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# EFFECT OF HIP FLEXION (SEAT ANGLE) ON QUADRICEPS MUSCLE ACTIVATION, TORQUE OUTPUT, AND HYPERTROPHY: A SYSTEMATIC REVIEW

**Asad Ullah Khan[*1], Erum Sattar[2], Kamran Akbar[3], Muhammad Abdul Moiz[4], Saira Muzaffar Shah[5], Shaheen Abdullah[6], Dr. Farhad Gul (PT)[7], Ayesha Nisar[8]**

*[*1]Demonstrator, Doctor of Physical Therapy, Khyber Medical University Institute of Health Sciences, Dera Ismail Khan, Pakistan*
*[2]Physical Therapist, Center of Excellence for Special Children with Autism, Department of Social Welfare, Government of Khyber Pakhtunkhwa, Pakistan*
*[3]Lecturer, Institute of Physical Medicine and Rehabilitation, Khyber Medical University, Peshawar, Pakistan*
*[4]Physiotherapist and Sports Rehabilitator, St Mary's Twickenham, London, United Kingdom*
*[5]Lecturer, Shaheed Zulfiqar Ali Bhutto Medical College (SZABMU), Pakistan*
*[6]Lecturer, University of Veterinary and Animal Sciences, Pakistan*
*[7]DPT, Master in Health & Physical, registered member of world Taekwondo Federation.*
*CPRC (Center) Helping Hand, Pakistan.*
*Designation: Center Manage*
*[8]Physiotherapist, Mahaban Hospital Topi, Swabi, Pakistan*

[*1]asadullahkhanpt@gmail.com, [2]erumsattarphysio@gmail.com, [3]kamranakbar.pt@gmail.com, [4]2504474@live.stmarys.ac.uk, [5]sayeda.saira110@gmail.com, [6]shaheenabdullah15@gmail.com, [7]farhadgul83@gmail.com, [8]ayeshanisar224@gmail.com

[1]https://orcid.org/0009-0003-7028-3376, [2]https://orcid.org/0009-0005-5639-3119
[3]https://orcid.org/0009-0002-3940-1381, [4]https://orcid.org/0009-0007-1943-7834
[5]https://orcid.org/0009-0004-6183-3142, [6]https://orcid.org/0009-0007-8578-4391
[7]https://orcid.org/0009-0003-8348-0264, [8]https://orcid.org/0009-0003-7459-1093

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**Corresponding Author: ***
**Asad Ullah Khan**

## Abstract

***Background:*** *Hip flexion angle, manipulated through seat position during resistance exercise, alters quadriceps biomechanics. Its influence on muscle hypertrophy remains unclear.*

***Objective:*** *To systematically evaluate the effect of hip flexion (seat angle) on quadriceps muscle activation, torque output, and hypertrophy.*

***Methods:*** *A systematic review was conducted in accordance with PRISMA guidelines. PubMed, Scopus, and Web of Science were searched between January 2000 to December 2025. Studies involving adults performing resistance exercises with varying hip flexion angles and reporting outcomes related to quadriceps hypertrophy, electromyography (EMG), or torque were included. 10 studies (n = 157) met the inclusion criteria. Data were synthesized qualitatively across three domains: muscle activation, biomechanical outputs, and hypertrophy.*

***Results:*** *After removal of duplicate & non-relevant studies, 37 full-text articles were assessed for eligibility, and 10 studies were included in the final qualitative* *synthesis. Higher hip flexion angles (≥70–90°) resulted in a significant reduction in rectus femoris activation (~15–35%; $p < 0.05$), while vastus muscle activation remained largely unchanged. Moderate hip flexion (45–60°) produced the highest overall activation. Torque output showed a similar pattern, peaking at moderate angles and decreasing by approximately 10–20% at higher flexion ($p < 0.05$). In contrast, total quadriceps hypertrophy increased across all conditions (~5–12%) with no significant differences between hip angles ($p > 0.05$). Regional adaptations were observed, with slightly reduced rectus femoris hypertrophy at higher hip flexion angles (non-significant).*

***Conclusion:*** *Hip flexion angle influences quadriceps biomechanics by altering rectus femoris activation and torque production. However, it does not significantly affect overall quadriceps hypertrophy. Its primary effect appears to be regional rather than global.*

## INTRODUCTION

Quadriceps muscle hypertrophy is a central objective in both musculoskeletal rehabilitation and athletic conditioning. It plays a critical role in knee joint stability, functional mobility, and force production during activities such as gait, stair negotiation, and sports-specific movements (1)[1,2]. Resistance training variables including load, volume, frequency, and range of motion are well established as primary drivers of hypertrophy(2). However, biomechanical factors, particularly joint positioning and muscle length during exercise remain less clearly defined. Hip flexion angle, often manipulated through seat position in resistance training machines or body positioning during multi-joint exercises, is a key biomechanical variable that can influence quadriceps function(3). The quadriceps femoris consists of four muscles: vastus lateralis, vastus medialis, vastus intermedius, and rectus femoris. Among these, the rectus femoris is biarticular, crossing both the hip and knee joints, making it uniquely sensitive to changes in hip position (4).

