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A Study on Quantification of Maximum Voluntary Contraction of Quadriceps at Various Functional Knee Range of Motion, Using Surface EMG (sEMG)

Yüzey Elektromiyografisi (sEMG) Kullanılarak Kuadriseps Kasının Farklı Fonksiyonel Diz Hareket Açıklıklarında Maksimum İstemli Kasılmasının Nicel Olarak Değerlendirilmesi

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ABSTRACT

Objective: Surface electromyography (sEMG) is an essential tool in physiotherapy education, enabling students to objectively analyze muscle activation and understand joint-angle–dependent changes in force production. Teaching maximum voluntary contraction (MVC) assessment enhances clinical reasoning skills, accuracy of muscle testing, and evidence-based exercise prescription. This study evaluates quadriceps MVC at 70°, 90°, and 110° of knee flexion and highlights its educational relevance for physiotherapy training. Previous studies suggest that mid-range knee flexion allows optimal muscle activation, but comparative evidence across 70°, 90°, and 110° remains limited. Research using sEMG supports the idea that quadriceps activation changes with joint angle, yet findings are inconsistent. Therefore, examining individual differences in MVC at these specific angles is essential. Healthy participants aged 18-25 years who were free from knee injuries, musculoskeletal disorders, and neurological issues were included. All subjects were able to perform isometric quadriceps contractions and provided informed consent.

Methods: Forty-five healthy adults aged 18-25 years were assessed in a controlled laboratory setting. sEMG electrodes were placed over the vastus medialis oblique (VMO) and vastus lateralis (VL) muscles. MVC was recorded during isometric quadriceps contraction at knee flexion angles of 70°, 90°, and 110, which were measured using a universal goniometer. Statistical analysis included one-way analysis of variance, Bonferroni post-hoc tests, and paired t-tests.

ÖZ

Amaç: Yüzey elektromiyografisi (sEMG), kas aktivasyonunun nesnel olarak analiz edilmesini ve eklem açısına bağlı kuvvet üretimindeki değişikliklerin anlaşılmasını sağlayan, fizyoterapi eğitiminde önemli bir değerlendirme yöntemidir. Maksimum istemli kasılmanın (MVC) değerlendirilmesi, öğrencilerin klinik karar verme becerilerini geliştirmekte, kas testlerinin doğruluğunu artırmakta ve kanıta dayalı egzersiz reçetelendirilmesini desteklemektedir. Bu çalışmanın amacı, kuadriseps kasının 70°, 90° ve 110° diz fleksiyon açılarındaki maksimum istemli kasılmasını değerlendirmek ve bulguların fizyoterapi eğitimi açısından önemini ortaya koymaktır.

Yöntemler: Kontrollü laboratuvar ortamında 18–25 yaş aralığında 45 sağlıklı gönüllü değerlendirildi. Yüzey EMG elektrotları vastus medialis oblikus (VMO) ve vastus lateralis (VL) kasları üzerine yerleştirildi. Maksimum istemli kasılma, evrensel gonyometre ile ölçülen 70°, 90° ve 110° diz fleksiyon açılarında izometrik kuadriseps kasılması sırasında kaydedildi. İstatistiksel analizlerde tek yönlü varyans analizi, Bonferroni post-hoc testi ve eşleştirilmiş t-testi kullanıldı.

Bulgular: VMO ve VL kaslarında üç farklı diz fleksiyon açısı arasında MVC değerleri açısından istatistiksel olarak anlamlı farklılık bulundu ($p < 0,001$). Post-hoc analiz sonuçları, VMO için 70°–90° ve 70°–110°; VL için ise 70°–90° ve 70°–110° açıları arasında anlamlı farklılık olduğunu gösterdi. Kuadriseps toplam aktivasyonunda 70°–90° ve 70°–110° açıları arasında anlamlı fark saptanmazken, 90°–110° açıları

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ABSTRACT

Results: VMO and VL showed significant differences in MVC across all three knee angles ($p < 0.001$). Post-hoc analysis indicated significant differences between VMO 70- 90 and VMO 70-110, and between VL 70-90 and VL 70-110. Quadriceps composite activation showed no significant difference between 70°-90° and 70°-110°, while 90°-110° showed significant variation ($p < 0.001$). Mid-range knee flexion demonstrated the highest activation efficiency.

