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ORIGINAL ARTICLE

ULTRASONOGRAPHIC ASSESSMENT OF TRICEPS SURAE MUSCLE THICKNESS AND ITS CORRELATION WITH LOWER LIMB POWER AND JUMP PERFORMANCE

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ABSTRACT

Background: Ultrasonography is widely used to assess muscle structure and function, offering precise muscle thickness analysis. The gastrocnemius and soleus muscles are essential for lower limb strength in activities like jumping and running. Morphological analysis aids sports and rehabilitation by evaluating motor function and optimizing training. Understanding muscle structure-function relationships can improve training programs and injury prevention strategies.

Objective: To determine the relationship between the thickness of the triceps surae muscles and selected motor performance parameters, including jump height and power.

Methods: The study involved 47 participants (24 women, 23 men) aged 18–25, selected based on inclusion criteria. High-resolution ultrasonography assessed triceps surae muscle thickness, with probe placement individually adjusted. After measurements, participants performed motor tests, including vertical and squat jumps, each repeated three times with 1-minute rest intervals.

Results: Significant correlations were found between soleus muscle thickness and jump test outcomes, particularly among male participants. The correlation between the transverse dimension of the soleus muscle and vertical jump height was $r = 0.8831$, $p < 0.001$, while for squat jump height, it was $r = 0.9418$, $p < 0.001$. Similarly, the longitudinal dimension of the soleus muscle showed a strong correlation with vertical jump height ($r = 0.8847$, $p < 0.001$) and squat jump height ($r = 0.9413$, $p < 0.001$), confirming its crucial role in power generation during jumping tasks.

Conclusions: Soleus muscle thickness is a reliable predictor of lower limb power. These findings underscore the potential of ultrasonography in biomechanical diagnostics and emphasize the importance of accounting for sex differences in muscle function analysis.

KEYWORDS

Motor performance, muscle thickness, triceps surae, power, ultrasonography

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INTRODUCTION

Contemporary sports and physical activity science focuses on various aspects of muscle morphology and functionality. Increasing attention is being given to the relationships between muscle structure, thickness, and physical performance, including motor abilities such as power generation, physical endurance, and jump height[1,2]. Understanding these relationships is crucial for optimizing athletic performance, particularly in disciplines that demand high levels of physical activity, such as running, jumping, or strength-based sports[3]. In this context, the study of lower limb muscle morphology holds a particularly important place, as these muscles play a pivotal role in generating the power required for jumping, running, and other dynamic movements[4]. Muscles such as the gastrocnemius, a component of the triceps surae, and the soleus are responsible for a range of critical functions related to movement, posture stabilization, and force generation during physical activity. Their structure is of significant importance in the context of strength, endurance, and power production[5-7].

A key characteristic of muscles is their thickness, structure, and the changes in their architecture in response to various forms of training[8,9]. Increased muscle thickness often reflects the body's adaptation to intense training loads, which in sports translates to enhanced performance and greater force generation capabilities. Conversely, changes such as decreased muscle thickness may reduce power output, negatively impact physical performance, and increase the risk of injury[10]. Consequently, examining muscle thickness is critical not only for performance evaluation but also for injury prevention and monitoring rehabilitation progress[11].

In rehabilitation, lower limb muscles are integral to the recovery process and restoring functional abilities. Regular monitoring of muscle structural changes provides valuable insights into therapy effectiveness and enables the customization of training and rehabilitation plans to meet individual patient needs[12]. Thus, assessing muscle structure has become an indispensable tool in modern sports medicine and rehabilitation. The ability to precisely analyze structural changes using imaging techniques such as ultrasonography allows for the early detection of muscle-related issues and facilitates accurate monitoring of treatment progress. This enables rehabilitation plans to be tailored to individual patient requirements[13,14].

Ultrasonography is currently one of the most precise methods for assessing muscle morphology, enabling accurate measurement of muscle thickness and evaluation of other structural characteristics, such as muscle fiber length, pennation angle, and connective tissue distribution[15]. It is a relatively straightforward method to apply in clinical settings, offering rapid and precise monitoring of muscle structural changes. Its application in diagnostics is invaluable, providing detailed information on muscle structure, thickness, fiber length, and other parameters that influence the efficiency of force and power generation during movement[16,17].

Monitoring speed generation capability is essential for evaluating power production during movement. This parameter is crucial not only in training and rehabilitation contexts but also for a deeper understanding of the fundamental properties and functions of the neuromuscular system[18].

Various testing procedures involve a range of measurement tools, such as accelerometric devices, force plates, video analysis systems, contact mats, and photoelectric cells. Different types of jumps are used to assess power generation capacity, including squat jumps (SJ), countermovement jumps (CMJ), drop jumps, and vertical jumps (VJ)[19]. Performance metrics, such as jump height, flight time, mechanical power, and body center of mass displacement, can be calculated using various methodologies. Depending on the measurement device, vertical jump assessments are classified as laboratory-based or field-based. Laboratory methods often involve force plates or video analysis systems, which provide high measurement accuracy[20,21]. However, these methods require expensive and non-portable equipment. In contrast, field-based assessments using contact mats, photoelectric cells, or accelerometric devices are more accessible to coaches, physiotherapists, and researchers, enabling measurements under conditions that closely resemble real physical activity[22].

An example of an accelerometric device is the Myotest, a tool designed to measure acceleration during movement, particularly in training conditions. This lightweight, wireless, and portable device is attached to a specially designed belt worn at the pelvic level. Using the Myotest, various variables can be estimated, including speed, power, force, jump height, and other aspects of physical activity[23].