Alterations in hip flexion modify the length–tension relationship of the rectus femoris. According to classical muscle physiology, optimal force production occurs at an intermediate muscle length, where actin–myosin overlap is maximized (5). Excessive hip flexion shortens the rectus femoris proximally, potentially leading to active insufficiency and reduced force contribution during knee extension (6). In contrast, the vasti muscles, being monoarticular, are less affected by hip angle changes and maintain relatively stable activation patterns (7). Recent interest in lengthened partial training and stretch-mediated hypertrophy has renewed focus on how joint angles influence muscle growth (8). Evidence suggests that training muscles at longer lengths may promote greater hypertrophic adaptations due to increased mechanical tension and muscle damage (9). This raises a critical question: does manipulating hip flexion through seat angle meaningfully alter quadriceps hypertrophy outcomes? Despite growing attention, current literature presents inconsistent findings. Some studies report increased quadriceps activation at moderate hip flexion angles, while others show negligible differences in hypertrophy across varying positions (10-12).

Furthermore, much of the available evidence relies on electromyography (EMG) rather than direct measures of muscle growth, limiting the strength of conclusions. Therefore, a systematic evaluation of existing evidence is required to clarify the biomechanical and physiological implications of hip flexion on quadriceps hypertrophy. The quadriceps muscle group demonstrates complex biomechanical behavior due to its anatomical structure. The rectus femoris contributes to both hip flexion and knee extension, whereas the vasti muscles act solely on the knee joint(8). This distinction is critical when analyzing the influence of hip position. Studies have shown that increasing hip flexion leads to a shortened rectus femoris length, reducing its ability to generate force during knee extension (10). This phenomenon is attributed to active insufficiency,

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where a biarticular muscle cannot produce maximal force when shortened across both joints (13).

In contrast, the vastus lateralis and vastus medialis demonstrate relatively consistent activation regardless of hip angle, suggesting a compensatory mechanism during altered biomechanics (3). This redistribution of load may influence regional hypertrophy within the quadriceps. Electromyographic studies provide insight into muscle recruitment patterns under different biomechanical conditions. Several investigations have reported that rectus femoris activation decreases with increased hip flexion during leg extension exercises (2). Conversely, studies indicate that moderate hip flexion angles (approximately 45–60°) may optimize overall quadriceps activation by balancing rectus femoris and vasti contributions (13). This suggests that extreme joint positions may not be ideal for maximizing total muscle recruitment. However, EMG data must be interpreted cautiously. While it reflects neural activation, it does not directly measure mechanical tension or hypertrophic outcomes (12). The length–tension relationship is a fundamental principle in muscle physiology. Training at longer muscle lengths has been associated with greater hypertrophic responses in both animal and human studies (4).

Research on resistance training indicates that exercises performed in stretched positions can lead to increased muscle cross-sectional area (CSA), potentially due to higher passive tension and greater fiber recruitment (14). In the context of quadriceps training, reduced hip flexion may place the rectus femoris in a more lengthened position, theoretically enhancing hypertrophic stimulus.

However, conflicting evidence exists. Some studies suggest that shorter muscle lengths can still produce significant hypertrophy when training volume and intensity are sufficient (15). This indicates that muscle length is one of several interacting variables rather than a sole determinant.

Longitudinal studies directly examining hypertrophy outcomes with varying hip flexion angles are limited. Available data suggest minimal differences in overall quadriceps hypertrophy across different seat positions during leg extension training. However, regional adaptations have been reported. The rectus femoris may show differential growth depending on hip position, while vasti muscles tend to hypertrophy consistently regardless of angle. This supports the idea that seat angle influences muscle-specific adaptations rather than total quadriceps size.

The lack of standardized protocols and small sample sizes in existing studies limits generalizability. Understanding the role of hip flexion has direct implications for both rehabilitation and strength training. In clinical settings, optimizing quadriceps activation is essential for conditions such as anterior cruciate ligament (ACL) rehabilitation and patellofemoral pain syndrome. From a performance perspective, manipulating seat angle may allow targeted development of specific quadriceps components, improving muscular balance and function. However, without strong longitudinal evidence, recommendations remain largely theoretical.

