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ORIGINAL ARTICLE

The Anatomical Basis of Muscle Tone in the Pakistani Population, Causes, Mechanisms, and Functional Significance

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ABSTRACT

Background: Muscle tone, which is the continuous passive contraction of muscles, is necessary for maintaining a correct posture, joint stability, and coordinated movement. Muscle tone is determined by anatomical structures and neural input, however underlying determinants of muscle tone in the Pakistani population are underexplored.

Methodology: This 12-month cross-sectional study was conducted in Khawaja Muhammad Safdar Medical College Sialkot and Nawaz Sharif Medical College, Gujrat from June 2022 to June 2023 and evaluated 60 healthy Pakistani adults aged 20–45 years, 35 males and 25 females. High-resolution ultrasound and MRI were used to assess muscle architecture, specifically muscle CSA and pennation angle in the quadriceps and biceps brachii. Surface electromyography (sEMG) was used to record resting muscle activity using electrophysiological assessments. Blood samples were collected to measure biochemical markers (creatinine kinase (CK), lactate dehydrogenase (LDH), and inflammatory cytokines (IL-6, TNF-α)) from venous blood. Pearson's correlation coefficient and independent t-tests were used to analyse the data.

Results: CSA and pennation angles for the quadriceps were significantly higher than those for the biceps brachii, and there were strong positive correlations between CSA and resting sEMG amplitude ($r = 0.45$, $p = 0.002$) and between pennation angle and sEMG amplitude ($r = 0.35$, $p = 0.01$). There were no significant differences between genders about demographic and biochemical parameters, and no correlation with biochemical markers was found with muscle tone.

Conclusion: It was shown that anatomical features, especially muscle CSA and pennation angle, are important determinants of resting muscle tone in the Pakistani population. Targeted interventions to improve musculoskeletal health can be based on these findings. Further investigation of these relationships can be done in the future.

Keywords: Muscle tone, Pakistani population, muscle architecture, sEMG, ultrasound, MRI, anatomical determinants, neuromuscular function.

INTRODUCTION

Muscle tone is a continuous, passive contraction of muscles that is a fundamental attribute for maintaining posture, joint stability, and coordinated movement. The resulting intrinsic property is the dynamic interplay between the mechanical properties of muscle fibers, the structure of connective tissues, and the regulatory effects of the central and peripheral nervous systems[1]. Muscle tone is a well-known clinical parameter in neuromuscular assessments, which however has yet to be fully understood anatomo and neurophysiologically at the population level[2].

Literature that has already been written on the mechanisms that govern muscle tone in Western populations, such as muscle fiber composition, connective tissue elasticity, and the feedback loops from the nervous system, has been extensively documented. Yet, such studies typically do not take into consideration the distinctive genetic, cultural, and environmental features of non-Western populations[3]. As Pakistan has a unique demographic profile, pattern of lifestyle practices, and genetic diversity, it is an ideal site to explore these under-investigated muscle physiology aspects. Very few studies in this region and, indeed, very few studies elsewhere suggest that dietary habits, physical activity patterns, and even local environmental stressors may modulate muscle architecture and function in ways that diverge significantly from the rest of the world[4].

The advances in imaging and electrophysiological technologies have enabled us to probe muscle structure and function with high precision. Details of muscle fiber orientation, cross-sectional area, and connective tissue characteristics can now be assessed using high-resolution ultrasound and magnetic resonance imaging[5]. Surface electromyography (sEMG) is an effective method for recording neural activation patterns and can provide functional information about anatomical variation. This study attempted to correlate specific anatomical parameters with a baseline neural activity underlying muscle tone by integrating these complementary methodologies[5].

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The present study was aimed to describe the anatomical and neurophysiological factors that determine variations in muscle tone in healthy Pakistani adults. The study focused on key metrics associated with muscle fiber architecture, connective tissue structure, and electrophysiologic signatures to elucidate the causes and mechanisms that underlie muscle tone in this population[6]. In time, such an understanding is most timely considering the rising prevalence of musculoskeletal disorders in Pakistan, with an increasing trend towards sedentary lifestyles and an aging demographic making these findings clinically relevant[7].

The present study attempts to give an in-depth analysis of the anatomical basis of muscle tone in the Pakistani population. The study aimed to bridge the gap in current knowledge by applying state-of-the-art imaging and electrophysiological techniques to the study of muscle physiology[8]. This work is not only highly important for the scientific community, but it also sets the stage for the development of culturally tailored interventions and rehabilitation strategies to improve musculoskeletal health in the region[9].

