한국무용과학회지, 2026, 제43권 제2호, pp.19~30
Official Journal of Korean Society of Dance Science
2026, Vol.43, No.2 pp.19~30

1229-7836/26/702

DOI http://dx.doi.org/10.21539/Ksds.2026.43.2.19

# Ultrasonographic Analysis of Rectus Femoris and Tibialis Anterior Architecture in Professional Ballet Dancers

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**Abstract** This study investigated the muscle architectural characteristics of the rectus femoris (RF) and tibialis anterior (TA) in professional ballet dancers (PD, n=15) compared to untrained non-dancer controls (ND, n=15) using B-mode ultrasonography. Thirty female participants aged 18-25 underwent assessments for muscle thickness (MT), pennation angle (PA), and fascicle length (FL). Independent t-tests and Cohen's *d* were utilized for statistical analysis. The results revealed that the PD group exhibited significantly greater MT in the RF ($p < .001$) and substantially longer FL across all measured sites in both the RF and TA ($p < .01$) than the ND group, with the right RF exhibiting the most prominent difference ($d$ = 4.44). Notably, professional dancers demonstrated significantly smaller PA in the RF ($p < .05$) but greater PA in the right TA ($p < .01$), indicating a muscle-specific structural optimization. These findings suggest that professional dance training induces profound fascicle-level remodeling, where elongated fascicles and modulated pennation angles facilitates the dual demands of explosive power, extended range of motion, and joint stability. In conclusion, this study provides a scientific foundation for understanding the functional adaptations of ballet dancers with long-term training and developing evidence-based conditioning and injury prevention protocols.

**Key words** : Muscle architecture, Ultrasonography, Professional dancers, Rectus femoris, Tibialis anterior

## Ⅰ. Introduction

### 1. Background and Rationale of the Study

The rigorous and repetitive characteristic of professional ballet training induces structural and functional adaptations within the human motor system to meet specific aesthetic and technical demands. Unlike general physical activities, professional dance training requires extraordinary neuromuscular control, extensive range of motion, and the ability to maintain repeated high-intensity loading, placing dancers in a physiological category comparable to elite competitive athletes (Leanderson, Eriksson, Nilsson, & Wykman, 1996; Lepelley, Thullier, Koral & Lestienne, 2006). The musculoskeletal system of a professional dancer undergoes continuous and extreme functional strain due to the need to meet specialized technical demands, such as forced turnout, extreme joint excursion, and rigid postural alignment against gravity. Approximately 86% of

