



Evaluation of Quadriceps Femoris Muscle Electromyography Activity in Healthy Adult Males During Common Strength Exercises: A Systematic Review

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ABSTRACT

Aims: The primary objective of this study was to systematically review the existing literature on quadriceps femoris muscle activity, as measured by sEMG, in healthy adult males during common strength exercises.

Method and Materials: This systematic review used the PRISMA guidelines. Original research articles published up to December 2023 were retrieved from the PubMed/Medline, Scopus, and Web of Science databases. The inclusion criteria required studies to (a) be available in full-text English, (b) utilize cross-sectional or longitudinal study designs (experimental or cohort), (c) report electromyography activity as a percentage of Maximal Voluntary Isometric Contraction (%MVIC), (d) analyze Rectus Femoris (RF), Vastus Lateralis (VL), and Vastus Medialis (VM) muscles, (e) focus on resistance training exercises as the primary intervention, (f) be published within the last ten years, and (g) include healthy adult male participants.

Findings: The review results indicated that the VL was the most frequently studied quadriceps muscle across different exercises. Notably, the leg press demonstrated the highest activation levels for both the VL and VM, while the Spanish squat elicited the highest activation for the RF. Additionally, the deadlift showed substantial activation of the VL, though to a lesser extent than the leg press.

Conclusion: These findings highlight the importance of exercise selection for targeting specific quadriceps muscles during strength training. Furthermore, to ensure the accuracy and reliability of sEMG data, it is critical to establish standardized methodological criteria for its use.

Keywords: Strength Exercises, Electromyography, Quadriceps Muscles, Systematic Review

Introduction

Strength training has been shown to play a protective role against cartilage loss while improving bone tissue mass, tendon health, and muscle function [1]. Despite the well-established connection between muscle-strengthening exercises and overall health and well-being, more than 80% of adults fail to meet the recommended guidelines (≥ 2 times per week), as clinical and epidemiological evidence indicates. Furthermore, public health initiatives for chronic disease prevention have historically focused more on aerobic physical activity than muscle-strengthening exercise [2]. Resistance training has become crucial in strength training programs, particularly for older adults [3]. These programs often

include exercises targeting the muscles of the lower limbs, with the quadriceps serving as the primary muscle responsible for movements and locomotion in daily life. Impairments in the mechanical function of lower limb muscles, such as reduced muscle strength, significantly impact lower limb functional capacity [4]. Quadriceps muscle activation, specifically, has garnered considerable attention in the literature [5, 6].

Muscle activation patterns are essential when selecting strength training exercises, as they vary depending on fitness goals such as hypertrophy, performance, or injury prevention [7]. Electromyography (EMG), which captures the electrical signals produced by muscle contractions, offers a valuable tool for

assessing muscle activation. EMG data can reflect human movement intentions and facilitate more natural and fluent human-machine interactions by mirroring these physiological signals [8].

To the best of our knowledge, there is no comprehensive review of the current literature on quadriceps muscle activation in adult men, and there is considerable disagreement regarding the specific exercises involved. For example, some studies have shown greater Vastus Medialis (VM) activity during the leg press exercise compared to the squat exercise [9], while Sjöberg et al. (2021) reported similar quadriceps activity in both exercises.

The primary aim of this manuscript is to systematically review the current literature investigating quadriceps femoris muscle activity, measured using sEMG, in healthy adult males during common strength exercises. A deeper understanding of quadriceps activation in these exercises will give researchers, clinicians, trainers, and athletes valuable insights for selecting the most effective exercises for targeting specific muscles.

Method and Materials

This study was a cross-sectional observational. This systematic review was conducted following the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [10]. The protocol for this review was registered in the International prospective register of systematic reviews (PROSPERO) database. The quality of the included studies was assessed by two reviewers using the Physiotherapy Evidence Database quality scale (PEDro scale), which consists of 11 questions. The final score was proportionally distributed based on the total number of questions answered. However, due to the inability to blind researchers and trainees, three of the 11 questions were excluded, resulting in a maximum score of 8 [11].