MATERIALS AND METHODS

Study Design and Setting: This 12-month cross-sectional study was conducted in Khawaja Muhammad Safdar Medical College Sialkot and Nawaz Sharif Medical College, Gujrat from June 2022 to June 2023. Healthy Pakistani adults (n = 60; 35 males and 25 females) between the ages of 20 and 45 years were selected from local community centers and university campuses.

Inclusive and exclusive criteria: Written informed consent was obtained from all participants before their participation, and inclusion criteria included no neuromuscular, musculoskeletal, or systemic disorder, and exclusion criteria included participants with chronic illness, recent musculoskeletal injuries, or medications known to affect muscle tone. High-resolution ultrasound and magnetic resonance imaging (MRI) were used to evaluate muscle architecture. Muscle fiber orientation, pennation angle, and cross-sectional area (CSA) of the biceps brachii and quadriceps muscles

were measured in the biceps brachii and quadriceps muscles using high-resolution ultrasound. Participants were placed comfortably, and standardized scanning protocols were followed to ensure consistency. Both longitudinal and transverse planes were imaged, and image processing software was used to analyze the later images. To visualize muscle tissue with high anatomical detail, MRI scans were conducted on a 3.0 Tesla scanner manufactured by Manufacturer. Quantification of parameters such as muscle volume and connective tissue thickness was done using axial images, with standardized protocols on inter-scan variability.

Data Collection and Measurements: Surface electromyography (sEMG) was used to assess baseline muscle tone and neural activation, and sEMG signals were recorded using a multi-channel electromyography system (Manufacturer model DEF) with the disposable surface electrodes placed on the skin overlying the biceps brachii and quadriceps muscles according to standard electrode placement guidelines. Reduction of impedance was accomplished by cleaning the skin with alcohol wipes, and the participants were instructed to fully relax during baseline recordings. Then, a standardized passive stretching protocol was developed, and sEMG responses to passive mechanical stress were recorded to assess how muscle activity changed as a result of passive mechanical stress. The data were sampled at 1000 Hz, and signal processing was applied to remove artifacts and baseline noise.

Each participant's blood was collected through venous samples to test markers of muscle metabolism and inflammation. Blood was drawn from the antecubital vein, processed immediately by centrifugation at 3000 rpm for 10 minutes, and the resulting serum was stored at –80 °C until analysis. Commercally available enzyme-linked immunosorbent assay (ELISA) kits were used to quantitate markers, including creatine kinase (CK), lactate dehydrogenase (LDH), and inflammatory cytokines IL-6 and TNF-α, and assays were performed in duplicate to increase reproducibility.

Statistical Analysis: Data were collected and maintained via a secure electronic database and were analyzed using SPSS software (version 25.0, IBM Corp.). Participant demographics and baseline measures were summarized with descriptive statistics; Pearson's correlation coefficient was also used to examine the relationship between anatomical parameters (for example, muscle CSA and fiber orientation) and electrophysiological data (sEMG amplitudes). Independent t-tests or analysis of variance (ANOVA) were used to compare subgroups (i.e., gender differences) with a p-value <0.05 deemed statistically significant.

RESULTS

The study involved a total of 60 healthy Pakistani adults (35 male and 25 female). Table 1 summarizes the demographic characteristics and baseline physical parameters for the subjects. The age of the participants was 32.5 ± 6.7 years and did not differ by gender in age or BMI. Table 1 illustrates that the study group was homogeneous in terms of age, BMI, and reported physical activity levels, minimizing the influence of these confounders on muscle tone measurements.

Table 1: Demographic Characteristics and Baseline Physical Parameters (N = 60)

Parameter	Overall (Mean ± SD or n)	Males (n = 35)	Females (n = 25)	p-value
Age (years)	32.5 ± 6.7	33.1 ± 6.5	31.7 ± 6.9	0.40
BMI (kg/m²)	24.8 ± 3.2	25.1 ± 3.0	24.4 ± 3.4	0.32
Physical Activity (min/week)	150 ± 45	155 ± 50	145 ± 40	0.28

High-resolution ultrasound and MRI were used to assess muscle architecture, and sEMG was used to obtain the electrophysiological parameters. The mean cross-sectional area (CSA) of the quadriceps was 50.2 ± 8.5 cm², and for the biceps brachii, it was 15.3 ± 3.2 cm². The mean pennation angle of the quadriceps was 14.6° ± 2.3°. Quadriceps (45.1 ± 8.9 μV) versus biceps brachii (28.4 ± 5.7 μV) resting sEMG amplitude was significantly higher (p = 0.0007).

