Acta of Bioengineering and Biomechanics
Vol. 27, No. 3, 2025

Original paper
DOI: 10.37190/abb/209793

Relationship between lower extremity alignment, adductor longus muscle architecture and anaerobic power parameters in adolescent football players

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Purpose: To examine the relationship between the frontal plane alignment of the lower extremity, adductor longus muscle architecture (cross-sectional area and thickness), and anaerobic power capacity. *Methods*: Football players aged 14–16 joined the study and were evaluated for lower extremity alignment in the frontal plane radiographs. We examined adductor longus muscle thickness and cross-sectional area on both sides with ultrasound. To evaluate anaerobic power capacity, we did a 30-second Wingate test. Correlation analysis and multiple regression analysis were performed. *Results*: 27 football players were enrolled in the study. The anatomical axis angle of the right side was 2.85 ± 1.75, and left side was 2.67 ± 1.62. A positive and strong correlation was found between both side muscle cross-sectional area and maximum and average power (right: $r = 0.829$, $p < 0.001$; $r = 0.851$, $p < 0.001$, left: $r = 0.742$, $p < 0.001$; $r = 0.789$, $p < 0.001$, respectively), and the right and left muscle thickness and the maximum and average power (right: $r = 0.678$, $p < 0.001$; $r = 0.717$, $p < 0.001$, left: $r = 0.714$, $p < 0.001$; $r = 0.741$, $p < 0.001$, respectively). The multiple regression analysis found that average power could be assessed with right and left axis angles, right muscle cross-sectional area, age, body mass index, and career duration. The analysis showed that these variables accounted for 80.3% of the variability in the average power (F (6,20) =13.558, $p < 0.001$). Same independent variables could explain 77.6% of the variability in the maximum power (F (6,20) = 11.577, $p < 0.001$). *Conclusions*: Muscle thickness and cross-sectional area strongly correlate with average and maximum power. The cross-sectional area and lower extremity alignment angle in the dominant leg could be used to estimate anaerobic power outputs.

Key words: *lower extremity alignment, adductor longus, muscle thickness, cross- sectional area, Wingate test*

1. Introduction

Football players participate in various physical activities, including running, sprinting, jumping and shooting. These activities require both aerobic and anaerobic metabolic processes [12]. They also need to exhibit explosive power, which is the ability of the neuromuscular system to generate maximum force in the shortest amount of time [17]. The strength and speed of the players' lower body muscles, as well as their anaerobic metabolic outputs, directly impact their performance on the field [3]. This explosive power is crucial for movements like quick accelerations, sudden stops, jumps and changes in direction during the game and is particularly important for sprinting ability [11], [28].

The adductor muscles play an important role in facilitating hip adduction in the frontal plane. These muscles ensure that the femur and pelvis work together during complex activities involving both lower extremities [5], [7]. For example, when kicking a ball, the adductor muscles contract bilaterally, creating varus stress on the alignment of the lower extremities. Additionally, studies have shown that adolescent football players have a sig-

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Received: May 22nd, 2025
Accepted for publication: August 21st, 2025

nificantly higher incidence of genu varum compared to their peers. Beyond their role in frontal plane stabilization, the adductor muscles particularly the adductor longus demonstrate significant activity across multiple planes of motion, adapting their function based on hip position and dynamic demand [19].

From a different standpoint, the adductor muscles, particularly the adductor longus, exhibit significant versatility in the sagittal plane. They function in conjunction with the hip extensors (such as the gluteus maximus and adductor magnus) and hip flexor muscles, depending on the position and movement of the hip. For instance, during a quick run, the adductor longus primarily performs adduction, but can also contribute to hip flexion or extension, depending on the angle of the hip [5], [7], [31]. This dual role of the adductor longus is an intriguing aspect of its function in athletic performance. The contractions of the adductor muscles in various planes are critical for hip movements that require sudden wide-angle acceleration [13]. Therefore, the strength and capability of the adductor muscles are essential for athletes involved in football, running, hockey and cycling, while also helping to maintain proper alignment of the lower extremities. Several studies have examined the alignment of the lower extremities to assess athletes' performance and its correlation with injuries. However, most studies have concentrated on the relationship between alignment and injury. Much research indicates that alignment issues, especially in the frontal plane, can raise the risk of different types of injuries [1], [15], [18].