CONCLUSION: Quadriceps MVC is greatest between 70° and 90° of knee flexion. Integrating sEMG-based MVC assessment into physiotherapy education enhances students' understanding of muscle biomechanics, objective evaluation, and optimal exercise positioning. This study supports the incorporation of technology-assisted EMG training into physiotherapy laboratory teaching to improve competency.

Keywords: Surface EMG, maximum voluntary contraction, quadriceps, physiotherapy education, knee biomechanics

ÖZ

arasında anlamlı farklılık belirlendi (p < 0,001). Orta düzey diz fleksiyon açılarında en yüksek kas aktivasyonu elde edildi.

Sonuç: Kuadriseps kasının maksimum istemli kasılması 70° ile 90° diz fleksiyon açıları arasında en yüksek düzeydedir. Fizyoterapi eğitiminde sEMG tabanlı MVC değerlendirmesinin kullanılması, öğrencilerin kas biyomekaniği, objektif değerlendirme yöntemleri ve optimal egzersiz pozisyonlandırması konularındaki bilgi ve becerilerini geliştirmektedir. Bu çalışma, teknoloji destekli EMG uygulamalarının fizyoterapi laboratuvar eğitimine entegrasyonunu desteklemektedir.

Anahtar Sözcükler: Yüzey elektromiyografi, sEMG, kuadriseps, maksimum istemli kasılma, diz fleksiyonu, fizyoterapi eğitimi

INTRODUCTION

Surface electromyography (sEMG) has become an essential component of modern physiotherapy education, offering a reliable and objective method for analyzing muscle activation patterns (1). Unlike traditional subjective approaches such as manual muscle testing, sEMG provides quantifiable data on the timing, amplitude, and recruitment order of motor units. For physiotherapy students, learning to interpret sEMG signals enhances clinical reasoning, improves assessment accuracy, and strengthens the application of biomechanical principles in practice (2). As healthcare increasingly incorporates technology-assisted assessment, familiarity with sEMG prepares students to meet contemporary professional standards and deliver evidence-based interventions. Muscle force production varies significantly with joint angle, a concept rooted in the length-tension relationship and mechanical advantage of muscles around a joint. The quadriceps femoris, the primary extensor of the knee, is responsible for functional movements such as stair climbing, sit-to-stand transitions, gait propulsion, and athletic tasks requiring forceful extension. Physiotherapy curricula emphasize quadriceps strength evaluation because weakness or altered activation patterns can cause patellofemoral pain, gait abnormalities, reduced stability, and compromised performance. Teaching students to analyze quadriceps activation across various joint positions helps bridge theoretical knowledge with practical application (3).

The quadriceps muscle group consists of four muscles: rectus femoris, vastus lateralis (VL), vastus medialis, and vastus intermedius, which converge at the patella and function collectively to extend the knee. Among these, the vastus medialis oblique (VMO) and VL play crucial roles in patellar tracking. An imbalance between these components is commonly associated with patellofemoral dysfunction, making their assessment highly relevant to physiotherapy training. sEMG allows students to visualize the differential activation of VMO and VL, helping them understand patellar biomechanics and recognize how variations in muscle control may contribute to clinical symptoms. Knee flexion angles influence quadriceps mechanical efficiency (4). At mid-range flexion (between 70° and 90°), the quadriceps exhibit optimal force production. This is attributable to favorable muscle fiber length, patellofemoral joint alignment, and the mechanical advantage of the extensor mechanism. In physiotherapy education, understanding these biomechanical principles is crucial for teaching appropriate exercise selection, progression, and functional retraining. Students frequently encounter clinical scenarios where they must decide which knee position is best suited for strengthening exercises, pain reduction strategies, or postoperative rehabilitation. Evidence-based training supported by sEMG enhances their decision-making capacity. Historically, assessment of quadriceps strength relied on subjective tools such as the MRC grading system (5). While widely used, these traditional methods lack sensitivity for detecting mild strength deficits or subtle neuromuscular differences. This limitation poses challenges in both research and clinical practice, particularly for early-stage rehabilitation, for high-performance athletes, and for conditions that require precise muscle monitoring. Use of sEMG overcomes these limitations by enabling fine-grained detection of activation patterns and facilitating accurate comparison between muscle groups. When integrated into physiotherapy laboratory sessions, sEMG enhances students' understanding of muscle performance beyond basic clinical palpation or observation. Functional knee positions of 70°, 90°, and 110° are commonly used in daily movements such as sitting, squatting, lifting, and stair negotiation. Evaluating quadriceps MVC at these angles enables students to relate electrophysiological findings to real-world functional biomechanics. As physiotherapy increasingly emphasizes task-oriented training, understanding how muscle activation changes across functional ranges equips students to plan safer and more effective interventions. By engaging with sEMG-based assessments, students gain practical skills, develop a scientific mindset, and strengthen their competence in musculoskeletal evaluation (6).

