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Influence of overlying soft tissue thickness on tensiomyographic parameters

Influencia del espesor de los tejidos blandos suprayacentes sobre los parámetros tensiomiográficos

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Abstract

Introduction. Tensiomyography (TMG) is widely used to assess the contractile mechanical properties of superficial muscles. Although overlying soft tissue morphology may influence TMG outcomes, few studies have examined the effect of overlying soft tissue thickness (OSTT) on tensiomyographic measurements. Objectives. To explore the potential influence of OSTT on tensiomyographic parameters of lower-limb muscles in healthy adults. Methods. A total of 109 physically active adults were assessed (39 women; age = 37 ± 19 years; BMI = 25.4 ± 3.8 kg/m²), of whom 45.8% were classified as overweight or obese. Tensiomyographic parameters (Dm, Tc, Td, Ts, and Tr) were recorded from the rectus femoris (RF) and biceps femoris (BF) muscles. OSTT was determined by ultrasound at the same anatomical site. Associations were analyzed using Spearman's correlations and multiple linear regression models ($p < 0.05$). Results. Significant, albeit weak, correlations were observed between OSTT and Tc in both muscles (RF: $\rho = 0.288$, $p = 0.002$; BF: $\rho = 0.427$; $p = 0.019$) and between OSTT and Dm in the RF only ($\rho = -0.321$; $p < 0.001$). After adjustment for age and sex, only the association between OSTT and RF Dm remained statistically significant (standardized $\beta = -0.392$, $p < 0.001$). No significant associations were found for the remaining parameters. Conclusions. OSTT may act as a biomechanical modulating factor of the TMG signal, particularly affecting amplitude-related variables such as Dm in a muscle-dependent manner. Considering OSTT may improve interpretation of TMG results and reduce potential biases associated with superficial tissue composition.

Keywords: Tensiomyography, overlying soft tissue thickness, muscle mechanical properties, rectus femoris, biceps femoris.

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Resumen

Introducción. La tensiomiografía (TMG) es una técnica ampliamente utilizada para evaluar las propiedades mecánicas contráctiles de los músculos superficiales. Aunque la morfología de los tejidos blandos suprayacentes podría influir en los resultados de la TMG, pocos estudios han examinado el efecto del espesor de estos tejidos blandos suprayacentes (OSTT) sobre las mediciones tensiomiográficas. Objetivos. Explorar la posible influencia del OSTT sobre los parámetros tensiomiográficos de músculos del miembro inferior en adultos sanos. Métodos. Se evaluaron 109 adultos físicamente activos de ambos sexos (39 mujeres; edad = 37 ± 19 años; IMC = 25,4 ± 3,8 kg/m²), de los cuales el 45,8% fueron clasificados como obesos o con sobrepeso. Los parámetros tensiomiográficos (Dm, Tc, Td, Ts y Tr) se registraron en los músculos recto femoral (RF) y bíceps femoral (BF). El OSTT se determinó mediante ecografía en el mismo sitio anatómico de medición. Las asociaciones se analizaron mediante correlaciones de Spearman y modelos de regresión lineal múltiple ($p < 0{,}05$). Resultados. Se observaron correlaciones significativas, aunque débiles, entre el OSTT y Tc en ambos músculos (RF: $\rho = 0{,}288$, $p = 0{,}002$; BF: $\rho = 0{,}427$; $p = 0{,}019$), así como entre el OSTT y Dm únicamente en el RF ($\rho = -0{,}321$; $p < 0{,}001$). Tras ajustar por edad y sexo, solo la asociación entre OSTT y Dm del RF permaneció estadísticamente significativa (β estandarizado = -0,392; $p < 0{,}001$). No se encontraron asociaciones significativas para los parámetros restantes. Conclusiones. El OSTT podría actuar como un factor modulador biomecánico de la señal tensiomiográfica, afectando particularmente variables relacionadas con la amplitud, como el Dm, de manera dependiente del músculo evaluado. Considerar este factor podría mejorar la interpretación de los resultados de la TMG y reducir posibles sesgos asociados a la composición de los tejidos superficiales.