On the other hand, a lower Quadriceps (Q) angle is associated with better jumping performance [9]. However, we have not found any studies in the literature that examine the relationship between lower extremity alignment and anaerobic metabolic power outputs in athletes, and this situation deserves investigation.

This study aims to examine the relationship between the frontal plane alignment of the lower extremity, adductor longus muscle architecture (including cross-sectional area and thickness), and anaerobic capacity parameters in adolescent football players under 16.

2. Materials and methods

Our study was conducted at Istanbul University, Istanbul Faculty of Medicine, Department of Sports Medicine, with the approval of the Istanbul Faculty of Medicine, Clinical Research Ethics Committee, dated 08.06.2023 and numbered 1797608, according to regulations of the Declaration of Helsinki.

We included licensed 27 football players aged 16 and under playing on the same youth football team for at least one year. The players and their parents gave written and verbal consent for the study. We excluded those who had a current lower extremity injury and had undergone surgery in the last six months, as well as those with a chronic pathology that would prevent them from participating in the anaerobic power test.

The players underwent a health check by a sports physician and an orthopedist. We recorded individual characteristics such as age, height, weight, years of professional football with licensed, position on the field, dominant extremity side, and previous injury history.

Measures

The lower extremity alignment in the frontal plane was evaluated by taking leg-length radiographs (X-rays) of the athletes. The pelvis, femoral heads and ankle joints were seen in a single-section radiograph, and X-rays were taken. During the radiological examination, care was taken to ensure that both patellas were facing straight ahead and that the knee and hip joints were in full extension position. The presence of knee varus and valgus according to the anatomical axis of the individuals' lower extremities was revealed and the angular values were determined separately for both extremities (Fig. 1). A straight line was drawn from the tip of the greater trochanter to the center of distal femoral joint surface, bisecting the medullary canal of the

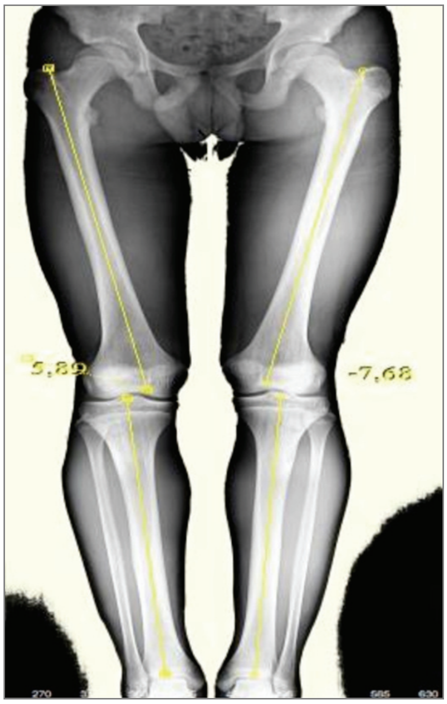

Fig. 1. Evaluation of lower extremity alignment in the frontal plane using leg length radiograph

femur. Another straight line was also drawn from the center of proximal tibial joint surface to the center of distal tibial joint surface, bisecting the medullary canal of the tibia. The angle between this lines should be 6° valgus [27].

Ultrasound evaluations of all athletes were performed by a sports medicine specialist using a Toshiba Aplio 500 (Toshiba Medical Systems Corporation, Otawara, Japan) device [11]. These ultrasound measurements were made at room temperature (23 °C) with Aqua-sonic 100 ultrasound gel (Parker Laboratories, Inc., Fairfield, New Jersey), and a 10 MHz (5–14 MHz) linear probe was used. During the ultrasonographic evaluation of the adductor muscles, athletes were positioned supine with the thigh abducted and slightly externally rotated and the knee joint flexed between 30 and 60°.