For educational institutions, incorporating sEMG into teaching offers several advantages. It enhances student engagement, supports blended learning models, and provides objective feedback that can improve technique and performance. Students can observe how electrode placement, posture, joint angle, and contraction type influence muscle activation. This experiential learning fosters deeper comprehension of neuromuscular physiology and facilitates the transition from novice learners to confident clinicians (7). Given the clinical, biomechanical, and educational significance of quadriceps activation, this study investigates, using sEMG, maximum voluntary contraction (MVC) at knee flexion angles of

70°, 90°, and 110° in healthy young adults. In addition to its clinical applications, sEMG has become an important component of modern physiotherapy education, enabling students to analyze muscle activation objectively and to understand joint-angle-dependent changes in force production. Teaching MVC assessment enhances clinical reasoning skills, improves the accuracy of muscle testing, and supports evidence-based exercise prescription. The study not only examines angle-dependent neuromuscular performance but also demonstrates how sEMG-based assessment can be effectively integrated into physiotherapy education to enhance student competency, improve understanding of functional biomechanics, and promote evidence-based practice (8). Despite the growing body of literature on quadriceps activation using sEMG, several gaps remain. Many existing studies have focused on generalized knee positions or isolated joint angles, with limited direct comparisons across multiple functional knee-flexion angles, such as 70°, 90°, and 110°. Furthermore, inconsistencies in reported findings regarding optimal activation angles highlight the need for more standardized evaluation. In addition, relatively few studies have explored the application of sEMG-based quadriceps assessment within a physiotherapy educational context, particularly in relation to teaching MVC and joint angle-dependent muscle performance. Therefore, it is necessary to systematically examine angle-specific quadriceps activation using sEMG and to emphasize its relevance for physiotherapy training.

Review of Literature

sEMG has been widely recognized as a valid and reliable tool for assessing neuromuscular activation during static and dynamic tasks. sEMG provides an objective representation of muscle recruitment patterns, timing, and amplitude, allowing clinicians and students to interpret muscle performance with greater accuracy than traditional manual methods. sEMG is capable of recording the algebraic sum of motor unit action potentials, making it a valuable technique for understanding neuromuscular physiology and fatigue responses during high-intensity contractions. Their foundational work established sEMG as a cornerstone for evaluating muscle behavior in both research and clinical settings. The quadriceps femoris muscle group plays a fundamental role in knee extension and contributes significantly to lower limb stability, gait efficiency, and functional movement performance (9). Studies have demonstrated that quadriceps activation varies with knee joint angle due to changes in muscle length-tension relationships and mechanical leverage. Morrish et al. (10) investigated quadriceps activity at different knee angles and reported increased maximal voluntary contraction (MVC) as flexion increased from 60° to 90°, suggesting that mid-range knee positions may offer a biomechanical advantage. These findings are consistent with the biomechanical principle that muscle force production is optimal when fiber length and joint mechanics are aligned to maximize tension.