On March 21st, 2023, a systematic search was conducted using the PubMed/Medline, Scopus, and Web of Science databases. Medical Subject Headings (MeSH) descriptors,

relevant terms, and keywords were employed, with an example of the complete PubMed search strategy as follows:

“resistance training” [Abstract] OR “strength training” [Abstract] OR “resistance exercise” [Abstract] OR “weight lifting” [Abstract] OR “weight bearing” [Abstract] AND electromyography [Abstract] OR EMG [Abstract] OR “muscle activation” [Abstract] OR “muscle activity” [Abstract] OR “sEMG amplitude” [Abstract] OR “neuromuscular activation” [Abstract] OR “muscle excitation” [Abstract] OR “muscular activity” [Abstract] AND “thigh muscle” [Abstract] OR “quadriceps” [Abstract] OR “quads” [Abstract] OR “knee extensors” [Abstract].

Only studies that met the following inclusion criteria were selected: (a) full-text availability in English, (b) cross-sectional or longitudinal study design (experimental or cohort), (c) data on electromyography (EMG) activity as a percentage of maximal voluntary isometric contraction (%MVIC), (d) analysis of RF, vastus laterals (VL), and VM muscles, (e) focus on resistance training exercises as the primary intervention, (f) published within the last 10 years, and (g) inclusion of healthy adult males.

Studies were excluded if they lacked sufficient data, contained unclear or ambiguous protocols, or were review articles, conference papers, books, theses, or congress abstracts. Samples involving participants with metabolic disorders, musculoskeletal trauma, a history of back pain, spinal cord injury, or neurological deficits were also excluded, as were studies on elderly or young populations. Additionally, studies focusing on aerobic, isometric, plyometric, or calisthenics exercises were excluded.

Two independent reviewers selected the studies based on the inclusion and exclusion criteria. After duplicates were removed, titles and abstracts were screened. The full texts of the remaining articles were then reviewed, and only those that met the inclusion criteria were selected. In cases of disagreement between the two reviewers, a third colleague was consulted to reach a consensus. Figure 1 provides a graphical representation of the study selection process.