The insertion site of the iliopsoas tendon on the lesser trochanter was examined. From this point, the probe was moved medially and placed over most adductor muscles in the long-axis plane. Then, three muscle layers (adductor longus, brevis, and magnus) were defined in axial planes. Among the superficial muscles, the adductor longus on the outer side was visualized as the gracilis muscle on the inner side, and the adductor brevis muscle was detected in the middle muscle group and the adductor magnus muscle in the deep muscle group. The long axis of these muscles was scanned and recorded to investigate any pathological conditions. Again, in the long axis, the distance between the fat–tissue–muscle border on the middle part (thickest) of the adductor longus muscle on the upper side and the adductor longus–brevis border on the lower side was recorded as muscle thickness (Fig. 2A). The cross-sectional area of the region where the muscle was thickest was determined by scanning the muscle body on the transverse axis (short axis of the muscle) (Fig. 2B). This measurement was recorded separately and twice for both lower extremities. The average of the figures obtained from the measurements taken twice was used for statistical analysis [26].

The Wingate Anaerobic Power Test (WAnT) (Monark Ergomedic 894 E, Sweden) evaluated the football players' anaerobic capacity. Before the test, a warm-up exercise was performed on a bicycle for 7 minutes under low resistance at 50–60 rpm, and then a stretching exercise was performed. Then, the load was calculated according to the individual body weight, and WAnT was performed when the individual pedaled against this resistance. The following formula was used to calculate the resistance/load that was appropriate for the individuals [14]: Load (kp) = –0.4914 – [0.2151 × Weight [kg]] + [2.1124 × Leg volume (liters)].

Power output was measured by the number of revolutions the athlete could achieve on the ergometer during the test period of 30 seconds. The recorded peak power was evaluated as the maximum power (watt) output obtained in the first 5 seconds. The athlete's average power (watt) was recorded as the average power of the 30-second test. The lowest power (watt) was recorded as the lowest value during the test for 5 seconds. All data were also evaluated according to body weight (watt/kilogram). The fatigue index was calculated with the highest and lowest power output power ratio. In the post-test recovery phase, athletes performed an active cool-down at minimum resistance for 5 minutes at 30–50 rpm [4].

Statistical analysis

Data were evaluated using the SPSS version 28.0 package program for statistical analysis. Mean (average),

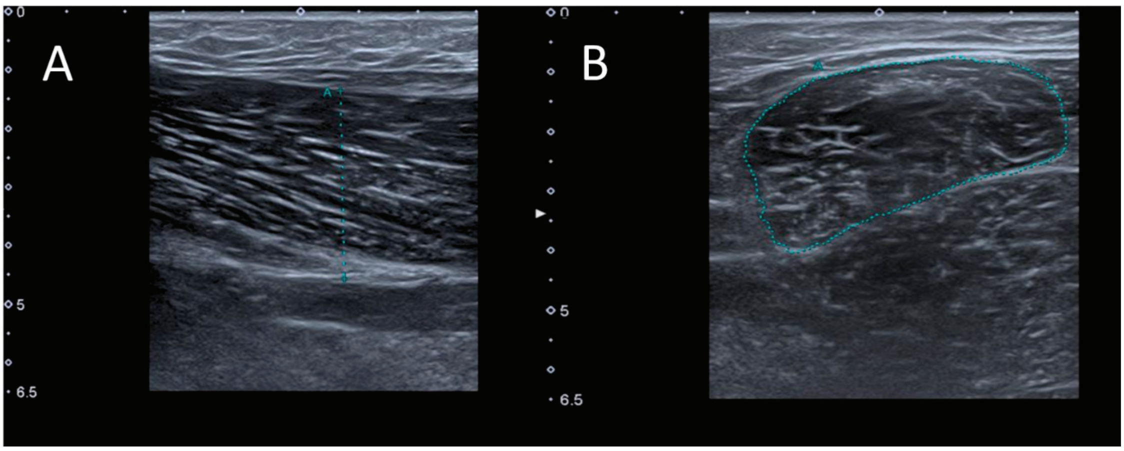

Fig. 2. A) Measure the muscle thickness of the adductor longus muscle in the long axis (longitudinal) as the farthest distance between the upper and lower aponeuroses of the muscle, B) measurement of the cross-sectional area of the adductor longus muscle in the short axis (transverse)