The aim of the study was to determine the relationship between the thickness of the triceps surae muscles and selected motor performance parameters, including jump height and power. This study aims to bridge the existing gap in understanding how triceps surae muscle thickness impacts power generation and jump height, potentially advancing knowledge in biomechanics and athletic performance optimization. It was hypothesized that the thickness of the lateral and medial heads of the gastrocnemius muscle and the soleus muscle significantly affects power generation and jump height. Conducting such an analysis may contribute to a better understanding of the role of muscle morphology in shaping human motor abilities.

MATERIAL AND METHODS

The study involved 47 participants (24 women and 23 men) aged 18–25 years (mean age: 22.6 years; mean BMI: 22.41 kg/m^2). *Table 2* shows the most important data about the participants. They were not professional athletes and met strictly defined inclusion and exclusion criteria *(Table 1)*.

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Inclusion criteria	Exclusion criteria
Age 18–25 years	BMI >34.9 kg/m^2
No lower limb injuries or pain within the last year	History of abdominal or lower limb surgeries
No diagnosed somatic diseases	Pain during testing procedures
	Participation in competitive-level sports

Table 1. *Criteria of inclusion and exclusion of the participants.*

Participants were selected to ensure a high level of health and physical fitness, facilitating reliable data collection and result interpretation *(Table 2)*. The study was conducted at the Teaching Center of the Faculty of Health Sciences, Medical University of Silesia in Katowice, from 12th to 16th February 2023. To reach a broader audience, posters were placed on the university campus and shared on social media, featuring QR codes that provided easy access to an online registration form. Participants could select convenient appointment times, and each was assigned an individual identification number. The implementation of modern registration and communication methods streamlined the enrolment process and enhanced the study's appeal. All participants provided written informed consent for their participation in the study and the processing of their data for scientific and publication purposes. The study was approved by the Ethics Committee of the National Chamber of Physiotherapists (approval no. 5/2022 of March 4, 2022), and all participants provided written informed consent for their participation and data processing.

Research procedures

The study was conducted by two trained researchers who underwent prior training in ultrasonography and testing methodologies. To ensure high-quality measurements and minimize errors, the project was preceded by a pilot study aimed at verifying method reliability, estimating the time required to examine a single participant, and identifying potential organizational challenges.

Before starting the procedures, participants:

- Signed informed consent forms;
- Completed a questionnaire regarding their dominant lower limb, pain history, and any injuries or surgeries within the last 12 months;
- Filled out the International Physical Activity Questionnaire (IPAQ), which assessed their physical activity levels during the previous week[24].

Ultrasonographic measurements

Ultrasonographic measurements were performed using a portable Edan DUS 60 ultrasound device equipped with a 10 MHz linear transducer. The procedure included assessing the thickness of the gastrocnemius and soleus muscles and measuring calf circumference. Measurements were conducted in both female *(Fig. 1)* and male participants *(Fig. 2)*, enabling a comparative analysis of muscle morphology between sexes. For comprehensive structural assessment, the examined muscles were imaged in both transverse and longitudinal planes *(Fig. 3)* using a standardized measurement protocol.

To ensure measurement consistency, the ultrasound device was calibrated in B-mode, and the transducer length was set at 40 mm. The examination was conducted in a prone position, with participants' lower limbs extended and slightly positioned beyond the edge of the examination couch.

- Calf circumference was measured using a tape measure at the thickest point of the calf, serving as a reference for ultrasonographic assessment in both cross-sectional and longitudinal views;
- To prevent distortions, the ultrasound transducer was gently applied to the skin without additional pressure;

Each measurement was performed three times per limb to ensure accuracy and reliability[25].

Functional tests

After the ultrasonographic measurements, participants performed jump tests, including the Vertical Jump (VJ) and the Squat Jump (SJ).

Vertical jump (VJ)

The vertical jump test evaluated jump height and indirectly assessed lower limb muscle strength and power:

- A slatted jump measurement device with an accuracy of

Variable	Women (n = 24)	Men (n = 23)	p value*
Mean age (years)	22.4 ± 1.8	22.7 ± 1.6	0.452
BMI (kg/m^2)	20.6 ± 1.8	24.9 ± 2.3	0.001
Body weight (kg)	59.2 ± 5.4	82.2 ± 7.1	0.001
Height (cm)	165.4 ± 5.2	178.6 ± 6.1	0.001
Fat mass percentage (%)	26.8 ± 5.4	19.9 ± 3.2	0.001
Physical activity level (MET-min/week)	2263.6 ± 345.2	2831.1 ± 410.3	0.076