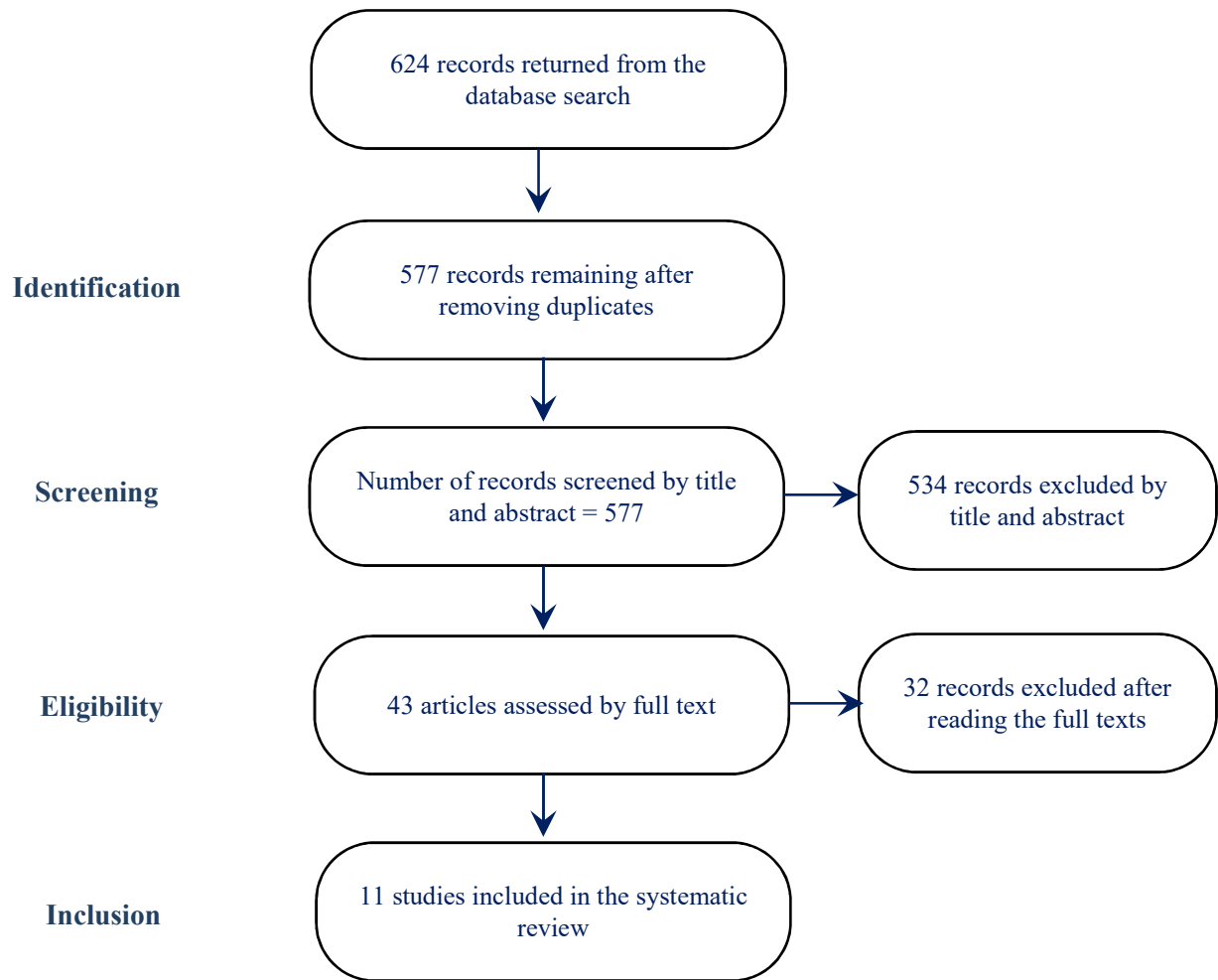


Figure 1) Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA).

The authors analyzed the data in two consecutive meetings to finalize the inclusion of eligible articles in the review. After reviewing each article, the following information was extracted: (1) exercise performed, (2) EMG collection method, (3) electrode placement, (4) target muscles, (5) main findings, (6) average %MVIC values for each exercise, (7) number and age of participants, and (8) reference. For exercises evaluated by two or more studies, data were pooled to calculate the mean %MVIC for each exercise. Only the mean % of MVIC data from each study was used in this analysis.

Quadriceps muscle activation was categorized into the following levels [12]: 0-20%MVIC as low activation, 21-40%MVIC as moderate activation, 41-60%MVIC as high activation, and >60%MVIC as very high activation.

The selected studies reported muscle activation separately for each exercise and muscle group. sEMG activity was the primary data collected, and sEMG data were recorded for both the

eccentric and concentric phases when available. Due to the methodological inconsistencies and varying analyses across studies, conducting a meta-analysis of the results was not feasible.

Findings

Two independent reviewers conducted an initial survey and identified 624 articles. After reviewing the titles and abstracts (483 removed) and eliminating duplicates (47 removed), 43 articles were selected for full-text review. Following two meetings and discussions on the data, 32 records were evaluated using a methodological quality scale and inclusion/exclusion criteria, of which 11 articles were deemed eligible for this systematic review.

In total, 179 male participants, aged between 19 and 33 years, were evaluated. All selected studies employed a cross-sectional design with randomized practice test arrangements. The studies were published within the last 10 years (between 2013 and December 2022).

Moreover, based on the PEDro scale, the studies were classified as having well to excellent quality, as assessed by their methodological reporting process and data.