Keywords: Tensiomiografía, espesor de los tejidos blandos suprayacentes, propiedades mecánicas musculares, recto femoral, bíceps femoral

Introduction

Tensiomyography (TMG) is a validated, highly reliable, and non-invasive technique for assessing the mechanical contractile properties of superficial muscles. It enables the quantification of muscle response to an extrinsic electrical stimulus through a high-sensitivity radial displacement sensor (Park, 2020).

The resulting signal allows for the analysis of five temporal and amplitude parameters that characterize neuromuscular status: maximum radial displacement (Dm), which measures muscle belly deformation and serves as a direct indicator of muscle stiffness or tone; contraction time (Tc), defined as the time between 10% and 90% of Dm, associated with muscle fiber type distribution; sustain time (Ts), during which deformation remains above 50% of Dm, related to fatigue resistance; relaxation time (Tr), the time required for the muscle to transition from 90% to 50% of Dm, related to accumulated fatigue levels; and delay time (Td), the interval between stimulus application and 10% of Dm, which evaluates neuromuscular activation speed (Macgregor et al., 2018; Martín-Rodríguez et al., 2017).

The accuracy in evaluating these parameters depends intrinsically on the transfer of movement from the muscle belly to the cutaneous surface where the sensor is located. Along this path, radial displacement must traverse various overlying soft tissues, including the skin, subcutaneous adipose tissue, and superficial fascia. From a biomechanical perspective, it has been suggested that these tissues are not merely passive transmitters; rather, due to their viscoelastic properties, they may act as mechanical filters, damping the signal detected by the sensor. For example, greater subcutaneous adipose tissue thickness could underestimate Dm by absorbing part of the mechanical energy, or even alter Tc or Td by delaying the detection of contraction onset (Hatt et al., 2023).

Despite its potential relevance, there is currently a significant gap in the scientific literature regarding the precise quantification of these possible interferences. Although some previous studies have suggested that body composition and subcutaneous tissue characteristics may affect the reliability and interpretation of TMG-derived measurements (Calvo-Lobo et al., 2018; Toskić et al., 2019), evidence directly examining the relationship between OSTT and specific TMG parameters remains limited. In particular, few studies have systematically examined whether the thicknesses of the skin, subcutaneous tissue, and superficial fascia are associated with variations in Dm, Tc, Td, Ts, and Tr.

The present study aimed to evaluate the influence of soft-tissue thickness overlying the rectus femoris (RF) and biceps femoris (BF) muscles on their mechanical response, as assessed by TMG, in healthy adults. Specifically, this study sought to determine whether the responses observed in the different TMG parameters are solely attributable to intrinsic muscle characteristics or are significantly influenced by the morphological features of the soft tissues overlying the muscle belly.

Based on the proposed biomechanical behavior of superficial soft tissues as potential mechanical filters of the TMG signal, it was hypothesized that greater OSTT would be associated with lower Dm values and longer temporal parameters, particularly Tc.

Methods

Ethical Approval and Study Design

The present study was approved by the Ethics Committee of the Higher Institute of Physical Education, University of the Republic, Uruguay (Resolution No. 26/2023). It was designed as an analytical cross-sectional observational study and conducted in accordance with the STROBE checklist for cross-sectional studies (Cuschieri, 2019). All procedures fully complied with the Declaration of Helsinki (2013 revision) and were carried out in accordance with personal data protection regulations (Uruguayan Law No. 18.331).

Participants

A total of 109 healthy adult participants (39 [35.8%] women) were included in the study. Participants were recruited on a voluntary basis through convenience sampling from the university community where the study was conducted, as well as from physically active adults in the local community connected to the research environment. Participants had a mean age of 37 ± 19 years (range: 18–82) and a body mass index (BMI) of 25.4 ± 3.8 kg/m² (range: 19.5 – 36.4 kg/m²). All were physically active but not elite athletes.