Table 2. *Collected data about the participants.*
**Analysis of variance ANOVA*

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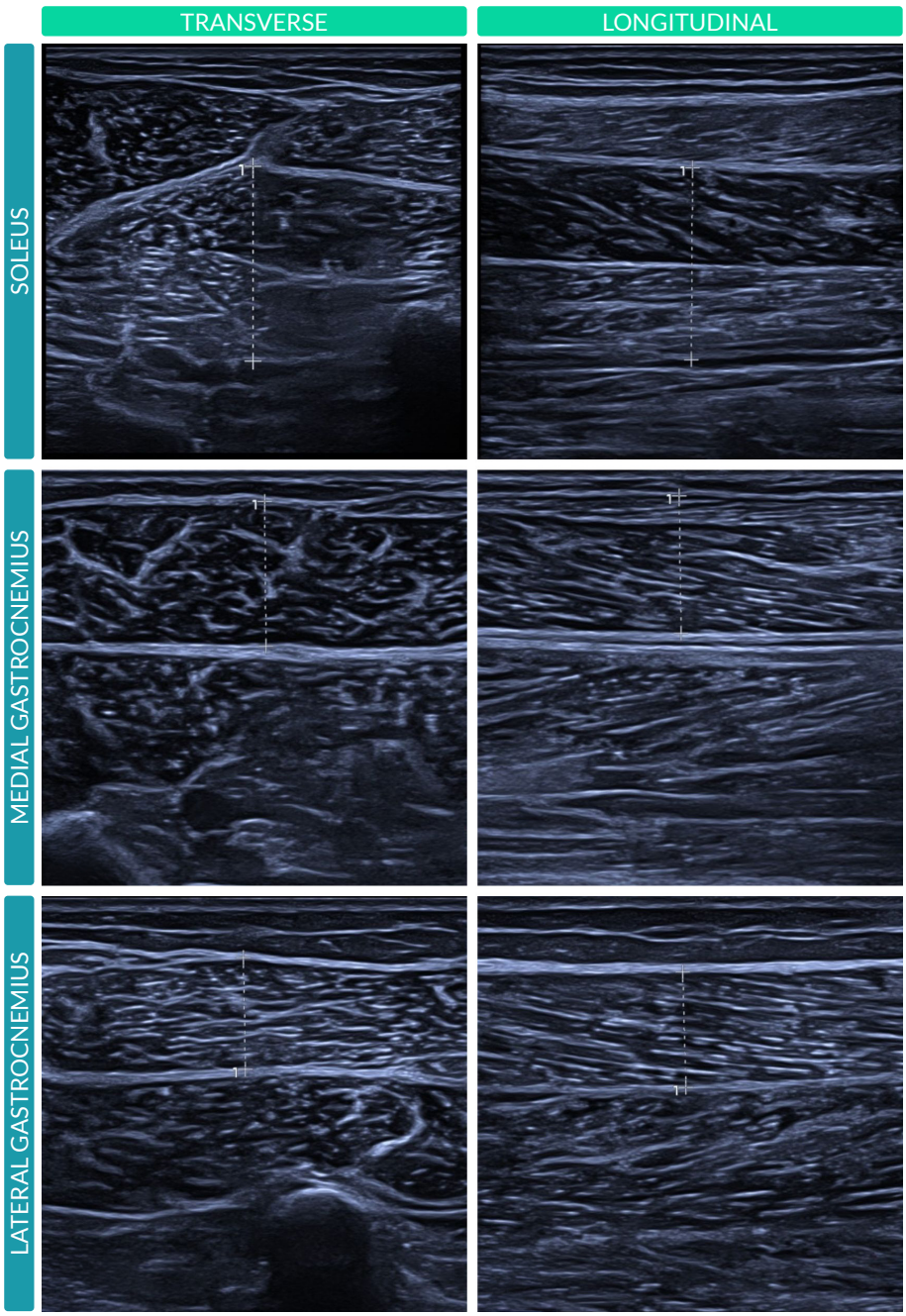


Figure 1. *Ultrasound images of female calf muscles (self-developed data).*

1 cm was used for the test;

- Participants started in a standing position, with arms relaxed at their sides and feet parallel at hip-width apart;

The task required participants to perform a maximal upward jump with an arm swing to increase movement speed and height *(Fig. 4)*[26]. The result was calculated as the difference between the reach height in a neutral standing position and the height achieved after the jump. Each participant performed three trials, with 1-minute rest intervals between attempts.

Squat jump (SJ)

- The squat jump test assessed vertical jump height and the speed generated by the lower limb muscles.
- Participants started in a position with knees bent at a 90-degree angle and hands on their hips *(Fig. 5A)*.

The jump was initiated from this position without arm swings or trunk movement[27].

The Myotest accelerometer was used to measure jump height and speed (expressed in cm/s). Each trial consisted of three jumps performed after an auditory signal from the device. A 2-minute rest interval was provided between sets to prevent muscle fatigue[28].

Statistical analysis

Statistical analysis was conducted using STATISTICA 13.3 software. To determine significant differences in mean values between groups based on sex, analysis of variance (ANOVA) was applied. Pearson correlation was used to assess the strength and direction of the relationships between two quantitative variables and their co-occurrence. A p value of less than 0.05 was considered statistically significant. To determine the reliability of the