The coordination between the VMO and VL plays an essential role in patellar tracking and stabilization. Research comparing EMG ratios of VMO and VL in healthy individuals and individuals with patellofemoral pain indicates that activation imbalances may contribute to lateral patellar maltracking, knee pain, and dysfunction. Souza and Gross (9) reported that altered activation ratios could serve as clinical indicators for patellofemoral disorders (11). Their study highlights the importance of evaluating both components of the quadriceps, particularly when designing rehabilitation programs targeting knee stability. Further studies have explored how joint angle influences quadriceps activation. MVC varies significantly with knee joint position, reinforcing the need to assess quadriceps performance across a range of functional knee angles (12). Similarly, research has demonstrated that the interaction between agonist and antagonist muscles during maximal isometric contractions influences activation patterns that may contribute to injury prevention. These observations support the assessment of muscle performance across multiple joint angles to better understand neuromuscular function (13).

While traditional manual muscle testing, such as the Medical Research Council (MRC) grading system, provides a basic assessment of muscle strength, it lacks sensitivity in detecting subtle deficits or early-stage neuromuscular dysfunction. Several researchers have noted that subjective grading methods may not correlate directly with true muscle force production, as minor changes in strength are often undetectable without the use of objective instruments. sEMG, by contrast, offers precise quantification, improving accuracy in clinical assessment and research applications (14). Studies examining quadriceps activation in functional knee positions emphasize the importance of evaluating MVC at angles commonly encountered during activities of daily living. Knee flexion angles of 70°, 90°, and 110° represent key positions used during squatting, stair climbing, and sit-to-stand transitions. Research suggests that evaluating MVC at these angles provides insight into optimal activation ranges and helps clinicians understand how joint position influences neuromuscular efficiency. Such knowledge aids in designing effective rehabilitation programs and supports physiotherapy students in developing evidence-based decision-making skills (15). Despite extensive research on quadriceps activation, few studies have specifically compared MVC at 70°, 90°, and 110° using sEMG in healthy young adults. Understanding these variations is valuable for both clinical practice and physiotherapy education, as it enhances comprehension of joint biomechanics, exercise prescription, and performance analysis. Therefore, this study aims to address this gap by evaluating angle-specific MVC using sEMG and highlighting its relevance in physiotherapy training and skill development (16).

MATERIALS AND METHODS

Study Design

This study employed an observational cross-sectional design and was conducted in a physiotherapy laboratory. The aim was to analyze MVC of the quadriceps at three functional knee flexion angles 70°, 90°, and 110°using sEMG.

Participants

A total of 45 healthy adults took part in the study. Participants were recruited from the local community and screened using a questionnaire to ensure they met the required criteria. Basic demographic details were collected, and all sessions were scheduled at similar times of day for consistency. Participants were asked to avoid strenuous activity and caffeine before testing. All procedures were conducted in accordance with ethical guidelines.

Inclusion Criteria

Participants were required to be 18-25 years old and free from musculoskeletal or neurological injuries. Only healthy individuals who fully understood the study and were willing to participate were included. Screening procedures ensured that all selected individuals could safely complete the testing protocol.

Exclusion Criteria

Individuals with a lower limb injury in the past three months were excluded. Those who were regularly involved in resistance training, who were using steroids, or who were taking performance-enhancing substances were also not eligible. Anyone with conditions that could interfere with MVCs or pose health risks was excluded.

Ethical Approval Statement

The study protocol received official approval from the Institutional Research Committee (IRC) of Y.M.T. College of Physiotherapy, Navi Mumbai. The research proposal titled "A study on Quantification of Maximum Voluntary Contraction of Quadriceps at Various Functional Knee Range of Motion Using Surface Electromyography (sEMG)" was reviewed and approved by the Chairperson of the IRC (reference number: ymtibpth/1201125, date: 24/03/2025). The Committee confirmed that the proposed research met the ethical standards required for studies involving human participants and granted permission to proceed with data collection.

Instrumentation

The study used a sEMG unit equipped with silver/silver chloride disposable electrodes to record muscle activation. A universal goniometer was utilized to ensure precise measurement of knee flexion angles at 70°, 90°, and 110°. A quadriceps exercise table with adjustable height provided optimal limb positioning, while a stabilization belt was used to minimize compensatory movements during testing. Alcohol swabs were used to clean the skin prior to electrode placement to reduce impedance. All equipment was calibrated before testing to ensure accuracy and consistency in data collection throughout the study. The raw sEMG signals were processed using standard signal conditioning procedures to ensure accuracy and reliability. Signals were sampled at a frequency of 1000 Hz to adequately capture muscle activity without aliasing. A band-pass filter (20-450 Hz) was applied to remove movement artifacts and high-frequency noise. The signals were then full-wave rectified to convert all values to a positive scale, and then smoothed using a root mean square (RMS) algorithm with a 50-ms window to obtain a representative amplitude of muscle activation. All signal processing procedures were performed using the software associated with the sEMG system to ensure consistency and standardization across all participants.