Based on the World Health Organization classification (Centers for Disease Control and Prevention, 2024), 59 participants (54.1%) were normal weight (BMI ≥ 18.5 and < 25.0 kg/m²), 36 (33.0%) were overweight (BMI ≥ 25.0 and < 30.0 kg/m²), 12 (11.0%) presented class I obesity (BMI ≥ 30.0 and < 35.0 kg/m²), and two (1.8%) presented class II obesity (BMI ≥ 35.0 and < 40.0 kg/m²).

Exclusion criteria included the presence of pathologies or the use of substances that could affect muscle contractility in the lower limbs, as well as inflammatory or other conditions that might alter the morphological characteristics of the skin, subcutaneous adipose tissue, or superficial fascia in the assessed anatomical regions. Considering the effect of fatigue on TMG parameters (García-manso et al., 2011), participants were instructed to refrain from intense physical activity for at least 48 hours before testing. Additionally, all participants read and signed an informed consent form before data collection.

Procedures

Assessments were conducted in an exercise physiology laboratory under standardized environmental conditions (23 °C, maintained by air conditioning). Muscle mechanical response was evaluated using TMG (TMG S2 system; EMF-Furlan & Co., Ljubljana, Slovenia), recording the parameters Dm, Tc, Td, Ts, and Tr from the BF and RF muscles.

For BF assessment, following the manufacturer's recommendations, participants were positioned prone with the knee flexed at 150° (considering 180° as full extension), supported by a foam wedge placed under the ankle. The point of greatest muscle belly thickness was identified by manual palpation during a voluntary isometric contraction at 90° of knee flexion. At this location, the displacement sensor was positioned perpendicular to the tangential plane of the skin surface.

Electrodes were placed symmetrically at 2.5 cm from the sensor in the proximal (anode) and distal (cathode) directions, avoiding tendinous structures. Specifically for BF, and to minimize co-contraction of adjacent muscles that could affect Dm values, electrodes were positioned laterally rather than longitudinally relative to the sensor (Macgregor et al., 2018). Throughout the procedure, participants were instructed to remain fully relaxed, in accordance with previous recommendations (Rodríguez-Matoso et al., 2010).

The stimulation protocol started at 20 mA, with progressive increments of 10 mA until a plateau in Dm was reached or a decrease was observed. Ten-milliampere increments were selected to avoid premature signal stabilization. A 10-second recovery interval between stimuli was applied to minimize the effects of fatigue or post-activation potentiation (Labata-Lezaun et al., 2022).

For RF assessment, participants were positioned supine with the lower limb supported on a foam wedge to maintain 120 ° knee flexion. Sensor placement criteria were analogous to those used for BF, with the measurement point identified during a hip flexion effort with the knee extended. Electrodes were aligned longitudinally with the sensor, and the stimulation protocol was identical to that used for BF (Fig. 1). For both muscles, analysis was performed using the curve that exhibited the maximal Dm value in each assessment.

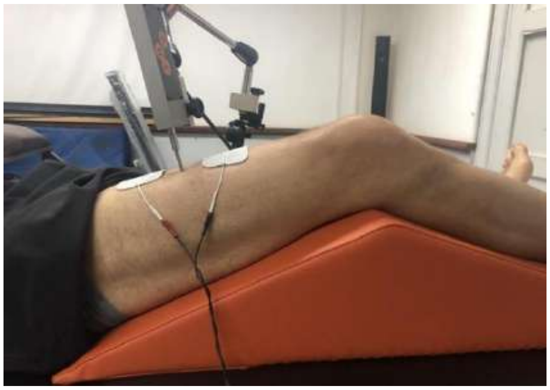

Figure 1. Representative image of the tensiomyograph placement for rectus femoris (RF) assessment.

Source: Own elaboration.

Subsequently, ultrasound images of both assessed muscles and their overlying soft tissues were obtained in B-mode using a longitudinal (long-axis) view with a Sonosite Micromaxx ultrasound system (USA; frequency range: 6–13 MHz). The transducer was placed on the skin at the same location as the TMG sensor. A generous amount of conductive gel was applied to minimize the pressure exerted by the transducer on the participant's skin (González-Seguel et al., 2023).