standard deviation (SD), and minimum and maximum values of the range were calculated in the presentation of descriptive data. Shapiro–Wilk test was applied to examine the data's distribution characteristics and show normal distribution. In evaluating relationships between variables, Pearson correlation analysis was applied for normally distributed variables, and Spearman correlation analysis was applied for qualitative variables and non-normally distributed quantitative variables. The correlation score (r) being "+" or "–" indicates the direction of the relationship between variables: in a positive "+" relationship, as one of the variables increases, the other also increases, or as one decreases, the other also decreases; in a negative "–" relationship, as one of the variables decreases, the other increases. The absolute magnitude of the relationship (r) is between 0 and 1, and the strength of the relationship increases as it approaches 1 [8]. Linear regression analysis examined the relationships between variables by controlling for confounding variables. Statistical significance was accepted as $p < 0.05$.

3. Results

Demographic characteristics and descriptive data of the football players included in the study are given in Table 1.

The athletes' lower extremity frontal plane alignment angles, muscle cross-sectional area and thickness determined by ultrasound and WAnT data are presented in Table 2. The Kolmogrov–Smirnov test determined that the data showed a normal distribution.

In Tables 3, right side, and Table 4, left side, the correlation analyses between the anatomical axis angles of the football players' right and left sides and the USG and WAnT results are presented.

Although statistical significance was not reached, a negative and weak correlation was observed between the right anatomical axis angle and the average power value ($r = -0.370$, $p = 0.057$). A positive and strong correlation was found between the right muscle cross-sectional area and the right side average muscle thickness value ($r = 0.796$, $p < 0.001$). A positive and strong correlation was found between the right muscle cross-sectional area and the maximum and average power ($r = 0.829$, $p < 0.001$; $r = 0.851$, $p < 0.001$, respectively). A positive and strong correlation was found between the right muscle thickness and the maximum and average power ($r = 0.678$, $p < 0.001$; $r = 0.717$, $p < 0.001$, respectively). A positive and moderate correlation was found between the right muscle cross-sectional area and maximum and average power by body weight ($r = 0.550$, $p = 0.003$; $r = 0.531$, $p = 0.004$, respectively). A positive and moderate correlation was found between the right muscle thickness, maximum and average power by body weight ($r = 0.511$, $p = 0.006$; $r = 0.541$, $p = 0.004$, respectively) (Table 3).

No statistically significant correlation was found between the left anatomical axis angle and USG and WAnT results. A positive and strong correlation was found between the left muscle cross-sectional area and the left muscle thickness value ($r = 0857$, $p < 0.001$).

Table 1. Demographic characteristics and descriptive data of the football players

	n	Mean (SD)	Minimum–maximum
Age [year]	27	14.85 (± 0.53)	14–16
Height [cm]	27	172.50 (± 7.35)	152.0–184.0
Weight [kg]	27	58.74 (± 6.91)	42–66
BMI [kg/m^2]	27	19.70 (± 1.71)	15.89–22.41
Football duration [year]	27	4.68 (± 1.88)	1.0–10.0
	n	%	
Gender			
Girl	0	0	
Boy	27	100 %	
Dominant Side			
Right	20	74.1	
Left	7	25.9	
Position			
Goalkeeper	2	7.4	
Defender	8	29.6	
Midfielder	15	55.6	
Attacker	2	7.4	