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professional dancers experience lower extremity ligamental or musculotendinous injuries during their dance careers (Walter, Docherty & Schrader, 2011). The incidence rate is reported at nearly 0.8 injuries per 1,000 hours of dancing, with ankle sprains and various tendinopathies being the most prevalent diagnoses (Leanderson et al., 1996; Leanderson C, Leanderson J, Wykman, Strender, Johansson, & Sundquist, 2011). In addition, as the vast majority of these injuries are localized in the lower extremities, the ankle and foot complex is the most frequently affected area (53.0%), followed by the hip (21.6%) and the knee (16.1%) (Gamboa, Roberts, Maring, & Fergus, 2008). Considering these physical demands and injury risks, the rectus femoris (RF) and tibialis anterior (TA) were specifically selected for this study due to their unique anatomical and functional roles in specialized dance techniques. Unlike other muscles of the quadriceps femoris, the RF is the only bi-articular muscle that facilitates both hip flexion and knee extension. This duality is essential for explosive jumping maneuvers, such as the Grand Jeté or Sissonne, where rapid hip flexion must occur simultaneously with powerful knee extension to achieve both aesthetic line and maximum flight height (Koutedakis & Jamurtas, 2004). Furthermore, the RF is a primary contributor to eccentric deceleration during the plié phase of landing, acting as a critical shock absorber to manage high-intensity vertical impacts. Simultaneously, the TA was focused on as the principal dorsiflexor and distal stabilizer of the ankle-foot complex. In professional dance, the TA is vital for the precise execution of 'pointe' and 'flex' that defines the technical clarity of footwork. During fast-paced movements like Petit Allegro, the TA must rapidly transition between concentric contractions for clearance and eccentric control to stabilize the ankle during repetitive landings (Russell, 2011). Since the ankle is the most frequent site of injury in dancers, understanding the structural integrity of the TA, as a key mechanism for maintaining distal joint stability, is fundamental for performance optimization and injury prevention. Despite their functional significance, the chronic and repetitive mechanical loading inherent in professional training can lead to maladaptive changes in muscle morphology, which may increase susceptibility to overuse injuries. To investigate these internal adaptations, ultrasonography has emerged as a gold-standard, non-invasive tool for quantifying muscle architecture. Unlike traditional functional assessments that only measure external performance or joint range of motion, B-mode ultrasonography allows for the real-time, in vivo visualization of internal muscle structures. This modality was specifically selected for its ability to provide high-resolution imaging to precisely quantify three fundamental architectural parameters: Muscle Thickness (MT), Pennation Angle (PA), and Fascicle Length (FL). These parameters are crucial as they directly dictate a muscle’s functional capacity. Specifically, MT represents the distance between the superficial and deep aponeuroses, serving as a primary indicator of a muscle's maximum force-generating capacity (Lieber & Fridén, 2000). PA is defined as the angle between the longitudinal axis of the muscle and its internal fascicles. PA reflects the internal geometric arrangement of fascicles and exhibits significant structural plasticity in response to chronic physical loading (Aagaard, Andersen, Dyhre-Poulsen, Leffers, Wagner, Magnusson, Halkjær-Kristensen, & Simonsen, 2001). Specifically, an increase in PA allows for the packing of more contractile elements (sarcomeres in parallel) within a given volume, enhancing the physiological cross-sectional area and maximum force-generating capacity (Lieber & Fridén, 2000). Beyond force production, the PA is a critical determinant of joint stability. A well-adapted PA improves dynamic stiffness by facilitating the effective transmission of muscular tension to the tendons, allowing the muscle-tendon unit to manage multi-directional loads more efficiently (Blazevich, Gill, Bronks, & Newton, 2006). For professional dancers, this architectural fine-tuning may serve as a primary compensatory mechanism to enhance joint integrity and prevent injury during extreme ranges of motion and explosive movements. Lastly, FL refers to the absolute length of the muscle fascicle, which is a key determinant of the muscle's maximum shortening velocity and working range (Blazevich, 2006; Lieber & Fridén, 2000). Ultrasound-based analysis offers a unique advantage in dance science by capturing subtle architectural remodeling at the fascicle level, which may precede detectable changes in gross motor function or clinical symptoms. However, despite the clinical and biomechanical importance of muscle architecture in performance and injury prevention, comparative studies specifically examining the RF and TA in professional dancers and non-dancers remain insufficient. While existing dance science literature has extensively focused on joint range of motion, flexibility, and functional performance (Steinberg, Hershkovitz, Peleg, Dar, Masharawi, Heim, & Siev-Ner, 2006; Yin, Geminiani, Quinn, Owen, Kinney, McCrystal, & Stracciolini, 2019), objective data regarding the internal structural remodeling of specific lower-limb muscles are still lacking. This absence of architectural evidence limits the understanding of how professional-level training uniquely reshapes the muscular system at the fascicle level to withstand high-intensity mechanical strain.

Therefore, the purpose of this study is to compare the muscle architectural characteristics (MT, PA, and FL) of the RF and TA muscles in professional dancers and non-dancers using ultrasonography. By identifying these unique structural characteristics, this study aims to establish foundational data for developing optimized, dance-specific conditioning programs. Moreover, these findings can provide a basis for developing evidence-based injury prevention and rehabilitation protocols optimized for the unique biomechanical demands of professional dance, ultimately promoting the career longevity and physical well-being of dancers.

## 2. Research Questions

To achieve the purpose of this study, the following research questions were formulated.

1) Are there significant differences in the muscle architectural characteristics (muscle thickness, pennation angle, and fascicle length) of the rectus femoris (RF) between professional dancers and non-dancers?
2) Are there significant differences in the muscle architectural characteristics (muscle thickness, pennation angle, and fascicle length) of the tibialis anterior (TA) between professional dancers and non-dancers?