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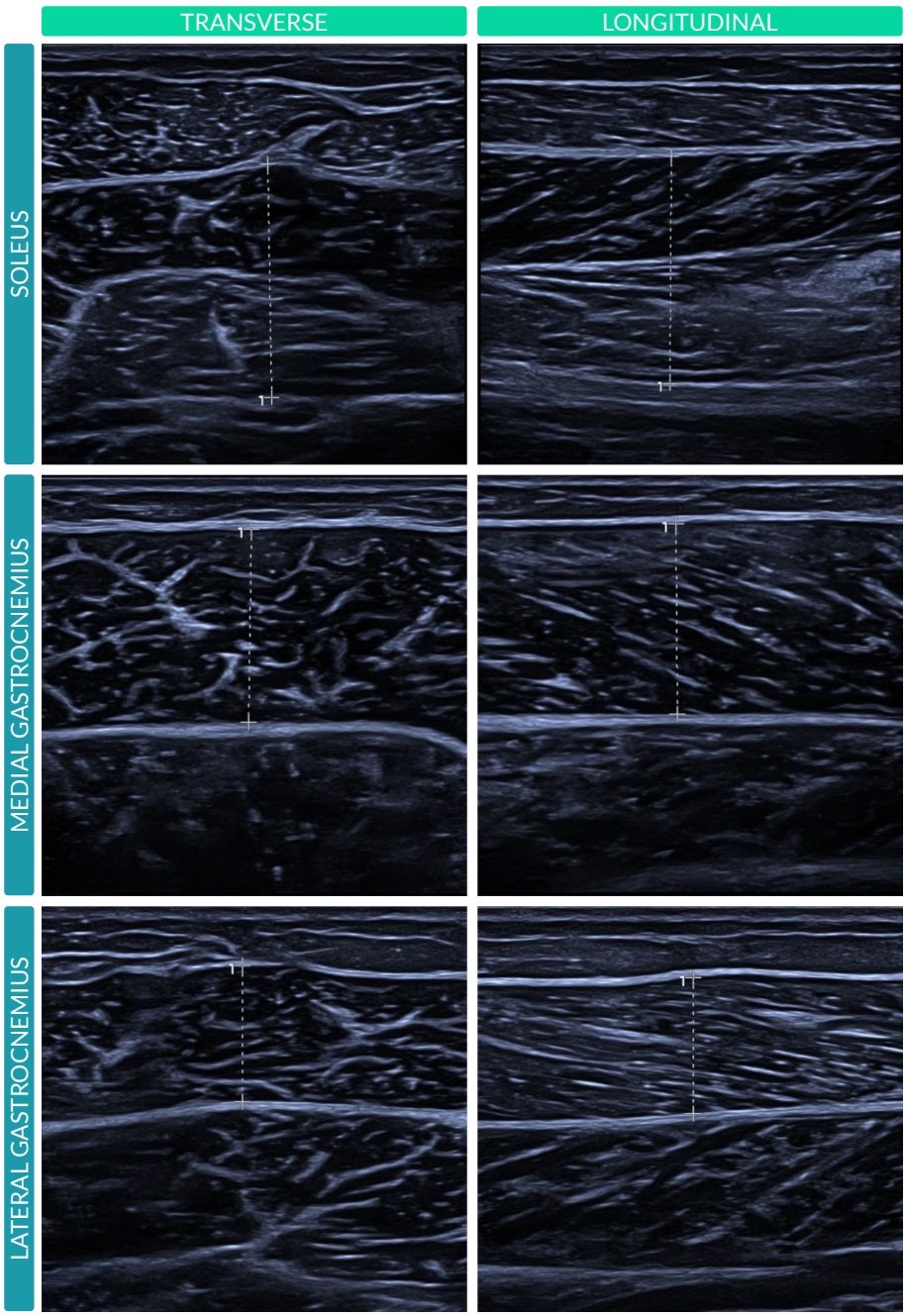


Figure 2. *Ultrasound images of male calf muscles (self-developed data).*

tests performed, the intraclass correlation coefficient for one researcher (ICC3.1) was established.

RESULTS

Descriptive statistics of triceps surae muscle thickness

Table 3 presents ultrasound measurements of the lateral and medial heads of the gastrocnemius muscle, as well as the soleus muscle, in transverse and longitudinal dimensions for 47 participants. The mean transverse and longitudinal dimensions for the lateral head of the gastrocnemius muscle are 12.7 mm (SD ≈ 2.19), while for the medial head they are 16.3 mm (SD ≈ 2.54). The soleus muscle shows mean transverse and longitudinal dimensions of 14.1 mm (SD ≈ 2.68), with the minimum and maximum values indicating substantial individual variability within the study group.

The ultrasonographic measurement the gastrocnemius and soleus muscle thickness in both cross-sections demonstrated excellent reliability, ICC3.1 = 0.99.

Correlation between ultrasonographic measurements of the triceps surae muscle and jump test results

Table 4 presents the correlation results between ultrasonographic measurements of the triceps surae muscle and jump test performance, divided by gender. Key observations:

Women: Moderate, statistically significant positive correlations were observed between vertical jump height and the thickness of the lateral and medial gastrocnemius heads (both transverse and longitudinal dimensions). Strong positive correlations were noted between vertical jump height and soleus muscle thickness ($p < 0.001$ for

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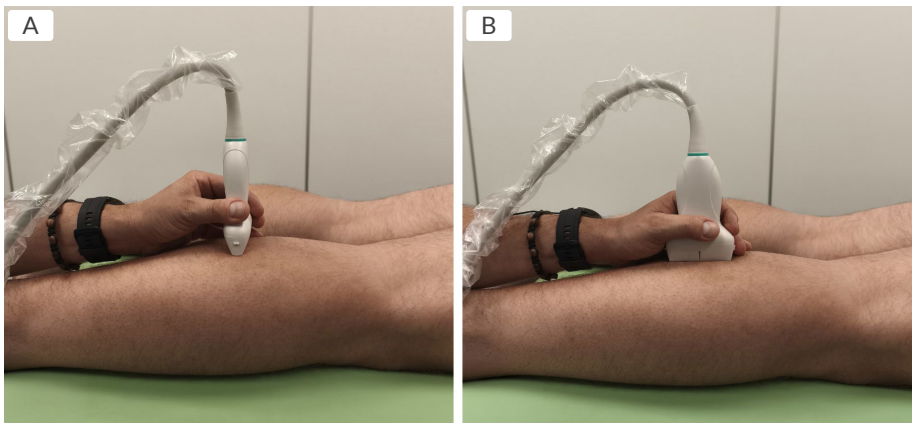


Figure 3. Ultrasound probe placement: A) transverse view; B) longitudinal view (self-developed data).