The exercises most commonly evaluated were knee extension, squat, deadlift, and leg press. In most studies, quadriceps EMG data were normalized using %MVIC, with measurements taken in the prone position with the knee flexed at 90. The Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) protocol was followed in these studies [13]. Table 1 describes the references, exercises tested; sample size, average age, participant experience, sEMG collection methods, muscle activation levels, and main findings.

Of the selected studies, four examined knee extension exercises [14-17], six focused on variations of the squat exercise [back, goblet, landmine, wall, and Spanish] [18-23], two investigated the leg press [24, 25], and one examined the deadlift [18]. External loads were prescribed as a percentage of 1RM (ranging from 30 to 100% of 1RM) or maximum repetitions (ranging from 6 to 10 RM). Two studies based load on a percentage of body weight [19, 22] (Table 1).

Vastus Lateralis

The leg press exercise elicited the highest EMG activity for the VL at 91.34%MVIC, followed by the deadlift at 84.55%MVIC. The goblet squat (76.4%MVIC), knee extension (70.43%MVIC), back squat (67.08%MVIC), and Spanish squat (63%MVIC) also demonstrated exceptionally high muscle activation (>60%MVIC). The landmine squat (59.3%MVIC) and wall squat (47.5%MVIC) elicited high muscle activation (41-60%MVIC).

Vastus Medialis

The leg press also demonstrated the highest EMG activity for the VM, reaching 85.08%MVIC. Other exercises with very high activation levels included knee extension (76.80%MVIC), goblet squat (67.8%MVIC), and Spanish squat (63%MVIC). The back squat (58.15%MVIC), landmine squat (55.4%MVIC), and wall squat (51%MVIC) showed high muscle activation levels.

Rectus Femoris

The Spanish squat elicited the highest EMG activity for the RF at 91.5%MVIC, followed by knee extension (76.46%MVIC) and leg press (69.5%MVIC), all exhibiting very high muscle activation. The back squat elicited high activation (41.72%MVIC), while the wall squat was the only exercise to achieve moderate activation (29.5%MVIC).

Table 1. Description of data extracted from each article regarding reference, Exercises tested, Sample and mean age, Experience, electromyography collection method, target muscles, and main findings.

Discussion

This systematic review aimed to assess the EMG activity of the quadriceps femoris muscles in healthy adult males during common strength exercises. The review revealed that the VL was the most frequently studied quadriceps muscle across various exercises. The main findings indicated that the leg press exercise produced the highest VL and VM activation, while the Spanish squat was most effective for RF activation.

Vastus Lateralis

For the VL, the leg press elicited the highest EMG activity (91.34%MVIC), followed closely by the deadlift (84.55%MVIC). Similar findings were reported by Martín-Fuentes et al. (2020), who observed greater VL activation compared to other muscles [11]. This increased activation could be attributed to the greater isokinetic strength of the VL at the end range of motion [26].

Vastus Medialis

The leg press also demonstrated the highest EMG activity for the VM (85.08%MVIC). Contrary to Stien, N. et al. (2020) findings, the leg press showed higher EMG activity than the knee extension exercise for the VM. While the GS and SS elicited similar EMG activity for the VM, the SS is relatively more difficult due to its demand for proper torso-pelvis alignment and knee joint positioning. Consequently, the GS may be more suitable for beginners and intermediate-level individuals.

Table1) Description of data extracted from each article regarding reference, Exercises tested, Sample and mean age, Experience, electromyography collection method, target muscles, and main findings