3) How do the structural adaptations of the RF and TA in professional dancers reflect the functional demands of long-term dance training?

# Ⅱ. Methods

## 1. Participants

A total of thirty female participants aged 18 to 25 years were recruited for this study. The participants were divided into two groups: fifteen professional ballet dancers (PD) currently affiliated with professional ballet companies in the Miami area, and fifteen non-dancers (ND) from the university community. Professional status and years of experience were utilized as primary indicators of dance proficiency, reflecting the cumulative training dosage necessary for long-term neuromuscular and structural adaptation. All participants provided signed informed consent approved by the Institutional Review Board (IRB No. D4000009E). Prior to the ultrasound measurements, demographic and anthropometric data were collected. Height and total body mass were measured simultaneously using a calibrated integrated stadiometer and an electronic scale. Participants were instructed to stand upright with their heads in the Frankfort plane, wearing light athletic clothing and no shoes. Height and body mass were recorded to the nearest 0.1 cm and 0.1 kg, respectively. The demographic and anthropometric characteristics of the participants are presented in 〈Table 1〉.

Table 1. Demographic and anthropometric characteristics of the participants (M±SD)

| | PD ($n$=15) | ND ($n$=15) | $p$ |
|---|---|---|---|
| Age (yrs) | 22.4 ± 1.8 | 21.3 ± 2.1 | .148 |
| Height (cm) | 165.0 ± 5.6 | 165.8 ± 3.4 | .640 |
| Mass (kg) | 50.8 ± 2.9 | 58.7 ± 4.2 | 〈.001* |
| Dance training (yrs) | 13.7 ± 2.4 | - | - |

## 2. Testing Procedures

Muscle architectural characteristics of the rectus femoris (RF) and tibialis anterior (TA) were assessed using the LOGIQ P9 R3 Ultrasound System (GE Healthcare, Buckinghamshire, UK) equipped with a 3-12 MHz linear array transducer. For all measurements, the frequency was set at 12 MHz with an initial depth of 6 cm, however, the depth was adjusted as necessary to ensure the deep aponeurosis of each muscle was clearly visible. To enhance acoustic coupling and minimize skin deformation, a water-soluble transmission gel was applied to the probe head. Prior to the assessment, participants rested for at least 20 minutes to ensure a stable resting state. Participants were positioned supine on a padded examination table with their hips and knees naturally extended and ankles in a neutral position. To ensure anatomical consistency and reproducibility of probe placement, specific landmarks were marked as follows: at 50% of the thigh length (measured from the anterior superior iliac spine to the superior border of the patella) for the RF, and at 30% of the distance from the head of the fibula to the tip of the lateral malleolus for the TA (Ren, Cheng, Ma, & Zheng, 2021; Kim, Lee, H & Lee, W, 2015). Three high-quality images were captured in the longitudinal view using brightness mode (B-mode) for each muscle. A single investigator conducted all measurements and assessments to eliminate inter-rater variability. The intra-rater reliability of the investigator was evaluated with a subsample of eight subjects, yielding intraclass correlation coefficients (*ICC*) of .96 for the RF and .93 for the TA. According to the interpretation criteria established by Koo and Li (2016), these values represent excellent test-retest consistency (*ICC* $\geq$ 0.75).

## 3. Data Analysis

The captured B-mode longitudinal images were analyzed using ImageJ software (National Institutes of Health, Bethesda, MD, USA) to quantify the muscle architectural parameters of the RF and TA. Muscle thickness (MT) was defined as the perpendicular distance between the superficial and deep aponeuroses at the thickest portion of the muscle, while the pennation angle (PA) was calculated as the angle formed between the muscle fascicle and the deep aponeurosis using the software's angle function. Fascicle length (FL) was measured by tracing a straight line along the fascicle path from the superficial to the deep aponeurosis. To ensure high reliability, all assessments were conducted by a single investigator, and the mean values obtained from three separate images per muscle were utilized for the final statistical analysis.