Electrode Placement

Electrodes were positioned following standardized sEMG placement guidelines to ensure reliable data. For the VMO, electrodes were placed approximately 2 cm above and medial to the patella, aligned with the muscle fiber orientation. For the VL, electrodes were positioned on the lateral thigh at one-third of the distance between the greater trochanter and the lateral femoral epicondyle. A ground electrode was placed over a bony prominence, typically the tibial shaft, to minimize electrical noise. Proper skin preparation included shaving and cleaning the electrode sites with alcohol to reduce impedance (17).

Procedure

Participants were seated upright on a quadriceps table, with the tested leg positioned at predetermined knee flexion angles of 70°, 90°, and 110°, as measured using a universal goniometer. A stabilization strap secured the thigh to prevent compensatory movement. For each angle, participants performed a MVC of the quadriceps while sEMG activity was recorded from the VMO and VL. Each contraction was sustained for five seconds, followed by 30-60 seconds of rest to minimize fatigue. Three trials were performed per angle, and the highest amplitude value was selected as the MVC measure for analysis (18).

Outcome Measures

The primary outcome measure was the amplitude of the MVC, recorded in microvolts, for the VMO and VL at knee flexion angles of 70°, 90°, and 110°. sEMG peak values were analyzed to determine angle-dependent variations in muscle activation. A secondary outcome was the comparison of activation differences between VMO and VL at each angle to assess their relative contributions. Composite quadriceps activation patterns across all angles were also evaluated (19). All outcome measures were statistically analyzed to identify significant differences and to interpret their functional relevance. The raw sEMG signals were processed using standard signal conditioning procedures to ensure accuracy and reliability. Signals were sampled at an appropriate sampling frequency (e.g., 1000 Hz) to capture muscle activity without aliasing. A band-pass filter (typically 20-450 Hz) was applied to remove movement artifacts and high-frequency noise. The signals were first full-wave rectified to convert all values to a positive scale and then smoothed using a RMS algorithm over a defined window (e.g., 50 ms) to obtain a representative amplitude of muscle activation. These processing steps were performed using the software associated with the sEMG system to standardize data acquisition and analysis across all participants.

Statistical Analysis

Data analysis was performed using the paired t-test to compare variables within the study groups. Both descriptive and inferential statistical methods were applied to summarize and interpret the collected data. All statistical computations were carried out using the Statistical Package for the Social Sciences (SPSS). Descriptive statistics, including the mean and standard deviation, were calculated for all measured parameters to provide a comprehensive overview of the dataset.

RESULTS

A total of 45 participants were included in the analysis of quadriceps MVC at knee flexion angles of 70°, 90°, and 110° measured using surface EMG. The descriptive characteristics of VMO and VL activation at all three angles are summarized in Table 1, which presents the mean microvolt amplitudes and measures of variability for each muscle. These values provide a clear baseline for understanding muscle recruitment across joint positions. The pattern of activation across angles establishes the foundation for subsequent inferential testing and comparative analyses performed in this study (Figure 1).

VMO Analysis

These findings confirm that VMO amplitude decreases progressively as the knee flexion angle increases. The overall ANOVA summary for VMO is shown in Table 2, supporting the conclusion that changes in angle substantially influence medial quadriceps activation. VMO activation across the three knee flexion angles showed a significant difference based on one-way ANOVA results (F: 40.392, $p < 0.001$), indicating angle-dependent variations in recruitment. Post-hoc Bonferroni comparisons, as presented in Table 3, revealed significant reductions in activation for VMO 70-90 ($p < 0.001$) and VMO 70-110 ($p < 0.001$).

Table 1. Descriptive statistics of VMO and VL at 70°, 90°, and 110°.