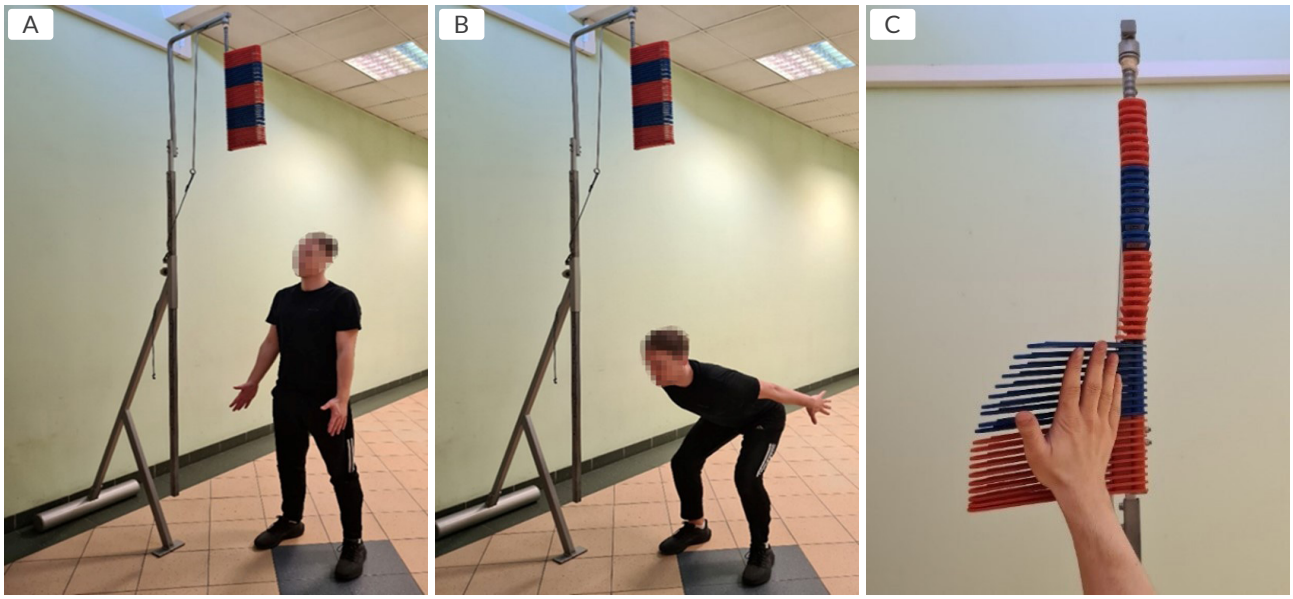


Figure 4. Methodology of the vertical jump test: A) starting position, B) take-off phase with arm swing; C) moment of contact with the measuring device (self-developed data).

Variable, ultrasound	Gender	N	Mean	Median	Min	Max	SD	p value*
Lateral head of gastrocnemius muscle, transverse dimension	Female	24	11.8	11.3	8.8	17.5	2.264	0.0016
	Male	23	13.7	13.4	10.2	17.8	1.629	
Lateral head of gastrocnemius muscle, longitudinal dimension	Female	24	11.8	11.3	8.8	17.7	2.290	0.0017
	Male	23	13.7	13.4	10.2	17.8	1.605	
Medial head of gastrocnemius muscle, transverse dimension	Female	24	15.1	14.7	11.7	22.6	2.598	0.0007
	Male	23	17.5	17.5	12.8	22.0	1,826	
Medial head of gastrocnemius muscle, longitudinal dimension	Female	24	15.1	14.7	11.8	22.6	2.579	0.0006
	Male	23	17.5	17.5	12.8	22.0	1.831	
Soleus muscle, transverse dimension	Female	24	12.4	12.6	9.5	14.7	1.639	0.0000
	Male	23	15.8	15.6	11.5	21.4	2.432	
Soleus muscle, longitudinal dimension	Female	24	12.4	12.6	9.6	14.8	1.640	0.0000
	Male	23	15.8	15.6	11.6	21.4	2.433	

Table 3. Results of the lateral and medial head of the gastrocnemius and soleus muscle measurements.
**Analysis of variance ANOVA*

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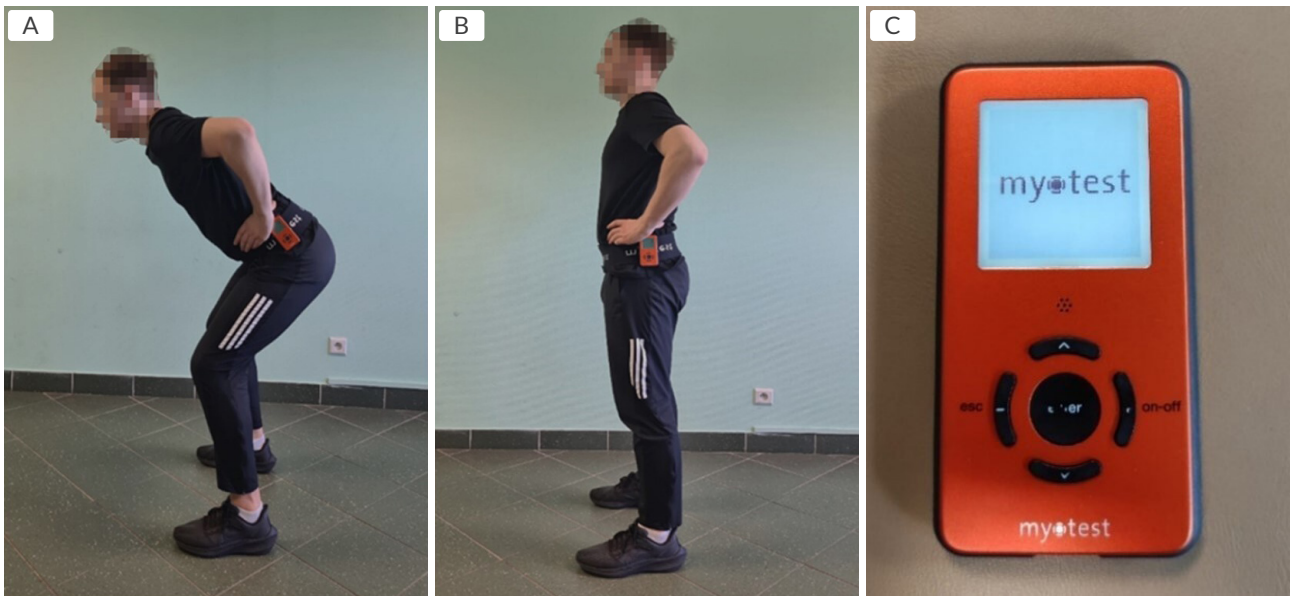