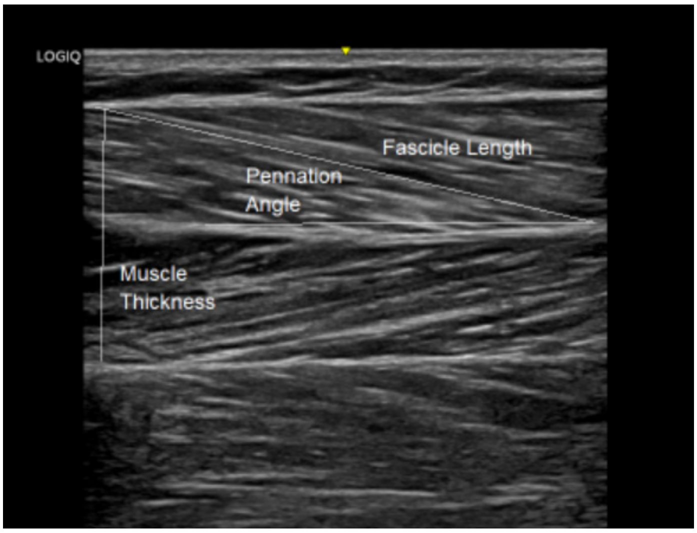


Figure 1. B-mode longitudinal ultrasound image of the TA muscle illustrating the measurement of muscle thickness, pennation angle, fascicle length

## 4. Statistical Analysis

Statistical analysis was performed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics, including means and standard deviations (M±SD), were calculated for all demographic data and muscle architectural parameters (MT, PA, and FL). The normality of the data distribution was verified using the Shapiro-Wilk test. An independent t-test was conducted to determine significant differences in muscle architectural characteristics between the professional dancers (PD) and the untrained controls (ND). To assess the magnitude of the differences, Cohen's *d* was calculated as an effect size, with values interpreted as small (0.2), medium (0.5), and large (0.8) (Cohen, 2013). The level of statistical significance was set at $p < .05$.

# Ⅲ. Results

## 1. Results of MT, PA, FL between PD and ND

The muscle architectural characteristics of the rectus femoris (RF) and tibialis anterior (TA) were compared between professional dancers (PD) and untrained controls (ND). The mean values, standard deviations, and statistical comparison results (*t-values*, *p-values*, and *Cohen's d*) for muscle thickness (MT), pennation angle (PA), and fascicle length (FL) are summarized in 〈Table 2〉.

### 1) Muscle Thickness (MT)

As shown in 〈Table 2〉, professional dancers exhibited significantly greater MT in the rectus femoris compared to the control group for both the left ($t$ (28) = 3.66, $p$ = .001, $d$ = 1.34) and right ($t$ (28) = 4.85, $p < .001$, $d$ = 1.77) sides. While absolute MT of the tibialis anterior showed no significant group differences ($p > .05$), the normalized MT (MT/Body Mass) revealed a significant superiority in the PD group for both the left ($p < .01$, $d$ = 1.01) and right ($p < .001$, $d$ = 2.82) sides. These results indicate that professional dancers possess higher relative muscularity in the lower limbs specialized for their body weight.

### 2) Pennation Angle (PA)

Significant group differences were observed in the pennation angle of both muscles. In the rectus femoris, the PD group demonstrated a significantly smaller PA than the ND group on both the left ($t$ (28) = -2.98, $p$ = .006, $d$ = -1.09) and right ($t$ (28) = -2.36, $p$ = .025, $d$ = - 0.86) sides. Conversely, in the tibialis anterior, the PD group showed a significantly greater PA in the right side ($t$ (28) = 2.61, $p$ = .014, $d$ = 0.95) compared to the ND group, while the left side showed a similar increasing trend without reaching statistical significance ($p$ = .089).

### 3) Fascicle Length (FL)

The most prominent differences were found in fascicle length across all measured sites. Professional dancers possessed significantly longer fascicles in both the RF and TA compared to non-dancers ($p < .01$). This structural dominance remained robust after normalizing for body mass (FL/Body Mass). For the RF, the PD group showed significantly higher normalized FL ($p < .001$) with exceptionally large effect sizes of left ($d$ = 3.39) and right ($d$ = 5.68). The normalized FL of the TA was also significantly greater in the PD group ($p < .001$), confirming a substantial longitudinal adaptation of muscle fascicles in response to professional dance training, independent of body size.