Table 2. Descriptive data of participants' lower extremity frontal alignment angles, USG measurements and WAnT results

	n	Mean (SD)	Minimum	Maximum	Shapiro–Wilk's test *p*-value
Right anatomical axis angle	27	2.85 ± 1.75	0	6	0.970 (0.60)
Left anatomical axis angle	27	2.67 ± 1.62	0	6	0.966 (0.49)
Right adductor longus CSA [cm^2]	27	13.60 ± 2.91	7.02	17.81	0.985 (0.95)
Left adductor longus CSA [cm^2]	27	13.13 ± 2.7	7.28	17.83	0.950 (0.21)
Right adductor longus thickness [mm]	27	35.34 ± 4.51	24.00	42.70	0.947 0.185
Left adductor longus thickness [mm]	27	33.15 ± 4.78	20.60	41.25	0.956 0.300
Maximum power [W]	27	593.89 ± 103.04	327.90	784.54	0.961 0.386
Maximum power by body weight [W/kg]	27	10.05 ± 0.96	7.81	12.26	0.991 0.997
Average power [W]	27	460.81 ± 74.23	273.45	609.52	0.975 0.745
Average power by body weight [W/kg]	27	7.81 ± 0.64	6.51	9.52	0.967 0.534
Fatigue index [%]	27	51.08 ± 10.87	35.48	88.74	0.979 0.829

CSA – cross-sectional area, SD – standard deviation, $p > 0.05$ indicates significance.

Table 3. Correlation analysis results between football players' right anatomical axis angle, ultrasound parameters and WAnT results

		Right anatomical axis angle	Right adductor longus CSA [cm^2]	Right adductor longus thickness [mm]	Maximum power [W]	Maximum power by body weight [W/kg]	Average power [W]	Average power by body weight [W/kg]	Fatigue index [%]
Right adductor longus CSA [cm^2]	*r*	–0.172	–						
	p	0.392							
Right adductor longus thickness [mm]	*r*	–0.212	**0.796****	–					
	p	0.288	**<0.001**						
Maximum power [W]	*r*	–0.326	**0.829****	**0.678****	–				
	p	0.097	**<0.001**	**<0.001**					
Maximum power by body weight [W/kg]	*r*	–0.300	**0.550****	**0.511****	**0.826****	–			
	p	0.128	**0.003**	**0.006**	**<0.001**				
Average power [W]	*r*	–0.370	**0.851****	**0.717****	**0.973****	**0.768****	–		
	p	0.057	**<0.001**	**<0.001**	**<0.001**	**<0.001**			
Average power by body weight [W/kg]	*r*	–0.375	**0.531****	**0.541****	**0.736****	**0.913****	**0.772****	–	
	p	0.054	**0.004**	**0.004**	**<0.001**	**<0.001**	**<0.001**		
Fatigue Index [%]	*r*	0.036	0.260	0.262	0.322	0.316	0.216	0.119	–
	p	0.858	0.191	0.187	0.101	0.108	0.280	0.553	

A strong positive correlation was found between the left muscle cross-sectional area and maximum and average power ($r = 0.742$, $p < 0.001$; $r = 0.789$, $p < 0.001$, respectively). A positive and strong correlation was found between the left muscle thickness and maximum and average power ($r = 0.714$, $p < 0.001$; $r = 0.741$, $p < 0.001$, respectively). A positive and moderate correlation was found between the left muscle cross-sectional area and maximum and average power by body weight ($r = 0.457$, $p = 0.017$; $r = 0.486$, $p = 0.01$, respectively). A positive and moderate correlation was found between the left muscle thickness and maximum and average power by body weight ($r = 0.458$, $p = 0.016$; $r = 0.450$, $p = 0.018$, respectively) (Table 4).