Figure 5. *Methodology of the Squat Jump (SJ): A) starting Position, B) final Position, C) myotest Accelerometer (self-developed data).*

both transverse and longitudinal dimensions). Similar patterns were seen for squat jump height, with strong correlations for soleus muscle thickness and moderate correlations for the gastrocnemius muscle.

Men: Significant strong positive correlations were found between vertical jump height and soleus muscle thickness ($p < 0.001$ for both transverse and longitudinal dimensions). In the squat jump test, significant positive correlations were noted for soleus muscle thickness, but not for the gastrocnemius muscle. A moderate negative correlation was observed between squat jump speed and the longitudinal dimension of the lateral gastrocnemius head ($p = 0.047$, $r = -0.4189$).

The graph *(Fig. 6)* illustrates the correlation coefficient (r) between muscle thickness dimensions and vertical jump height, differentiated by gender. For females, a moderate positive correlation ($r \approx 0.60–0.61$) is observed between vertical jump height and the transverse and longitudinal dimensions of both the lateral and medial gastrocnemius muscles. In contrast, males exhibit negligible or no correlation in these parameters ($r \approx -0.06$ to -0.01).

The soleus muscle demonstrates a strong positive correlation with vertical jump height for both genders, with females showing $r = 0.83$ and males $r = 0.88$ for both

Variable, ultrasound	Gender	Vertical jump height (cm)	Squat jump height (cm)	Squat jump speed (cm/s)
Lateral head of the gastrocnemius muscle, transverse dimension	Female	r = 0.6067, p* = 0.002	r = 0.6076, p = 0.002	r = -0.0208, p = 0.923
	Male	r = -0.0552, p = 0.803	r = -0.2259, p = 0.300	r = -0.4113, p = 0.051
Lateral head of the gastrocnemius muscle, longitudinal dimension	Female	r = 0.5999, p = 0.002	r = 0.6054, p = 0.002	r = -0.0204, p = 0.924
	Male	r = -0.0604, p = 0.784	r = -0.2262, p = 0.299	r = -0.4189, p = 0.047
Medial head of the gastrocnemius muscle, transverse dimension	Female	r = 0.6058, p = 0.002	r = 0.5158, p = 0.010	r = -0.0096, p = 0.964
	Male	r = -0.0222, p = 0.920	r = -0.2666, p = 0.219	r = -0.2141, p = 0.327
Medial head of the gastrocnemius muscle, longitudinal dimension	Female	r = 0.6119, p = 0.001	r = 0.5199, p = 0.009	r = -0.0066, p = 0.976
	Male	r = -0.0066, p = 0.976	r = -0.2496, p = 0.251	r = -0.2063, p = 0.345
Soleus muscle, transverse dimension	Female	r = 0.8323, p <0.001	r = 0.9188, p <0.001	r = 0.2533, p = 0.232
	Male	r = 0.8831, p <0.001	r = 0.9418, p <0.001	r = 0.3423, p = 0.110
Soleus muscle, longitudinal dimension	Female	r = 0.8298, p <0.001	r = 0.9199, p <0.001	r = 0.2557, p = 0.228
	Male	r = 0.8847, p <0.001	r = 0.9413, p <0.001	r = 0.3432, p = 0.109

Table 4. *Correlation between ultrasonographic measurements of the triceps surae muscle and jump test results by gender (n = 47).*
**Analysis of variance ANOVA.*

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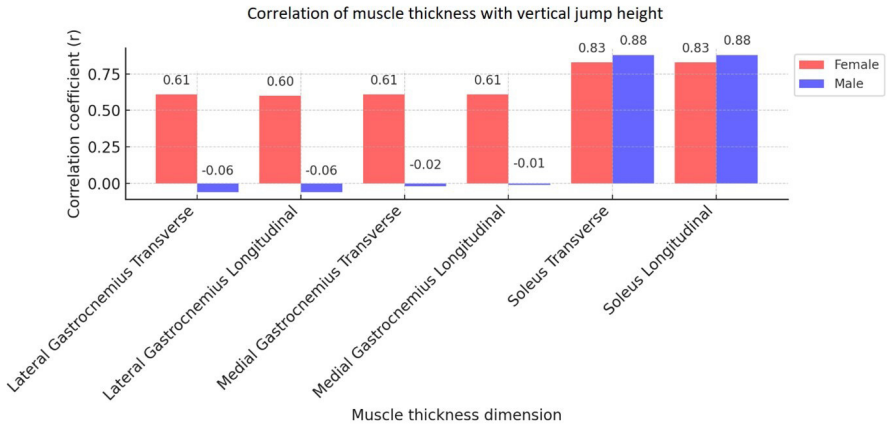


Figure 6. *Correlation graph between muscle thickness and vertical jump height by gender.*