Muscle	Angle	Mean (µV)	Standard deviation	Standard error mean
VMO	70°	233.11	92.01	13.72
	90°	147.93	46.44	6.92
	110°	117.56	37.03	5.52
VL	70°	123.22	39.30	5.86
	90°	186.22	108.92	16.24
	110°	286.56	144.72	21.57

VMO: Vastus medialis oblique, VL: Vastus lateralis.

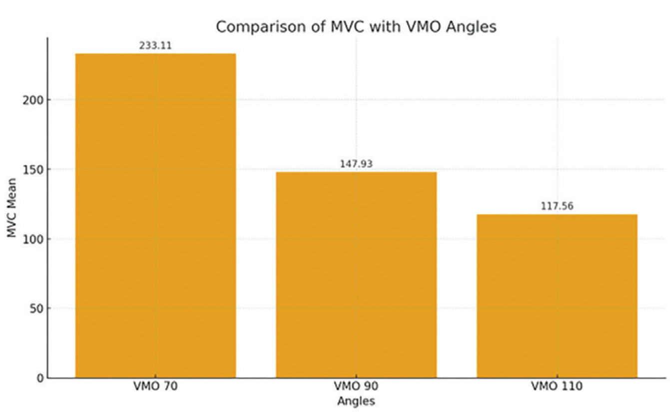

Figure 1. Comparison of mean MVC values of VMO at 70°, 90°, and 110° knee flexion.

MVC: Maximum voluntary contraction, VMO: Vastus medialis oblique.

VMO vs. VL Comparison

A paired t-test comparing overall VMO and VL activation revealed a statistically significant difference, as shown in Table 4. VL demonstrated a higher mean activation than VMO, with the test yielding t: 2.387 and $p = 0.018$. This suggests that, irrespective of the angle, the VL tends to exhibit a greater EMG amplitude during MVC. The variability in activation between the two muscles highlights functional differences in recruitment patterns, potentially reflecting differences in biomechanical roles and fiber composition. These results emphasize the importance of analyzing both muscles to fully understand quadriceps function during controlled knee flexion tasks.

Quadriceps Composite Activation

Comparisons of quadriceps MVC across angles are also presented in Table 4 and show no significant difference between 70° and 90° ($p = 0.330$) or between 70° and 110° ($p = 0.202$). However, activation was significantly higher at 90° than at 110°, with t: 3.849 and $p < 0.001$. This suggests that deeper knee flexion produces a marked increase in overall quadriceps recruitment. The absence of significant differences in the first two comparisons indicates that moderate changes in flexion angle may not substantially alter quadriceps output, whereas transitions from mid-range to deeper flexion create a more pronounced activation response (Figure 2).

As shown in Tables 1–4, VMO activation was highest at 70° and significantly reduced at 90° and 110°, while VL activation showed the opposite trend, peaking at 110°. A Comparison between VMO and VL confirmed that activation in VL was significantly greater. Quadriceps MVC revealed no significant differences between 70°-90° and 70°-110°, but revealed a highly significant increase between 90°-110°. Overall, these findings demonstrate angle-dependent modulation of quadriceps components, with VMO favoring more extended positions and VL becoming dominant in deeper flexion. This suggests differential neuromuscular strategies for stabilizing and producing force during knee movement.

DISCUSSION

sEMG provides a valuable non-invasive method for capturing muscle activation patterns and quantifying neuromuscular recruitment during voluntary contractions. As a diagnostic and teaching tool, sEMG allows physiotherapists and students to directly visualize the extent, timing, and relative activation of key muscle groups, thereby reducing ambiguity in clinical assessments. Because muscle activity can be recorded objectively during both isolated and functional tasks, sEMG has gained importance not only in research but also

Table 2. One-way ANOVA results for VMO and VL.

Muscle	Source	Sum of squares	df	Mean square	F	p-value
VMO	Between groups	322,967.200	2	161,483.622	40.392	<0.001
	Within groups	527,728.400	132	3,997.942		
	Total	850,695.600	134			
VL	Between groups	610,703.300	2	305,351.667	26.666	<0.001
	Within groups	1,511,507.000	132	11,450.808		
	Total	2,122,210.000	134			

ANOVA: Analysis of variance, VMO: Vastus medialis oblique, VL: Vastus lateralis.