For each assessment, two ultrasound images were acquired. In each image, overlying soft tissue thickness (OSTT) (including skin, subcutaneous adipose tissue, and superficial fascia) was estimated. Measurements were performed along the central axis of the image (50% of its total width), ensuring anatomical correspondence with the previously established sensor contact point. Thickness was determined using the ultrasound system's calibrated depth scale and measured perpendicular (90°) to the skin surface to minimize obliquity-related errors (Fig. 2). The values obtained from both images were averaged for subsequent analysis.

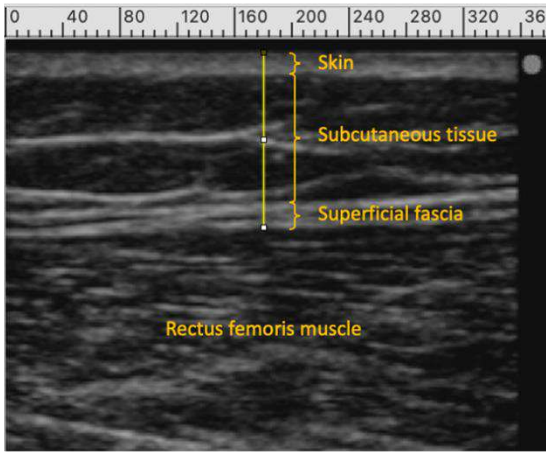

Figure 2. Representative ultrasound image showing the measurement of overlying soft tissue thickness in the evaluated muscle (rectus femoris in this example). Measurements were performed using ImageJ software.

Source: Own elaboration.

Measurements were conducted using the open-source software ImageJ (version 1.54; National Institutes of Health, USA). A single trained evaluator performed all measurements to reduce inter-observer variability and ensure consistency in image analysis. All measurements were obtained under standardized image acquisition conditions.

Statistical Analysis

Data are presented as mean ± standard deviation. To rule out potential laterality effects, OSTT and TMG parameters of RF and BF from both lower limbs were compared using a paired Student's t-test or, when normality assumptions were not met (Shapiro–Wilk test, $p < 0.05$), the Wilcoxon signed-rank test for related samples. When significant differences were found, the effect size was calculated using the rank-biserial correlation coefficient (rrb).

Subsequently, considering only the right lower limb, the strength of the association between OSTT and the corresponding TMG parameters of both muscles was assessed using Spearman's rank correlation coefficient (ρ), due to violation of the normality assumption. The magnitude of correlations was interpreted using predefined thresholds: values between 0 and 0.19 were considered negligible (no correlation), between 0.20 and 0.49 as weak, between 0.50 and 0.79 as moderate, and ≥ 0.80 as strong (Roy-García et al., 2019). Additionally, multiple linear regression analyses were performed on associations that were statistically significant in the correlation analyses to evaluate whether the observed relationships remained significant after adjustment for potential confounding variables (age and sex). Standardized regression coefficients (β) and adjusted coefficients of determination (adjusted R^2) were obtained.

A post hoc sensitivity analysis indicated that the final sample size ($n = 109$) was sufficient to provide approximately 80% statistical power to detect weak-to-moderate correlations ($\rho \approx 0.27$ or higher). Data processing and statistical analyses were performed using the open-source software JASP (version 0.19.2; JASP Team, 2024). The level of statistical significance was set at $p < 0.05$ for all analyses.

Results

The values corresponding to TMG parameters and OSTT of RF and BF in both lower limbs are presented in Table 1. For both muscles, no statistically significant differences ($p > 0.05$) were observed between the right and left sides, except for Td in RF ($p = 0.007$). However, for this variable, the effect size was small ($r_{rb} = 0.31$, 95% CI [0.513, 0.114]), and the percentage difference was low (2.37%), suggesting very similar values between limbs and limited practical relevance.