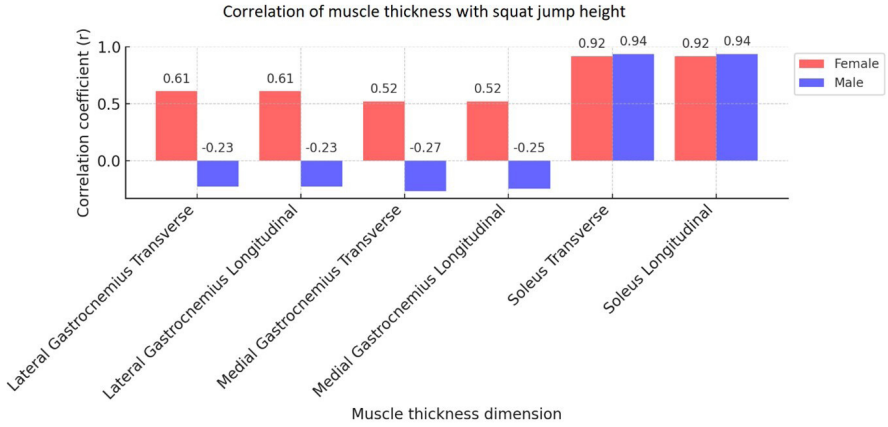


Figure 7. *Correlation graph between muscle thickness and squat jump height by gender.*

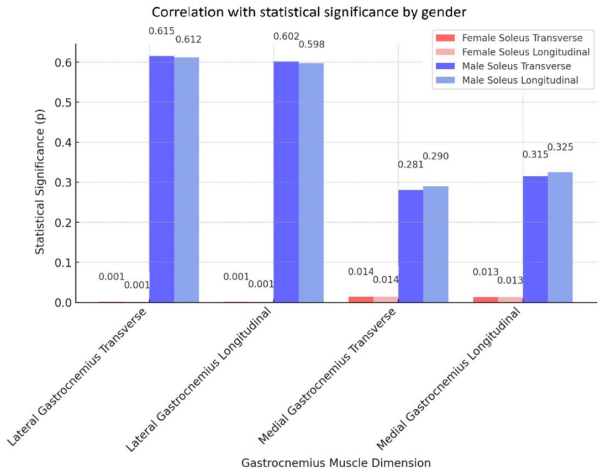


Figure 8. *Correlation graph with statistical significance by gender.*

transverse and longitudinal dimensions.

The graph in *Figure 7* illustrates the correlation coefficient (r) between muscle thickness dimensions and squat jump height, divided by gender. For females, a moderate positive correlation (r ≈ 0.52–0.61) is observed between squat jump height and the transverse and longitudinal dimensions of both the lateral and medial gastrocnemius muscles. In contrast, males show weak negative correlations in these parameters (r ≈ -0.23 to -0.27).

The soleus muscle demonstrates a very strong positive correlation with squat jump height for both genders, with r = 0.92 for females and r = 0.94 for males in both transverse and longitudinal dimensions.

Correlation between soleus and gastrocnemius muscle thickness

Table 5 presents the correlation results between soleus and gastrocnemius muscle thickness, divided by gender. Key findings:

Women: Statistically significant positive correlations were observed between soleus muscle thickness and the dimensions of the gastrocnemius muscle. Correlations were moderate in strength for both transverse and longitudinal dimensions.

Men: No statistically significant correlations were found between soleus and gastrocnemius muscle thickness.

Figure 8 illustrates the correlation coefficient (r) between the thickness of the lateral and medial heads of the gastrocnemius muscle and measured outcomes, divided by gender. In females, statistically significant positive correlations (p ≤0.014) of moderate strength (r ≈ 0.60–0.62) were observed across all transverse and longitudinal dimensions of both muscle heads. In males, the correlations were weaker and not statistically significant (p >0.28).

Figure 9 illustrates the distribution of jump heights for VJ and SJ tests, separated by gender. Males (blue boxes) demonstrated consistently higher jump heights in both tests compared to females (red boxes). The median jump

height for males in both tests exceeded that of females, with less variability observed in the male group for Squat Jump heights.

DISCUSSION

The role of muscle morphology in generating dynamic power

This study demonstrated that the thickness of the gastrocnemius and soleus muscles significantly impacts the results of jump tests, such as the SJ and VJ. These findings indicate that thicker muscle bellies of the triceps surae are associated with higher jump heights, particularly evident in the soleus muscle, which showed a very strong correlation with the results of both tests. These findings emphasize the importance of structural and functional muscle characteristics in generating power during dynamic tasks.

Similar conclusions were reported by Selva Raja et al.[29], who found that gastrocnemius muscle thickness was an independent predictor of vertical jump height (R^2 = 0.579, p <0.01). Their study used ultrasonography to measure muscle architecture, analyzing its relationship with strength and function. The measurement of gastrocnemius thickness in their study was performed at 30% of the distance between the lateral malleolus and the lateral condyle of the tibia, differing from the methodology used in this study, which measured at the point of the largest calf circumference. Despite these differences, both studies highlight the critical role of the gastrocnemius in generating dynamic power.

Earp et al.[30] confirmed that gastrocnemius muscle thickness was a strong predictor of absolute power in dynamic movements, such as SJ (R^2 = 0.181, p = 0.034) and CMJ (R^2 = 0.201, p = 0.014). In their study, ultrasonographic measurements were conducted on relaxed muscles, with thickness measured at two-thirds of the lower leg's length. Methodological differences in measurement locations may explain varying correlation results, but the key conclusions

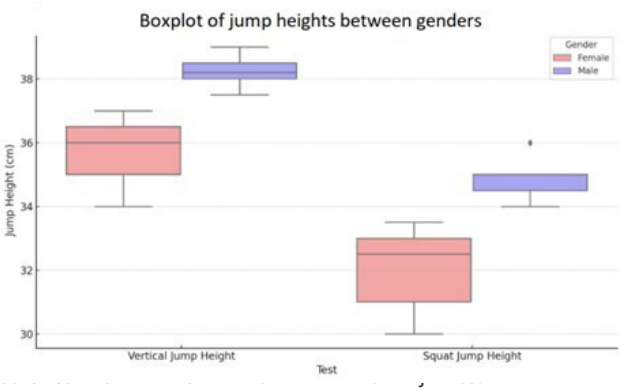


Figure 9. Graph of the relationship between the height of jumps and the gender.