Table 3. Bonferroni post-hoc comparisons for VMO and VL.

Muscle	Comparison	Mean difference (i-j)	Standard error	p-value
VMO	70° vs. 90°	85.18	13.33	<0.001
	70° vs. 110°	115.56	13.33	<0.001
VL	70° vs. 90°	−63.00	22.56	0.018
	70° vs. 110°	−163.33	22.56	<0.001

VMO: Vastus medialis oblique, VL: Vastus lateralis.

Table 4. Paired t-tests: VMO vs. VL and quadriceps at different angles.

Comparison	Mean difference	Standard deviation	Standard error mean	t-value	p-value
VMO vs. VL	32.47	158.02	13.60	2.387	0.018
Quadriceps 70° vs. 90°	11.09	107.33	11.31	0.980	0.330
Quadriceps 70° vs. 110°	23.89	176.40	18.59	1.285	0.202
Quadriceps 90° vs. 110°	34.98	86.21	9.09	3.849	<0.001

VMO: Vastus medialis oblique, VL: Vastus lateralis.

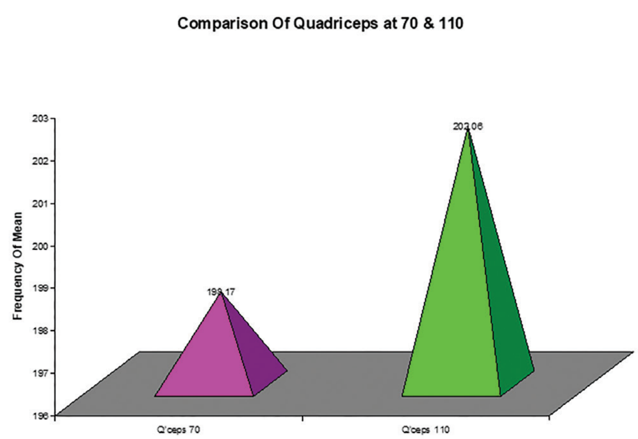

Figure 2. Comparison of mean quadriceps maximum voluntary contraction at 90° and 110° knee flexion demonstrating higher activation at 110°.

in educational environments where students must understand the physiological basis of movement and muscular coordination (20).

The present study demonstrated significant angle-dependent variations in quadriceps activation, with VMO activity highest at 70° and VL activity increasing progressively toward 110°. These findings are consistent with the established length-tension relationship and the mechanical advantage principles governing muscle force production. However, a broader comparison with previous sEMG-based studies provides deeper insight into these observations. Previous research has consistently reported that quadriceps activation varies with knee joint position, with several studies identifying mid-range positions (approximately 60°-90°) as optimal for force generation. The present findings partially align with these observations, as stable activation was observed between 70° and 90°, whereas a significant increase in overall quadriceps recruitment occurred at deeper flexion (110°). More recent sEMG investigations have highlighted that deeper knee flexion angles are associated with increased neuromuscular demand and altered patellofemoral joint mechanics, which support the current finding of higher activation at 110°. This may be attributed to increased mechanical load, changes in moment arm, and greater stabilization requirements at deeper joint angles. In contrast, the higher VMO activation observed at 70° suggests a mechanical advantage for medial stabilization in relatively extended positions. These findings demonstrate that quadriceps components do not function uniformly but instead exhibit angle-specific recruitment patterns.

The paired t-test demonstrated significantly greater overall activation in the VL than in the VMO, indicating lateral dominance in quadriceps recruitment among healthy young adults. While this finding may have potential clinical relevance, it should be interpreted with caution, as the present study was conducted exclusively in healthy individuals (21). This pattern may provide preliminary insight into neuromuscular behavior; however, direct extrapolation to clinical populations, such as individuals with patellofemoral disorders, is not justified without further investigation. Clinical conditions typically involve additional factors such as pain, inflammation, and structural alterations, which were not present in this study. Therefore, the observed activation pattern should be considered representative of normal physiology rather than pathological function.