| Reference | Exercises tested | Sample (age) | Experience | sEMG collection method | Activity sEMG recorded of muscles | Main findings |
|-------------------------------------|---|--------------|----------------|---|--|---|
| Antunes, L., et al. 2018[14] | leg extension | 12 (24) | 6 months | 3 sets 10RM | vastus lateralis, vastus medialis and rectus femoris | VL activity: traditional> fast =slow – RF activity: fast> traditional =slow – VM activity: fast =traditional=slow |
| Barnes, M. J., et al. 2019 [18] | squat or deadlift | 10 (24) | 2 years | 8 sets 2rep 95%RM | vastus lateralis | No difference was found between exercises |
| Coratella, G., et al. 2020 [20] | back-squat | 15 (27/4) | 5 years | 4 reps at 50% or 80% 1-RM sets | vastus lateralis | IF (internal focus) < EF (external focus) during the concentric phase |
| Haun, C. T., et al. 2017 [16] | knee extension | 15 (22) | Not indicated | 4 set 30% or 80% 1RM | vastus lateralis | heavy > light |
| Kephart, W. C., et al. 2016 [21] | barbell back squat | 30 (22.15) | 3 months | 1RM 60 deg/s and 120 deg/s | vastus lateralis | EMG variables were not differentially between groups |
| Schoenfeld, B. J., et al. 2014 [24] | leg press | 10 (21.3) | 1 year | 75 % 1RM & 30 % 1RM | vastus medialis, vastus lateralis | Significantly greater mean EMG activity during the high-load (HL) set compared to the Low-load (LL) set |
| Stien, N., et al. 2021 [25] | leg press – knee extension | 15 (27) | 8.0 ± 5.9 year | 1set 6RM | vastus lateralis, vastus medialis, rectus femoris | VL activity: leg press > knee extension – RF activity: knee extension > leg press - VM activity: leg press = knee extension |
| Trindade, T. B., et al. 2020 [23] | Barbell squat | 14 (28.4) | 7.5 year | 3 set 10RM | vastus lateralis, vastus medialis, rectus femoris | EMG activity increased in the rectus femoris, vastus lateralis, and vastus medialis for the stretching condition. For the non-stretching condition, activity only increased in the vastus lateralis and medialis. |
| Collins et al. 2021 [19] | goblet squat (GBS) - landmine squat (LMS) | 16 (23.2) | Not indicated | 5 rep 30% of their body mass | vastus lateralis, vastus medialis | the VM and VL showed decreased activity in the LMS compared with the GBS |
| Brentano, M. A., et al. 2017 [15] | knee extension: [GE] (super set of 1 muscle) or | 20 (25.7) | Not indicated | 5 set 8-10 RM | vastus lateralis (VL), vastus medialis (VM), rectus femoris (RF) | GE (grouped exercises) can promote greater muscle activity of the lower limbs compare to separated exercises (SE) |
| Lee, J. H., et al. 2022 [22] | general squat (GS), wall squat (WS), and Spanish squat (SS) | 22 (23) | Not indicated | 3 times (1 s to reach the nearest position to the floor, held 3s, returned to the original position for 1 s.) | rectus femoris (RF), vastus lateralis (VL), vastus medialis (VM) | SS shows more activation in the RF and VL muscles compared to GS and WS. |

Figure 2 illustrates the mean normalized %MVIC for the RF, VL, and VM across various exercises. Table 2 summarizes the average muscle activation levels for each exercise. In general, the

leg press elicited the highest %MVIC for the VL and VM, while the Spanish squat demonstrated the highest %MVIC for the RF.

Table 2) Pooled mean summary of mean percentage of maximal voluntary isometric contraction (%MVIC) for quadriceps in different exercises.

| Exercise | Number of articles | Mean %MVIC VL | Mean %MVIC VM | Mean %MVIC RF |
|----------------|--------------------|---------------|---------------|---------------|
| Back Squat | 5 | 67.08 | 58.15 | 41.72 |
| Knee Extension | 4 | 70.43 | 76.80 | 76.46 |
| Leg Press | 2 | 91.34 | 85.08 | 69.5 |
| Spanish Squat | 1 | 63 | 63 | 91.5 |
| Wall Squat | 1 | 47.5 | 51 | 29.5 |
| Goblet Squat | 1 | 76.4 | 67.8 | - |
| Landmine Squat | 1 | 59.3 | 55.4 | - |
| Deadlift | 1 | 84.55 | - | - |