In multiple regression analysis, where the dependent variable was the average power of WAnT and the independent variables were the right and left anatomical axis angles, right muscle cross-sectional area, age,

Table 4. Correlation analysis results between the left anatomical axis angle, USG, and WAnT results

		Left anatomical axis angle	Left adductor longus CSA [cm^2]	Left adductor longus thickness [mm]	Maximum power [W]	Maximum power by body weight [W/kg]	Average power [W]	Average power by body weight [W/kg]	Fatigue index [%]
Left adductor longus CSA [cm^2]	*r*	–0.084	–						
	p	0.676							
Left adductor longus thickness [mm]	*r*	–0.063	**0.857****	–					
	p	0.756	**<0.001**						
Maximum power [W]	*r*	0.118	**0.742****	**0.714****	–				
	p	0.556	**<0.001**	**<0.001**					
Maximum power by body weight [W/kg]	*r*	0.154	**0.457***	**0.458***	**0.826****	–			
	p	0.443	**0.017**	**0.016**	**<0.001**				
Average power [W]	*r*	0.022	**0.789****	**0.741****	**0.973****	**0.768****	–		
	p	0.914	**<0.001**	**<0.001**	**<0.001**	**<0.001**			
Average power by body weight [W/kg]	*r*	–0.020	**0.486***	**0.450***	**0.736****	**0.913****	**0.772****	–	
	p	0.921	**0.010**	**0.018**	**<0.001**	**<0.001**	**<0.001**		
Fatigue index [%]	*r*	0.305	0.169	0.107	0.322	0.316	0.216	0.119	–
	p	0.122	0.400	0.596	0.101	0.108	0.280	0.553	

body mass index, and licensed football player duration, it was shown that 80.3% of the variability in the average power data ($F(6,20) = 13.558$, $p < 0.001$). Among these independent variables, the right muscle cross-sectional area measurement ($B = 18.425$, $p < 0.001$) and the right anatomical axis angle ($B = –13.118$, $p = 0.019$) were found to be statistically significantly effective in predicting the average power.

Similarly, where the dependent variable was the maximum power of WAnT and the independent variables were the right and left anatomical axis angles, right muscle cross-sectional area, age, body mass index, and licensed football duration, it was shown that these independent variables explained 77.6% of the variability in the maximum power data (F(6,20) = 11.577, $p < 0.001$). Among these independent variables, the right muscle cross-sectional area ($B = 23.937$, $p = 0.001$) and the right anatomical axis angle ($B = –19.800$, $p = 0.017$) were statistically significantly effective in predicting the maximum power.

4. Discussion

This study aimed to investigate the relationship between the alignment of the lower extremity in the frontal plane, the architecture of the adductor longus muscle (specifically its cross-sectional area and thickness), and anaerobic capacity parameters in adolescent football players under the age of 16.

Our findings revealed a highly significant positive correlation between the thickness and cross-sectional area of the muscle in the right and left extremity and the WAnT data. A moderately positive correlation was also observed when comparing the data for the muscle thickness and cross-sectional area of the right and left leg with the WAnT by body weight. However, there was no statistically significant correlation between the anatomical alignment angles and WAnT and USG data on both sides. Regression analysis showed statistically significant results, indicating that the right extremity's alignment angle and muscle cross-sectional area could be valuable in determining both maximum and average power. Conversely, the alignment angle and muscle cross-sectional area of the left lower extremity were not associated with determining average and maximum power data.

The primary function of the adductor muscles in the frontal plane is to generate a moment for adduction at the hip, thus, during complex activities affecting both lower extremities, the femur and pelvis are controlled by the force produced by the adductors. During repetitive sports activities, such as sudden changes of direction in football, shooting and passing, sprinting, etc., the adductor muscles often play an active role in lower extremity biomechanics [12], [23]. In this context, the alignment changes as adaptation to the work performed develops. Previous studies on adolescent football players have shown that genu varum alignment has a higher incidence [1], [33].

In our study, football players with genu varum alignment were associated with having a larger adductor muscle mass and an increase in lower extremity workload as an outcome of this situation. Additionally, regression analysis revealed the effect of muscle mass and alignment angles on predicting average and maximum power. These findings open up new avenues for further research, particularly in understanding the relationship between muscle mass, alignment angles, and power generation in adolescent football players.