Table 1.
Tensiomyographic variables and overlying soft tissue thickness of the assessed muscles

Rectus femoris			
Variable	**Right limb**	**Left limb**	***p*-value**
Radial displacement (Dm)	**7.1 ± 3.0**	**7.4 ± 3.0**	**0.194**
Contraction time (Tc)	**30.4 ± 8.2**	**29.6 ± 7.2**	**0.350^{W}**
Sustain time (Ts)	**159.4 ± 85.1**	**154.1 ± 86.7**	**0.445**
Relaxation time (Tr)	**75.2 ± 47.7**	**77.3 ± 47.0**	**0.108^{W}**
Delay time (Td)	**25.3 ± 3.1**	**25.9 ± 2.6**	**0.007^{W*}**
OSTT (mm)	**10.1 ± 5.1**	**9.9 ± 4.7**	**0.627^{W}**
Biceps femoris			
Variable	**Right limb**	**Left limb**	***p*-value**

Radial displacement (Dm)	**4.8 ± 2.4**	**5.0 ± 3.2**	**0.333 ^{W}**
Contraction time (Tc)	**35.8 ± 17.0**	**36.2 ± 19.5**	**0.499 ^{W}**
Sustain time (Ts)	**216.3 ± 89.5**	**212.9 ± 102.0**	**0.224 ^{W}**
Relaxation time (Tr)	**69.2 ± 47.1**	**75.4 ± 43.8**	**0.158**
Delay time (Td)	**24.9 ± 4.1**	**25.1 ± 4.8**	**0.474 ^{W}**
OSTT (mm)	**10.7 ± 4.7**	**10.5 ± 4.5**	**0.729**

***Note.* Differences between body sides were assessed using the paired Student's t-test or the Wilcoxon signed-rank test (^{W}). * indicates a statistically significant difference ($p < 0.05$). Tc, Ts, Tr, and Td are expressed in milliseconds; Dm and OSTT, in millimeters. OSTT = overlying soft tissue thickness.**

Source: Own elaboration.

The results of the correlations between OSTT and TMG variables for both muscles in the right lower limb are presented in Table 2. For RF, significant ($p < 0.05$) but weak correlations were observed for Dm (negative; ρ = -0.321, 95% CI [-0.481, -0.141]) and Tc (positive; ρ = 0.288, 95% CI [0.105, 0.451]). In contrast, BF showed only a weak, positive, and significant association with Tc (ρ = 0.251, 95% CI [0.060, 0.425]). No significant associations were detected for the remaining variables in either muscle.

Table 2.

Correlation between overlying soft tissue thickness (OSTT) and tensiomyographic variables in the rectus femoris (RF) and biceps femoris (BF)

Rectus femoris		
TMG parameter	**Correlation**	***p*-value**
Radial displacement (Dm)	-0.321	<0.001*
Contraction time (Tc)	0.288	0.002*
Sustain time (Ts)	-0.047	0.686
Relaxation time (Tr)	0.022	0.847
Delay time (Td)	0.166	0.094
Biceps femoris		
TMG parameter	**Correlation**	**p-value**
Radial displacement (Dm)	-0.044	0.701

Contraction time (Tc)	0.251	0.011*
Sustain time (Ts)	-0.093	0.388
Relaxation time (Tr)	-0.029	0.793
Delay time (Td)	0.187	0.088

***Note.* Data correspond to the right lower limb. In all cases, Spearman's rho (ρ) correlation coefficient was used; * indicates a statistically significant difference ($p < 0.05$). TMG = tensiomyography.**

Source: Own elaboration.

In the adjusted regression analyses, OSTT remained independently associated with RF Dm after adjustment for age and sex (standardized $\beta = -0.392$, $p < 0.001$; adjusted $R^2 = 0.108$). However, the associations between OSTT and Tc were no longer statistically significant after adjustment in either RF (standardized $\beta = 0.135$, $p = 0.179$; adjusted $R^2 = 0.221$) or BF (standardized $\beta = 0.087$, $p = 0.417$; adjusted $R^2 = 0.215$).