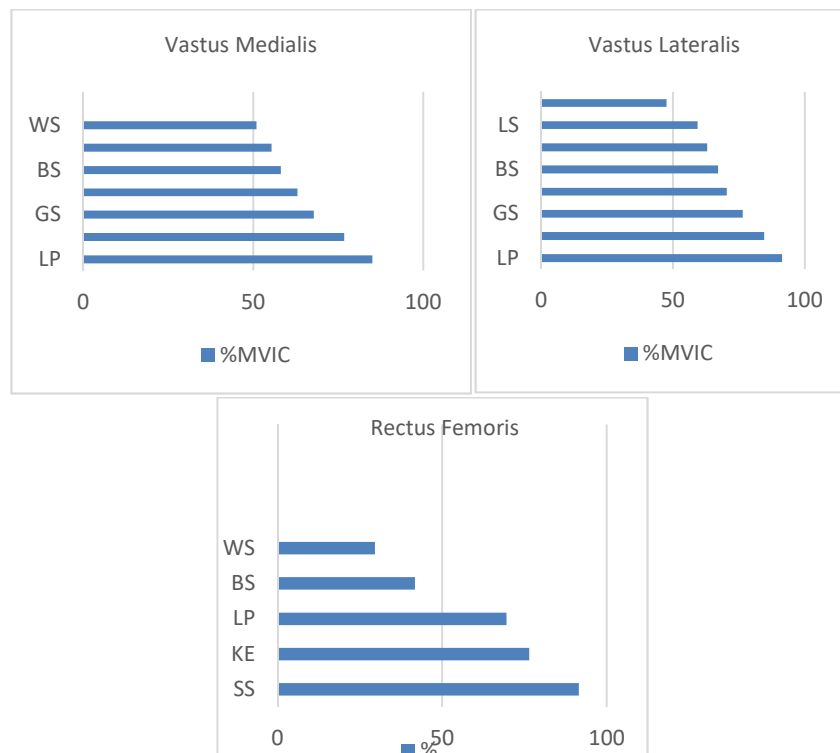


Figure 2) Mean percentage of Maximum Voluntary Isometric Contraction (%MVIC) for rectus femoris (RF), vastus lateralis (VL), vastus medialis (VM) in Leg Press (LP), Deadlift (DL), Goblet Squat (GS), Knee Extension (KE), Back Squat (BS), Spanish Squat (SS), Landmine Squat (LS) and Wall Squat (WS).

Rectus Femoris

The RF was the least studied muscle compared to the VL and VM, and the SS elicited the highest %MVIC for the RF (91.5%). This is likely due to the more upright torso relative to the hips during the SS, increasing RF activation. The RF during the wall squat (WS) was the only instance of moderate %MVIC in this review.

Limitations

A fundamental limitation of this review is the inconsistency in the methods used to measure EMG activity, which raises concerns about the interpretation of results and potential bias.

Future research should aim to reduce these methodological differences to improve the comparability of findings^[27]. Additionally, the current literature focuses exclusively on healthy adult males. Whether similar muscle activation patterns would be observed in injured athletes or women remains unclear. Furthermore, variations in load (ranging from 30% to 100% RM) or differences in training experience and familiarity with the exercises may impact quadriceps activation^[28].

Conclusion

Coaches, athletic trainers, and physical therapists can use the findings of this

systematic review to categorize various exercises by the level of quadriceps activation, ranging from low to high. This information can aid in developing progressive training programs to enhance quadriceps strength and improve overall athletic performance.

The main findings of this systematic review are as follows:

1. The VL was the most studied quadriceps muscle during common strength exercises.
2. The leg press elicited the highest EMG activity for the VL and VM, while the SS demonstrated the highest EMG activity for the RF.
3. Standardizing participants' resistance training experience, sEMG collection methods and electrode placement are essential for obtaining conclusive outcomes.

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