Table 2. Muscle thickness, pennation angle, and fascicle length of the RF and TA in PD and ND

| | | PD (n=15) | ND (n=15) | *t* | *p* | *cohen's d* |
|---|---|---|---|---|---|---|
| Muscle Thickness (cm) | | | | | | |
| Left | RF | 2.18 ± 0.56 | 1.61 ± 0.22 | 3.66 | .001* | 1.34 |
| | Normalized (cm/kg) | 0.043 ± 0.01 | 0.027 ± 0.004 | 5.58 | .001* | 2.05 |
| | TA | 2.66 ± 0.27 | 2.48 ± 0.77 | .85 | .40 | .31 |
| | Normalized (cm/kg) | 0.052 ± 0.005 | 0.042 ± 0.013 | 2.78 | .01* | 1.01 |
| Right | RF | 2.47 ± 0.50 | 1.69 ± 0.37 | 4.85 | .001* | 1.77 |
| | Normalized (cm/kg) | 0.049 ± 0.01 | 0.029 ± 0.006 | 6.66 | .01* | 2.44 |
| | TA | 2.59 ± 0.18 | 2.51 ± 0.01 | 1.71 | .09 | .63 |
| | Normalized (cm/kg) | 0.051 ± 0.004 | 0.043 ± 0.001 | 7.74 | .001* | 2.82 |
| Pennation angle (deg) | | | | | | |
| Left | RF | 8.00 ± 1.34 | 10.02 ± 2.25 | -2.98 | .006* | -1.09 |
| | TA | 11.56 ± 3.50 | 9.78 ± 1.74 | 1.76 | .089 | .06 |
| Right | RF | 9.23 ± 2.54 | 11.50 ± 2.71 | -2.36 | .025* | -.86 |
| | TA | 10.21 ± 1.33 | 8.39 ± 2.35 | 2.61 | .014* | .95 |
| Fascicle length (cm) | | | | | | |
| Left | RF | **11.72 ± 1.32** | **7.99 ± 1.76** | 6.56 | .01* | 2.39 |
| | Normalized (cm/kg) | 0.231 ± 0.026 | 0.136 ± 0.03 | 9.27 | .01* | 3.39 |
| | TA | **7.53 ± 1.51** | **6.15 ± 0.62** | 3.27 | .003* | 1.19 |
| | Normalized (cm/kg) | 0.148 ± 0.029 | 0.105 ± 0.01 | 5.41 | .01* | 1.98 |
| Right | RF | **12.44 ± 1.05** | **7.02 ± 1.37** | 12.16 | .01* | 4.44 |
| | Normalized (cm/kg) | 0.245 ± 0.021 | 0.12 ± 0.023 | 15.54 | .01* | 5.68 |
| | TA | **7.25 ± 0.70** | **5.65 ± 0.44** | 7.49 | .01* | 2.73 |
| | Normalized (cm/kg) | 0.143 ± 0.014 | 0.096 ± 0.007 | 11.50 | .01* | 4.21 |

PD: Professional Dancers, ND: Non-Dancers, RF: Rectus Femoris, TA: Tibialis Anterior. Normalized values (MT/Mass, FL/Mass) are calculated as the ratio of each parameter to body mass. $^*p < .05$.