Discussion

In the present study, the association between OSTT and TMG variables of RF and BF was analyzed. It is important to note that both muscles are particularly relevant for gait, other activities of daily living, and sports performance (Jiménez-Lupión et al., 2023; Neumann, 2010). The results demonstrated weak but significant correlations between OSTT and Tc in both muscles, and a negative correlation between OSTT and Dm in RF. However, after adjustment for age and sex using multiple linear regression models, only the association between OSTT and RF Dm remained statistically significant. These findings suggest that the influence of OSTT may be more pronounced on amplitude-related variables, such as Dm, than on temporal parameters, such as Tc. In contrast, Tc may be more strongly influenced by intrinsic neuromuscular and physiological factors, including those associated with age- and sex-related differences in muscle fiber composition, neuromuscular function, and muscle mechanical properties.

Previous studies have examined how overlying soft tissues or the body composition of the anatomical segment may affect certain TMG variables; however, findings remain inconsistent and inconclusive. In the study by Alfuraih et al. (2022), conducted in 25 young adults of both sexes, no significant correlations were found between OSTT (considering the three tissue layers defined in the present study) and the five TMG parameters ($r \leq 0.300$; $p \geq 0.1$) in the vastus lateralis and BF. The authors concluded that these variables appear to be independent of superficial tissue thickness. These findings partially align with those observed in the present study, as no significant correlations were found for most of the TMG parameters considered; however, unlike the findings reported by Alfuraih et al., the present study identified a significant negative association between OSTT and Dm in RF.

Conversely, Calvo-Lobo et al. (2018), who analyzed the erector spinae muscles in healthy adults of both sexes, reported a significant correlation between Dm and skin thickness ($r = -0.329$; $p = 0.020$) and between Dm and subcutaneous adipose tissue thickness (rs = −0.668; p = 0.077), as well as a weak, non-significant association between Dm and superficial fascia thickness (rs = −0.252; p = 0.077). Although the current investigation considered OSTT holistically rather than by individual tissue layers, these results are consistent with those observed for RF but not for BF.

Additionally, Calvo-Lobo et al. reported a weak but significant association between subcutaneous adipose tissue thickness and Tr (rs = −0.369; p = 0.008), a finding not observed in the present study when total OSTT was considered in either muscle evaluated. It is worth noting that subcutaneous adipose tissue typically makes the largest contribution to the total thickness of the overlying tissue, even in lean individuals. Taken together, these differences support the hypothesis that the effect of overlying tissues on the assessment of TMG parameters may vary depending on the muscle analyzed.

Furthermore, Toskić et al. (2019) reported a positive correlation between dominant lower limb fat mass and Tc in BF (r = 0.384; p = 0.043) in adult female participants (n = 30), and a negative correlation between fat mass and Dm in BF in male participants (n = 30) (r = −0.447; p = 0.013). In that study, no significant correlations were found for Tc in men or for Dm in women at the BF level, nor for these variables in RF for either sex. These findings differ in part from those observed in the present study. However, comparisons should be interpreted with caution, as Toskić et al. not only stratified their analyses by sex but also estimated lower-limb fat mass using bioelectrical impedance. Unlike the approach used in the present study, this method assesses total fat mass (including intramuscular adipose tissue) and does not account for the heterogeneous distribution of subcutaneous adipose tissue across anatomical regions or for other tissues such as skin or superficial fascia.

The present study identified an initial positive correlation between OSTT and Tc in both muscles; however, this association was no longer statistically significant after adjusting for age and sex. This suggests that the apparent relationship between subcutaneous thickness and contraction time may be partly explained by demographic factors. Specifically, the higher OSTT typically observed in females, and the age-related changes in muscle composition, may explain the variance previously attributed to tissue thickness alone (Kim & Won, 2022).

