which concluded that jumping height in males increases from the age of 14 onward.[41] Likewise, the study by Gonzalo-Skok et al.[14] reported significantly better V-cut performances in the U18 and U16 groups compared with the U14 group. Indeed, the magnitude-based inferences for the mean differences in the V-cut test times as a function of age were similar to our findings (U14 vs. U16 = − 6.4%; U14 vs. U18 = − 8.1%; U16 vs. U18 = − 1.8%). Also in this regard, a recent meta-analysis showed that, compared with basketball players aged ≤ 16.3 years, older players experienced greater improvements in their horizontal jump distance, linear sprint time across distances > 10 m, and COD performance time across distances ≤ 40 m following plyometric jump training.[42]

None of the ANCOVA analyses comparing the female age-categories showed any significant differences in the CMJ and V-cut tests. These results also agree with those by Kellis et al.,[13] who did not find significant differences in the CMJ test across different ages (U13, U14, U15, U16, U17, and U18). This lack of between-age differences could be due to earlier biological maturation and shorter growth periods in females compared to males. Accordingly, Drinkwater et al.[35] stated in a review article that the performance of female national-level basketball players aged between 13 and 17 years often showed a U-shaped pattern, with worse scores in anaerobic tests (20-m sprint). These authors suggested that the poorer test scores in females of this age likely reflected the disproportionate increase in adiposity compared with muscularity in females during adolescence.

Regarding US data, to the best of our knowledge, this is the first study to report US normative SFT values in young elite basketball players. Previous work has demonstrated the loss of subcutaneous fat in a particular region of the body ('spot reduction') as a consequence of exercising that specific site.[43] Therefore, we decided to study the SFT adjacent to the GM and RF because of the important role these muscles play during jumping and sprinting (with or without CODs). Both these abilities are critical for performance in basketball and are measured with the CMJ and V-cut tests, respectively. The SFT at these muscles can also be quickly and easily identified using US.[44] Of note, adipose tissue layer thicknesses can be measured taking a standardised US approach with an accuracy not reached by skinfold measurements.[22] This is because skinfold measurements are operator-dependent and influenced by anatomical site and skin thickness while US can overcome the problem of adipose tissue compressibility and viscoelasticity.[44,45] Moreover, a recent cross-sectional study with 56 well-trained athletes from various sports concluded that both the US and skinfold methods very accurately assess body composition in athletes compared to dual-energy x-ray absorptiometry.[46] However, the authors highlighted that US delivered consistently more accurate results.

In line with the results in the CMJ and V-cut tests, the between-gender comparison showed lower GM-SFT and RF-SFT values in males compared to females, with significant differences and moderate to large effect sizes in the U16 and U18 groups. Also consistent with the results in the physical tests, the between age-category comparisons showed a significantly lower GM-SFT and RF-SFT values in the U18 and U16 groups compared to the U14 group in males, but no significant differences between females. The age and gender-associated variation in SFT during childhood and adolescence is well documented in the general population.[47] In addition, it has been suggested that compared to BMI levels, subcutaneous fat patterns are a more accurate way of discriminating between young athletes and non-athletes.[48] However, there is a paucity of data on the longitudinal changes in SFT in young athletes. This information is important for describing the morphological growth status of youths participating in specific sports and it may provide insight into the role of regular exercise training on the development of SFT during adolescence.[49]

Our results agree with those obtained by other authors that also used US to compare the SFT between genders in other sports disciplines.[50,51] For example, Kelso et al.[50] measured SFT using US in 16 highly trained junior rowers (8 males) on the German national junior rowing team (U19). These authors used US using the protocol published by Müller et al.[52], which includes 8 body sites: upper abdomen, lower abdomen, erector spinae, distal triceps, brachioradialis, lateral thigh, front thigh, and medial calf. They concluded that female rowers showed a significantly higher amount of SFT overall and at all these specific sites. More recently, Sengeis et al.[51], used the same protocol to compare US thickness in 26 female and 35 male elite judokas (aged 21.4 ± 5.5 years) and found that the median SFTs in the adult females were significantly higher at all 8 body sites. Regarding the age-associated variations in SFT, our results partially agree with those by Gryko et al.[53], who evaluated the subcutaneous fat (by measuring the skinfold thickness) in 109 elite male basketball players. They reported significantly thicker calf measurements in the U15 group versus the U16, and no significant differences between the U16 and U18 groups. We are not aware of any studies analysing age-associated variations in SFT in young elite female basketball players. In contrast to the results found in males, there were no age-based differences in the SFT in the females in our study. These gender differences are not surprising because females have a shorter growth period and reach biological maturity at a different rhythm.[34,35]

Because significant interactions (gender × age-category) were found in the ANCOVA analyses, we performed age-adjusted partial correlation analyses separately for males and females to examine associations between the variables. Interestingly, in addition to the expected significant association between the two physical tests reported in both genders, GM-SFT and RF-SFT were among the variables that best correlated with these tests, rather than muscle size variables (i.e., GM-MT and RF-MT). Better CMJ and V-cut performance was associated with lower SFT in both males and females. Specifically, there was significant negative and moderate association of CMJ with GM-SFT and RF-SFT in males and with RF-SFT in females, while V-cut showed a significant positive and moderate association with RF-SFT in females. Furthermore, the stepwise multiple regression analysis in males revealed that V-cut and GM-SFT was included in the model of independent predictors for CMJ, together explaining 53.3% of its variation. Multiple factors (muscular, neuromuscular, biomechanical, and endocrine, etc.) may explain the variations in muscle force and torque in children and adolescents, thereby influencing their physical fitness (e.g., jumping and COD sprinting abilities). However, to the best of our knowledge, this is the first study conducted in elite athletes (of any discipline) to show the association and predictive role of SFT (measured by US) in physical performance.