## Ⅳ. Discussion

The primary objective of this study was to compare the muscle architectural characteristics of the rectus femoris (RF) and tibialis anterior (TA) between professional dancers (PD) and untrained controls (ND). Regarding the first and second research questions, the results clearly demonstrate significant structural differences between professional dancers and untrained controls. The substantially large effect sizes for the normalized values indicate that the architectural superiority of professional dancers is not a byproduct of body size but a robust physiological adaptation. This high power-to-weight ratio in muscle structure allows dancers to execute demanding technical elements with greater mechanical efficiency. Professional dancers exhibited significantly longer fascicle lengths (FL) in both the RF and TA compared to non-dancers. Fascicles are bundles of muscle fibers that dictate the force-generating capacity and power output of skeletal muscles by influencing contraction velocity. These structural shifts are consistent with chronic adaptation to the specialized mechanical demands of dance training (Ericsson, Krampe, & Tesch-Römer, 1993). From a biomechanical perspective, longer fascicles have been suggested to provide a higher maximum shortening velocity, offering a structural basis that could support the generation of greater power during explosive movements such as jumping and leaping (Kumagai, Abe, Brechue, Ryushi, Takano, & Mizuno, 2000). These movements are fundamental to professional dance technique and are refined through years of rigorous and repetitive training (Kawakami, Abe, & Fukunaga, 1998). Previous research has also demonstrated that intensive dance training can lead to significant increases in fascicle length over relatively short periods (Farris, Lichtwark, Brown, & Cresswell, 2016). This adaptation is likely driven by an increase in the number of sarcomeres in series, which enhances the muscle's contractile function and maximum shortening velocity (Lieber & Friden, 2000).

In addition, while the PD group exhibited significantly greater muscle thickness (MT) in the RF, they displayed a significantly smaller pennation angle (PA) than the ND group. This inverse relationship, increased thickness with decreased pennation angle, suggests a specific optimization for rapid force production. A smaller PA in the RF is expected to allow a greater proportion of the muscle force to be transmitted directly to the tendon along its longitudinal axis, which is typically associated with high-speed contractions over absolute maximum force (Moltubakk, Magulas, Villars, Seynnes, & Bojsen-Møller, 2018). Given that the RF is a bi-articular muscle essential for both hip flexion and knee extension, these longer and leaner fascicle arrangements likely facilitate the extreme joint excursions and rapid leg elevations (e.g., grand battement) required in professional dance.

In contrast, the tibialis anterior (TA) in professional dancers showed both significantly longer fascicles and a greater pennation angle, particularly in the right side, compared to non-dancers. A greater PA generally indicates a larger physiological cross-sectional area, which is associated with increased force production capacity. In the context of dance, the TA provides powerful ankle dorsiflexion and stability during complex footwork and landings. The combination of longer FL and greater PA implies that the TA in professional dancers may have undergone architectural remodeling that could potentially support the functional range of motion required for expressive foot articulation, such as the extreme dorsiflexion and plantarflexion, as well as the necessary strength for ankle stabilization (Kubo, Kanehisa, Takeshita, Kawakami, & Fukunaga, 2015). Therefore, the findings indicate that long-term professional dance training induces significant structural remodeling in those muscles, characterized by substantially longer fascicle lengths and muscle thickness in the RF, as well as distinct adaptations in pennation angles. These architectural adaptations are likely a result of the daily training regimen which includes intensive stretching and repetitive eccentric loading. However, it is noteworthy that these adaptations, particularly the pronounced asymmetry observed in the right RF fascicle length (d=4.44) and right TA pennation angle ($p < .01$) in dancers, may serve as a double-edged sword. While these shifts represent functional optimization for dance-specific tasks, bilateral asymmetry exceeding a certain threshold can lead to kinetic chain disruptions. From a biomechanical perspective, such unilateral dominance in muscle architecture may induce compensatory pelvic tilt or functional spinal misalignment, potentially increasing the risk of overuse injuries like scoliosis or patellofemoral pain syndrome. Furthermore, the significant difference in pennation angles could alter the line of pull at the joints, which may predispose dancers to long-term degenerative changes such as knee osteoarthritis if the structural imbalance is not managed. To mitigate the potential risks associated with the observed structural asymmetries, it is essential to implement customized conditioning strategies that prioritize unilateral corrective exercises and neuromuscular re-education. Such targeted interventions, focused on restoring bilateral symmetry and functional alignment, are critical for preventing overuse injuries and ensuring career longevity.