Pearson's correlation coefficient was used to correlate the anatomical parameters to baseline sEMG amplitude. Results for the correlation of the quadriceps CSA with the resting sEMG amplitude (r = 0.45, p = 0.002) are shown in Table 2. Secondly, the quadriceps pennation angle had a moderate correlation with sEMG amplitude (r = 0.35, p = 0.01). However, the correlations between CSA and sEMG amplitude were lower (r = 0.28, p = 0.04), though still statistically significant, for the biceps brachii. Table 2 demonstrates the significant relationships between muscle structural parameters and baseline neural activity as measured by sEMG, suggesting that larger muscle CSA and increased pennation angles are associated with higher resting muscle activity.

Table 2: Correlation Analysis Between Anatomical Parameters and sEMG Amplitude

Muscle Group	Parameter	Pearson's r	p-value
Quadriceps	Cross-Sectional Area (CSA)	0.45	0.002
Quadriceps	Pennation Angle	0.35	0.01
Biceps Brachii	Cross-Sectional Area (CSA)	0.28	0.04

Biochemical assays of muscle metabolism and inflammatory markers were also performed in addition to the anatomical and electrophysiological measures. The serum creatine kinase (CK) mean level was 145 ± 35 U/L and lactate dehydrogenase (LDH) 210 ± 50 U/L, with no gender differences. The levels of inflammatory cytokines (IL-6 and TNF-α) were within normal range, there were no significant correlations between these biochemical markers and either muscle CSA or sEMG amplitude.

The statistical analysis, overall, suggests that the anatomical parameters, especially the quadriceps CSA and pennation angle as a strong predictor of baseline muscle tone, as they are reflected in sEMG activity. The findings support the hypothesis that structural characteristics of muscles make an important contribution to the variations in muscle tone among the Pakistani population.

DISCUSSION

This study has found useful information on anatomical determinants of muscle tone as present in the healthy Pakistani adult population. We find that resting sEMG amplitudes are larger in individuals with larger muscle CSA or increased pennation angles, especially in the quadriceps[10]. This, therefore, implies that the fundamental structural properties of muscle tissue are important determinants of baseline neural activation that are important in the maintenance of muscle tone. Previous literature has shown that greater passive contractile activity is correlated with greater quadriceps CSA, and the observed correlation between quadriceps CSA and sEMG amplitude (r = 0.45, p = 0.002) supports their findings[11].

The moderate correlation between the pennation angle and sEMG amplitude (r = 0.35, p = 0.01) also indicates that fiber orientation is a key determinant of muscle function. Such architectural parameters are expected to affect the muscle's mechanical efficiency, force-generating capabilities, and ability to respond to neural input during both resting and active states[12]. However, the sEMG amplitude was positively correlated with CSA of the biceps brachii (r = 0.28, p = 0.04), a lower correlation, but significant, perhaps due to differences in muscle composition and function across upper and lower limbs[13].

Given that under resting conditions, muscle tone in this cohort is more related to structural attributes than biochemical or inflammatory processes, the lack of significant correlations between biochemical markers (e.g. CK, LDH, IL-6, TNF-α) and both anatomical and electrophysiological parameters suggests that muscle tone in this group is not regulated by these biochemical markers. This supports our central premise that anatomical factors determine skeletal muscle tone[14, 15].

However, these findings add to a better understanding of the physiology of the Pakistani muscle, and there are some limitations to these findings. Although the sample size was adequate for a pilot study, it was relatively small, and the cross-sectional design does not allow one to infer causality[16]. Future studies with larger cohorts and longitudinal designs are needed to further elucidate the complex interplay between muscle architecture, neural activation, and functional outcomes. In addition, while accounted for to some extent, variations in lifestyle factors, including diet and physical activity, may also affect muscle properties, and further research will explore these[17, 18].

CONCLUSION

Thus, this study shows that the anatomical features of muscles (i.e., cross-sectional area and pennation angle) are highly predictive of resting muscle tone in a healthy Pakistani population. Combining advanced imaging with electrophysiological measures offers a complete framework for how muscle structure affects neuromuscular function. Importantly, these findings offer insight into the development of targeted rehabilitation and intervention strategies that can increase musculoskeletal health. These preliminary observations need to be validated further with other factors, such as lifestyle and genetic predispositions, to demonstrate the effect of one or more of them on muscle tone.

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