Although the lack of a significant interaction for RF-MT prevented us from identifying specific between age-category differences, our results agree with those by Sekine et al.[19], who examined age-related changes in the quadriceps femoris in 70 male basketball players using US. These authors reported that the RF-MT was larger in 16–17-year-olds than those aged 12–13 or 14–15 years, and stated that marked RF growth is expected starting at age 16 years. They also concluded that different parts of the quadriceps femoris have different growth rates due to differing functions in each muscle head and suggested that coaches and trainers should consider differences in biological maturity among different age groups when training muscle force and power. In this regard, investigations in males on the association between muscle architecture and sprinting performance have indicated that faster athletes possess greater thigh MT.[54,55] In our study, the males with the higher RF-MT (the U18 players) were also the fastest in the V-cut test.

This study had several limitations that must be acknowledged. First, the cross-sectional study design limits us from making any conclusions regarding the cause-and-effect relationships. Second, our participants were young elite basketball players and so our results cannot be generalised to other sports or populations. Third, although all US imaging was performed by an experienced physiotherapist with more than 15 years of experience, and the reliability of US measurements in the lower extremity muscles have been widely demonstrated,[56,57] we did not determine the intrarater and interrater reliabilities of these measurements. Finally, we did not report other muscle size metrics such as cross-sectional area (CSA) or muscle volume (MV). It is well known CSA and MV are valuable predictors of muscular strength and power output (i.e., they represent the maximal number of acto-myosin cross-bridges)[16,58] and account for the irregularities in thickness across skeletal muscle.[59]. However, in large muscles, a single image from portable US only measures MT, not anatomical CSA or MV.[56] Furthermore, MT is faster and easier to calculate (which is important in a non-clinical environment), and a linear relationship has been observed between MT and muscle CSA or MV in the quadriceps and triceps surae muscles.[56]

In conclusion, this present study reports normative values from CMJ, V-cut, and US measurements (GM-SFT, GM-MT, RF-SFT, and RF-MT) of different age-category elite youth male and female basketball players. Our results showed that U16 and U18 males had better performance levels in the CMJ and V-cut tests and less GM-SFT and RF-SFT compared to U14 males and their age-category equivalent females. In addition, the comparisons between females of different age-categories did not show any significant difference in any of the studied variables. Of note, this is the first study conducted in elite athletes, of any discipline, to show the association and predictive role of SFT (measured by US) for physical performance. All this information will help coaches, athletic trainers, physiotherapists, and sport physicians monitor the physical and physiological workloads players experience and in turn, help them to assess the effectiveness of training programmes or to select players and identify talent.

Declarations

Conflict of interest

The authors declare that they have no competing interests.

Authors' contributions

JFL, SG, EG and JJA conceived of the study, and participated in its design and coordination; SG, BR, PC and JJ contributed to data collection; SN did the analysis and calculation of the muscle arquitecture parameters; JFL and PS performed the statistical analysis. All authors contributed to the manuscript writing. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Acknowledgements

This work was supported by the University CEU Cardenal Herrera (INDI 21/31), DAWAKO Medtech S.L. (Valencia, Spain), and the Instituto de Salud Carlos III, Spain. The authors would like to thank all the players and technicians from the Alquería Lab-Valencia and to Carmen Bernal who helped in the segmentation and processing of the ultrasound images. Lastly, author JJ is grateful to University CEU-Cardenal Herrera (CEU Universities, Valencia, Spain) for the doctoral scholarship.

Availability of Data and Materials

The datasets used and analysed during the current study available from the corresponding author (JJA) on reasonable request.