Varus and valgus alignments in the knee joint and the abnormal/disproportionate muscle loads caused by these alignments have different effects on the thigh adductors [13]. In a study conducted by Benneth et al. [2], it was shown that the adductor muscles were used more during pushing force, especially in those with varus alignment [2]. Again, in the same study, it was observed that there was excessive loading on the gluteus maximus and adductors during step climbing in those with varus alignment. At the same time, there was more loading on the gluteus medius, gluteus minimus, and abductor muscles in those with valgus alignment [2].

When the anatomical axis measurements of the athletes participating in our study were examined, it could be seen that the average values for the valgus angle between 0 and 6 were 2.85 for the right axis and 2.67 for the left axis. These numbers we determined are consistent with literature studies reporting that the lower extremity alignment of football players is in the direction of varus alignment [1], [16], [33]. As a result, the radiographic frontal lower extremity alignment and ultrasonographic muscle assessment allowed us to make quantitative evaluations, thereby adding objectivity to our scientific study and enhancing its credibility.

The evaluation of an athlete's performance and the prevention of injuries often involve functional and physical tests. One commonly used test for assessing anaerobic performance, particularly in sports requiring explosive power like football, is the Wingate Anaerobic Test (WAnT) [22], [24], [25].

Our study also noted a negative correlation between the average power and the right anatomical axis angle from the Wingate test results. However, we did not observe statistical significance. We believe these results could be attributed to the natural adaptations and varus alignment frequently observed in football players due to the repetitive of football-related activities [16].

Skeletal muscles are visco-elastic and have the ability to respond to external stimulus (exercise, stimulus, training, detraining, immobilization, etc.) by changing its architecture and elasticity both acutely and chronically [6]. Ultrasonography (US) is the most utilized and reliable imaging modality that can assess muscular architecture *in vivo* [10], [32]. US can assess thickness and cross-sectional area as one of the basic features of this dynamic tissue [29]. It provides us with information on how the muscle responds to training due to acute and chronic interaction [30]. In our study, genu varum alignment was associated with large adductor muscle mass, which was thought to result from the athletes' adaptation to football training. At the same time, larger adductor longus muscle mass was found to be related to the athletes'lower extremity explosive power outputs. Adductor longus muscle function can provide valuable information about lower extremity power and alignment in this context [22].

An intriguing finding was that only right-side alignment and muscle parameters emerged as significant predictors in our regression model, despite similar correlation patterns on both sides. This laterality effect may reflect the influence of limb dominance on neuromuscular development, as most participants were likely right-leg dominant. However, in the literature, a study of 352 youth athletes found that, one limb performed slightly better on hop tests, but limb dominance perception did not predict performance [20].

One of our study's limitations is that the lower extremity alignment, evaluated with anatomical parameters, needed to be evaluated with kinematic measurements regarding dynamic varus and valgus in certain movements, as in many studies in the literature [21]. Secondly, ultrasound measurements were performed only on the adductor longus muscle. However, if the adductor magnus muscle had also been evaluated -due to the effect of this muscle on hip extension, it could have been more enlightening in the analysis process of the alignment and WAnT-related outputs. On the other hand, it could not be examined since it is impossible to make reliable measurements due to the anatomically deep location of the adductor magnus muscle with ultrasound. These limitations highlight the need for future research to address these areas and further enhance our understanding of the relationship between muscle architecture, alignment, and anaerobic capacity in adolescent football players.

5. Conclusions

Genu varum alignment was not directly correlated with muscle cross-sectional area, thickness, or anaerobic power values. However, muscle thickness and cross-

-sectional area showed strong positive correlations with average and maximum power outputs. In the dominant leg, both muscle cross-sectional area and anatomical axis angle were predictors of anaerobic-explosive power. These results indicate that assessing adductor muscle architecture in the dominant limb can provide insights into an athlete's anaerobic performance potential and assist in tailoring training programs. These results underline the limited predictive role of frontal plane alignment. Further research is needed to explore the relationship between lower limb biomechanics and performance in youth athletes.

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