While these results provide a scientific foundation for evidence-based conditioning, it is important t o note that this study was limited to only female ballet dancers aged 18-25, necessitating future resea rch that includes diverse genders and age groups. Moreover, as this study focused on structural adapt ations, subsequent investigations should incorporate functional kinetic data, such as electromyography (EMG), ground reaction forces (GRFs), and rate of force development (RFD) to further clarify how th ese structural adaptations translate into actual dance performance efficiency and injury resilience.

The findings of this study suggest that ballet dancers with more than 10 years of long-term trainin g undergo profound structural remodeling of the RF and TA, optimizing their muscle architecture to m eet the dual demands of aesthetic perfection and elite athletic performance. This architectural shift pr ovides the mechanical basis for maintaining refined body lines during extended joint excursions, such as high leg elevations or intricate foot articulations that characterize balletic grace. Ultimately, this un derscores the importance of integrating architectural screening into conditioning programs to enhance performance and ensure the sustainable career longevity of professional ballet dancers.

## V. Conclusion

The present study demonstrates that long-term professional ballet training induces distinct structur al plasticity in the lower-limb musculature, specifically the rectus femoris (RF) and tibialis anterior (TA), to meet the unique biomechanical demands of elite performance. The findings reveal that profes sional dancers possess significantly greater muscle thickness and substantially longer fascicles in the RF compared to untrained controls, yet exhibit smaller pennation angles. This suggests an architectura l optimization that prioritizes contractile velocity and extensive range of motion over absolute maximu m force production. Furthermore, the TA in dancers is characterized by both longer fascicle lengths an d greater pennation angles, indicating a dual adaptation that supports both the strength required for an kle stabilization and the high degree of mobility necessary for aesthetic foot articulation, en pointe wo rk. In conclusion, professional dance training remodels the musculoskeletal system at the fascicle level to achieve a delicate balance between extreme joint excursion and high-level athletic performance. These findings provide a scientific basis for designing targeted conditioning and injury prevention strategies that reflect the unique physiological demands of dancers, ultimately promoting their long-term career sustainability and overall physical health.

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ABSTRACT

# 전문 발레 무용수의 대퇴직근 및 전경골근 구조적 특성에 관한 초음파 분석

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본 연구는 초음파 분석을 통해 전문 발레 무용수 (PD, 15명)와 비무용수 (ND, 15명) 간의 대퇴직근 (RF) 및 전경골근 (TA)의 근육 구조적 특성을 비교 분석하였다. 18~25세의 여성 30명을 대상으로 B-모드 초음파를 이용하여 근두께 (MT), 깃각 (PA), 근다발길이 (FL)를 측정하였으며, 독립표본 t-검정과 Cohen's d를 통해 그룹 간 차이를 검증하였다. 연구 결과, 전문 무용수 그룹은 비무용수에 비해 대퇴직근의 근두께가 유의하게 두꺼웠으며 ($p < .001$), 대퇴직근과 전경골근 모두에서 근다발길이가 유의하게 긴 것으로 나타났다 ($p < .01$). 특히 우측 대퇴직근의 근다발길이에서 가장 뚜렷한 차이가 관찰되었다($d$ = 4.44). 또한 전문 무용수는 대퇴직근에서 유의하게 작은 깃각을 보인 반면 ($p < .05$), 우측 전경골근에서는 유의하게 큰 깃각을 보여 ($p < .01$) 근육별로 특이적인 구조적 최적화 양상을 나타냈다. 이러한 결과는 전문적인 무용 훈련이 근다발 수준의 깊은 재구성을 유도하며, 길어진 근다발과 조절된 깃각의 조합이 폭발적인 파워, 큰 가동 범위, 그리고 관절의 안정성이라는 무용의 기능적 요구를 충족시키기 위한 적응임을 시사한다. 결론적으로 본 연구는 무용수들의 기능적 적응에 대한 과학적 토대를 제공하며, 발레 무용수들을 위한 근거 중심의 컨디셔닝 및 부상 예방 프로그램 개발의 기초자료로 활용될 수 있다.

주요어 : 근육 구조적 특성, 초음파 분석, 전문무용수, 대퇴직근, 전경골근

논문투고일: 2026.02.24
논문심사일: 2026.04.20
심사완료일: 2026.04.30

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