Additionally, the relatively high proportion of participants classified as overweight or obese (45.8%) should be considered when interpreting the present findings. Increased adiposity may influence both OSTT and muscle mechanical behavior, not only by increasing the thickness of superficial tissues but also by altering muscle composition, architecture, and neuromuscular function (Vieira et al., 2025). Moreover, sex-related differences in body fat distribution and muscle morphology may further contribute to the variability observed in TMG-derived measurements. These factors reinforce the importance of considering body composition characteristics when interpreting TMG parameters across heterogeneous populations.

Nevertheless, the potential influence of OSTT on Tc may require further investigation. From a bioelectrical perspective, subcutaneous adipose tissue acts as a capacitor and a high-resistance medium, thereby increasing total impedance and potentially hindering the transfer of electrical current from surface electrodes to the muscle belly (Petrofsky, 2008). This phenomenon could theoretically attenuate or delay the effective arrival of the stimulus at motor units, meaning that in individuals with greater OSTT, the muscle might require a slightly longer activation period to reach maximal displacement. Although stimulation intensity (mA) was not recorded in this study, future research should explore whether higher intensities are required to overcome this electrophysiological barrier.

Additionally, from a mechanical standpoint, the initial link between Tc and OSTT may be partially related to the viscoelastic and damping properties of adipose tissue. Subcutaneous fat can act as a mechanical filter, absorbing part of the energy generated during radial expansion of the muscle belly and reducing the rate at which deformation is transmitted to the skin surface (Hatt et al., 2023). This attenuation could decrease the slope of the TMG signal, thereby prolonging the measured contraction time. Although these mechanisms suggest that OSTT could influence Tc, our findings indicate that, when age and sex are accounted for, these interferences do not independently predict Tc. Consequently, Dm was the only parameter in our analysis that remained independently associated with OSTT after adjustment. This finding points to Dm as a potentially critical variable to account for when interpreting TMG data across different body composition levels.

Although OSTT was negatively correlated with Dm in RF ($p < 0.05$), no significant association was observed in BF ($p > 0.05$). This lack of consistency across muscles warrants further investigation. A plausible explanation for this regional discrepancy resides in differences in muscle architecture and deformation dynamics. RF features a bipennate structure that facilitates more concentric, perpendicular radial expansion toward the skin surface; in this context, adipose tissue functions as a mechanical filter that attenuates the displacement detected by the sensor. Conversely, the long head of the BF, with its more fusiform architecture, may produce deformation vectors that are less perpendicular to the surface or even induce lateral displacement of the muscle belly during contraction (Kapandji, 2011; Marrero et al., 2005). This dissipation of mechanical energy into surrounding tissues, combined with the lower compartmental constraint characteristic of the posterior thigh region, may explain why adipose tissue thickness does not significantly influence radial displacement in this muscle.

The present study has some limitations. First, the sample characteristics and non-probabilistic sampling, along with the analysis restricted to two muscles, limit the generalizability of the findings to other populations and anatomical regions. Additionally, the stimulation intensity required to reach maximal Dm was not recorded, which would have improved understanding of the underlying electrophysiological mechanisms. Finally, although environmental and postural conditions were standardized, the influence of uncontrolled individual factors (such as tissue hydration, local temperature, or muscle anisotropy) cannot be entirely ruled out.

Conclusions

The findings of the present study suggest that the OSTT may be associated with the

TMG characterization of muscle mechanical properties, particularly amplitude-related variables such as Dm. Moreover, this effect does not appear to be uniform across muscles but may depend on the structural and biomechanical features of the anatomical region considered. In contrast, the associations observed between OSTT and temporal parameters such as Tc were no longer significant after adjustment for age and sex, suggesting that these variables may be more strongly influenced by intrinsic neuromuscular and physiological factors, such as muscle fiber type distribution or motor unit recruitment patterns, than by the mechanical or electrical interference of the OSTT. Accordingly, treating OSTT as a methodological covariate may improve the interpretive accuracy and comparative validity of TMG assessments, particularly when comparing populations with markedly heterogeneous body composition profiles. Furthermore, these findings underscore the need for additional research to elucidate the biomechanical and electrophysiological mechanisms underlying this interaction.

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