Comparisons of quadriceps MVC revealed no significant differences between 70°-90° and 70°-110°, whereas a highly significant increase was observed between 90°-110°. While statistical findings indicate whether differences are present, assessing their physiological and practical significance yields a more meaningful interpretation. The absence of significant differences between 70° and 90° suggests that the quadriceps can maintain a relatively stable force output within this functional mid-range, which is commonly used in activities such as sit-to-stand and early-phase squatting. In contrast, the increased activation at 110° indicates that deeper knee flexion requires greater neuromuscular effort, likely due to increased mechanical demand and stabilization requirements. From a practical perspective, this suggests that exercises performed at higher flexion angles may provide a greater strengthening stimulus, although they may also increase joint loading. Therefore, interpretation of results should consider both statistical and functional significance (22).

The findings of this study should also be interpreted in light of certain methodological limitations inherent to sEMG. One important consideration is the potential for cross-talk between adjacent muscles, particularly between the vastus medialis and VL, which may affect signal specificity. Additionally, variations in electrode placement, even when standardized guidelines are followed, can influence signal amplitude due to differences in skin impedance and anatomical variability. Another limitation is the use of non-normalized sEMG amplitude values, which may restrict comparability across individuals and conditions. Furthermore, factors such as participant effort, fatigue, and slight variations in posture during testing may influence EMG recordings. Therefore, the results should be interpreted with caution, and future studies are encouraged to incorporate normalization procedures and advanced signal analysis techniques to enhance reliability (23). The educational relevance of sEMG in physiotherapy training can be more effectively understood when presented in a structured manner. Firstly, sEMG enables students to visualize real-time muscle activation, thereby bridging the gap between theoretical knowledge and practical application. Secondly, it enhances clinical reasoning by facilitating the interpretation of objective data rather than relying solely on subjective assessments. The present study provides a clear example of how joint angle influences muscle activation, helping students understand biomechanical principles and apply them to exercise prescription. Finally, structured integration of sEMG into physiotherapy curricula can support the development of essential skills in assessment, analysis, and decision-making, ultimately improving clinical competency (24). Overall, the present study supports existing literature by demonstrating that quadriceps activation is angle-dependent and underscores the need for cautious interpretation, methodological awareness, and consideration of functional relevance. The findings contribute to both biomechanical understanding and physiotherapy education, while highlighting the need for future research to validate these results in clinical populations (25).

Study Limitations

This study has several limitations that should be acknowledged when evaluating the results. First, the sample only included healthy young adults between 18 and 25 years of age, which limits the generalisability of the data to older adults, athletes, or patients with musculoskeletal and neurological diseases. The relatively small sample size may limit the external validity of the results. Secondly, the muscle activation was investigated only during isometric contractions at three specific knee-flexion angles (70°, 90°, and 110°). Dynamic functional tests such as walking, squatting, stair climbing, and sit-to-stand were not assessed, which may limit the applicability of the results to real-life motions. Third, just two quadriceps components, VMO and VL were studied, while others muscles contributing to knee stability.

CONCLUSION

This study demonstrates that the quadriceps MVC varies with knee flexion angle but not uniformly across all positions. No significant differences were observed between 70° and 90°, or between 70° and 110°, indicating that the quadriceps produce comparable activation levels across these ranges in young adults. However, a highly significant increase in MVC occurred between 90° and 110°, suggesting that deeper knee flexion elicits greater quadriceps recruitment. These findings indicate that while mid-range flexion maintains stable activation, maximal quadriceps output is achieved closer to 110°. This knowledge is valuable for physiotherapy training, exercise prescription, and the understanding of angle-specific muscle performance in functional and rehabilitative contexts.

Ethics

Ethics Committee Approval: This study was approved by the Institutional Research Committee (IRC) of Y.M.T. College of Physiotherapy, Navi Mumbai (reference number: ymtibpth/1201125, date: 24/03/2025).

Informed Consent: Written informed consent was obtained from all participants.

Footnotes

Authorship Contributions

Concept: S.D., J.S., S.V.S., V.P.S., Design: S.D., J.S., S.V.S., V.P.S., Data Collection or Processing: S.D., Analysis or Interpretation: S.D., J.S., S.V.S., V.P.S., Literature Search: S.D., J.S., Writing: S.D., J.S., S.V.S., V.P.S.

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