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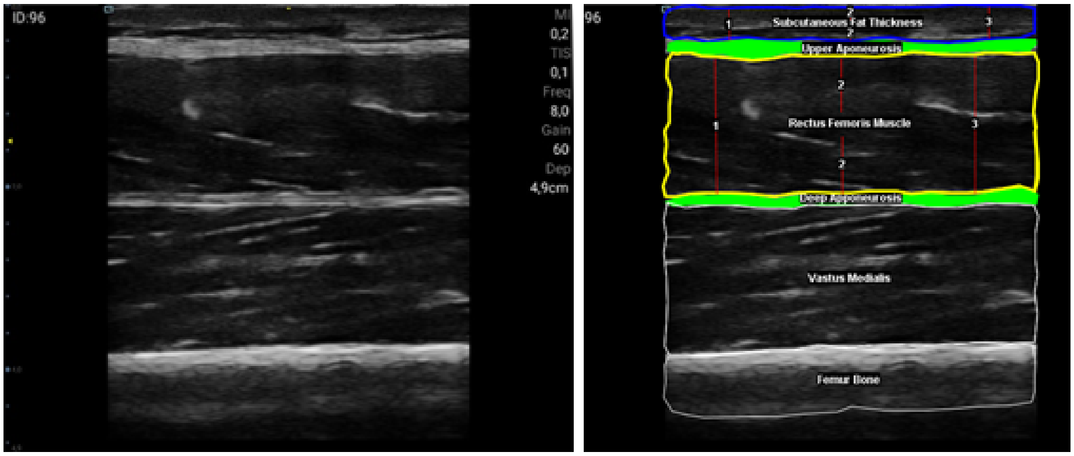
Figures

(a) (b)

Figure 1

(a) The SONOIQ YOUKEY Q7 and L11–4Ks linear probe head ultrasound device and the Samsung Galaxy Tab A tablet (2016) used in this study; (b) close up of the SONOIQ YOUKEY Q7 L11-4Ks linear probe head.



(a) (b)

Figure 2

Raw longitudinal plane ultrasound image of the rectus remoris muscle (a); segmented ultrasound image of the rectus femoris muscle (b) (yellow line), thick green lines). The red vertical lines, labelled as 1, 2, and 3, in both the subcutaneous tissue, and the rectus femoris muscle (b) show the three measurements to obtain the mean thickness value. The white lines bounding the rest of structures, (the vastus medialis muscle and the femur bone) in the ultrasound image were not considered in this study.

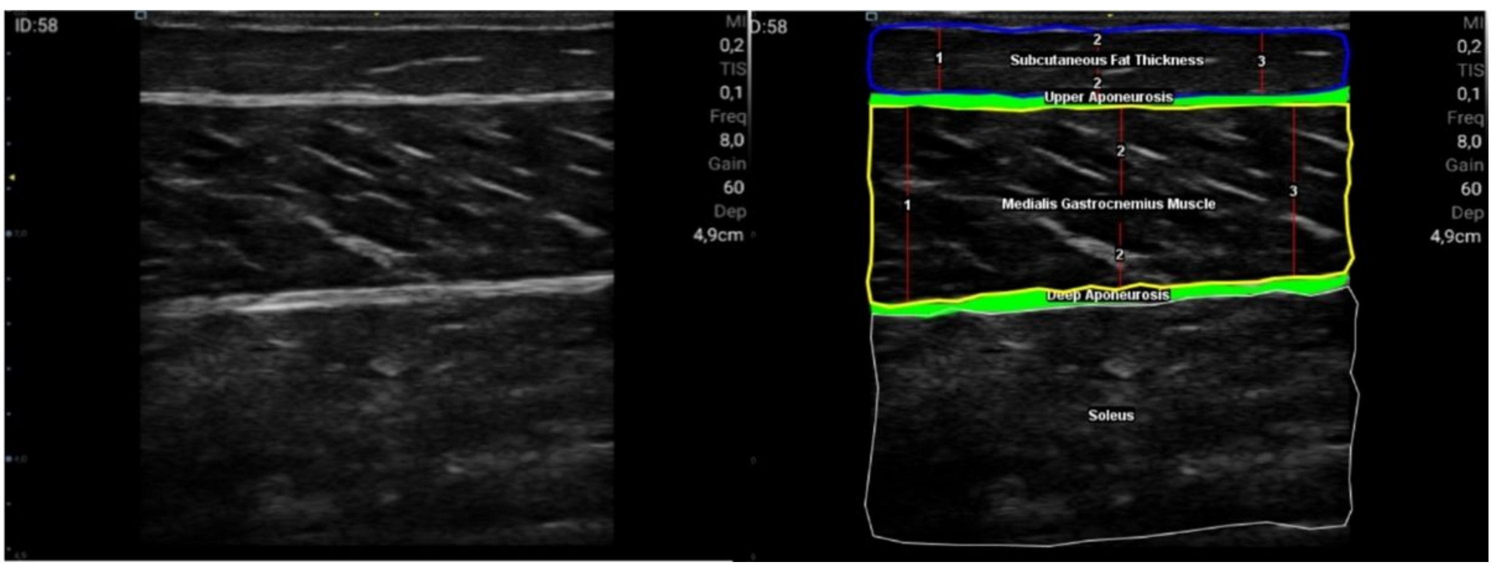


Figure 3

Raw longitudinal plane ultrasound image of the medialis gastrocnemius muscle (c); segmented ultrasound image of the medialis gastrocnemius muscle (d) (yellow line), subcutaneous fat tissue (blue line), and the upper and deep aponeuroses bounding the muscle belly (thick green lines). The red vertical lines, labelled as 1, 2, and 3, in both the subcutaneous tissue, and the medialis gastrocnemius muscle (d) show the three measurements to obtain the mean thickness value. The white lines bounding the rest of structures (the soleus muscle) in the ultrasound image were not considered in this study.