Lenhart et al.[31] demonstrated that the soleus acts as a dynamic stabilizer of the ankle joint, supporting knee extension and plantarflexion, particularly during running. Bohm et al.[32] found that the soleus alternates between functions of efficient force production during submaximal running and maximum power output at peak speeds. The findings of this study support these conclusions, underscoring the role of the soleus as a significant power generator in dynamic motor tasks, such as jumping.

Gender differences

The analysis revealed significant differences in muscle adaptations between women and men. Women exhibited greater harmony and interdependence between the gastrocnemius and soleus muscles, likely due to more efficient utilization of fascial structures during dynamic tasks. In men, the soleus muscle played a dominant role in generating power, possibly due to its capacity to achieve high force output during maximal exertion and its significant influence on cooperation with the gastrocnemius.

Similar differences were observed in the studies by Carboch and Váchová[33], which highlighted that lower limb injuries, such as "tennis leg," occur more frequently in men.

Variable	Gender	Soleus muscle, transverse dimension (mm)	Soleus muscle, longitudinal dimension (mm)
Lateral head of the gastrocnemius, transverse dimension	Female	r = 0.6389, p = 0.001	r = 0.6404, p = 0.001
	Male	r = -0.1108, p = 0.615	r = -0.1118, p = 0.612
Lateral head of the gastrocnemius, longitudinal dimension	Female	r = 0.6369, p = 0.001	r = 0.6385, p = 0.001
	Male	r = -0.1147, p = 0.602	r = -0.1161, p = 0.598
Medial head of the gastrocnemius, transverse dimension	Female	r = 0.4943, p = 0.014	r = 0.4963, p = 0.014
	Male	r = -0.2348, p = 0.281	r = -0.2304, p = 0.290
Medial head of the gastrocnemius, longitudinal dimension	Female	r = 0.4993, p = 0.013	r = 0.5012, p = 0.013
	Male	r = -0.2193, p = 0.315	r = -0.2148, p = 0.325

Table 5. Correlation between gastrocnemius and soleus muscle thickness by gender (n = 47).

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This could be attributed to greater soleus muscle loading during physical activity. Combined with increased passive stiffness of the posterior myofascial chain—confirmed in our previous studies, particularly in the hamstring group in men—this phenomenon may significantly affect shear forces within this complex. The gastrocnemius muscle plays a key role in this process[34]. These observations suggest that men may face a higher risk of overload at the fascial boundary between the gastrocnemius and soleus, constituting a potential mechanism predisposing them to myofascial injuries. Such findings open new avenues for future research in this area.

Epidemiology of "tennis leg" injuries

Epidemiological studies indicate that "tennis leg" injuries occur most frequently in physically active men, particularly those aged 35–65 years. Montalvan and Guillard[35] reported that men account for 60–70% of cases, while women comprise 30–40%. Dynamic loads, particularly in sports requiring sudden changes in pace, may be one of the key risk factors. These findings align with the results of this study, which highlight the significant impact of dynamic loads on the soleus muscle and its susceptibility to injuries.

Summary

The thickness of the soleus muscle can serve as a predictor for indirectly assessing lower limb power, as confirmed by strong correlations with vertical jump and squat jump performance. The study revealed notable gender differences: women exhibited greater interdependence between gastrocnemius and soleus thickness and jump test outcomes, while in men, the soleus muscle played a dominant role. This difference may be associated with greater posterior chain tension in men and its impact on dynamic force generation biomechanics in this complex. These observations highlight the importance of incorporating gender into future research.

Identified mechanisms, such as increased passive stiffness of the posterior myofascial chain in men and the resulting potential for higher shear forces at the fascial boundary between the gastrocnemius and soleus, may explain a higher susceptibility to injuries like "tennis leg" in this group. These findings form the basis for further analyses, particularly in the areas of:

- Biomechanical mechanisms of power generation in the triceps surae, accounting for gender;
- The role of structural and functional muscle differences in the prevention and treatment of myofascial injuries;
- The effectiveness of exploring this issue and developing training programs to reduce the risk of injuries related to dynamic loads, particularly in the lower leg.

Emphasizing these elements in future research could deepen the understanding of biomechanics and contribute to optimizing motor training and protecting the health of physically active individuals.

Limitations

1. Homogeneity of the age group: The study included only young adults aged 18–25, limiting the generalizability of the findings to other age groups.
2. Absence of professional athletes: The participants were recreationally active individuals, limiting the conclusions regarding professional athletes and their specific adaptations.

CONCLUSIONS

1. The thickness of the soleus muscle is a strong predictor of lower limb power, as evidenced by significant correlations with vertical and squat jump performance.
2. Notable gender differences were observed: in women, the gastrocnemius and soleus muscles demonstrated greater interdependence, whereas in men, the soleus muscle played a dominant role.

In summary, the obtained results indicate significant biomechanical differences between genders, which may influence injury risk and training effectiveness. In particular, increased posterior chain stiffness in men may elevate shear forces, potentially leading to a higher risk of injuries such as "tennis leg." These findings open new perspectives for analyzing muscle biomechanics and optimizing training strategies to minimize injury risk in physically active individuals.

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