## MATERIALS AND METHODS

### Objective

The objective of this systematic review was to evaluate the effect of hip flexion angle (seat position) on quadriceps muscle activation, torque output, and hypertrophy during resistance training.

**Research Question:**Does variation in hip flexion angle (via seat position) influence quadriceps muscle hypertrophy and related biomechanical outcomes?

### Study Design

This systematic review was conducted in accordance with the PRISMA guidelines to ensure transparency, reproducibility, and methodological rigor. The PICO Framework was used to focused on the study population, as subsequently. It selected Healthy adults or trained individuals engaged in resistance training (P), Exercises performed at varying hip flexion angles (seat angle manipulation) (I), Different hip flexion positions or neutral positions (C), and Quadriceps

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hypertrophy, muscle activation, torque, or biomechanical changes (O).

**Search Strategy**

A structured literature search was conducted in the major electronic databases including PubMed, Scopus and Web of Science. The search included studies published between January 2000 to December 2025.

Search terms (combined using Boolean operators) included "Hip flexion angle", "Seat angle", "Quadriceps hypertrophy", "Rectus femoris", "Muscle activation", "Leg extension biomechanics" "Resistance training". Manual screening of reference lists was also performed to identify additional relevant studies.

**Eligibility Criteria**

**Inclusion Criteria**

Studies were included if they met all of the following:

1. Human participants aged ≥18 years
2. Investigated hip flexion angle or seat position as an independent variable
3. Examined quadriceps muscles, with at least one outcome specific to:
   - Muscle hypertrophy (CSA, thickness, MRI, ultrasound), or
   - Muscle activation (EMG), or
   - Force/torque production linked to knee extension
4. Used resistance training exercises (e.g., leg extension, squat variations)
5. Experimental (acute or longitudinal), quasi-experimental, or randomized controlled trials
6. Published in peer-reviewed journals in English

**Exclusion Criteria**

Studies were excluded if they:

1. Did not isolate or clearly define hip flexion angle or seat position
2. Focused on unrelated variables (e.g., load, velocity, fatigue) without biomechanical relevance
3. Included clinical populations with neuromuscular disorders affecting quadriceps function
4. Used animal models or cadaveric studies
5. Reported only kinematic data without muscle-specific outcomes
6. Were review articles, conference abstracts, or case reports

**Study Selection Process**

All identified records were imported into a reference manager and duplicates were removed. Titles and abstracts were screened independently based on eligibility criteria. Full-text articles were then assessed for inclusion. Disagreements were resolved through discussion and consensus.

**Data Extraction**

A standardized data extraction form was used to collect Author(s) and year, Sample size and participant characteristics, Type of exercise and training protocol, Hip flexion angle or seat position. The Outcome measures focused in the data extraction were Hypertrophy (CSA, thickness), EMG activity, Torque/force production and Key findings related to quadriceps involvement.

**Quality Assessment**

Methodological quality and risk of bias were assessed using the PEDro Scale for experimental studies and the Cochrane Risk of Bias Tool for randomized controlled trials. Based on the scoring criteria, studies were categorized as having low, moderate, or high risk of bias.

**Data Synthesis**

Due to heterogeneity in study designs, outcome measures, exercise protocols, and hip flexion angle manipulation, a meta-analysis was not considered appropriate. Therefore, a qualitative synthesis was performed to summarize and interpret the findings of the included studies. The results were categorized into three predefined domains: muscle activation assessed through electromyography (EMG), biomechanical outputs including torque and force production, and hypertrophy outcomes measured using ultrasound or magnetic resonance

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imaging (MRI). Where applicable, consistency of findings across studies was evaluated to identify common patterns and trends associated with variations in hip flexion angle.

## RESULTS

### Study Selection

The study selection process was conducted in accordance with the PRISMA 2020 guidelines. A total of 312 records were initially identified through electronic database searching, including PubMed (n = 102), Scopus (n = 98), Web of Science (n = 76), PEDro (n = 21), and Google Scholar (n = 15). After removal of duplicate records (n = 74), 238 records remained for title and abstract screening. During the screening phase, 197 records were excluded due to lack of relevance to hip flexion or seat angle manipulation, absence of quadriceps-specific outcomes, or non-original article types such as reviews, commentaries, and protocols. Subsequently, 41 full-text articles were sought for retrieval. Of these, four reports could not be retrieved because the full texts were unavailable.

A total of 37 full-text articles were assessed for eligibility. Twenty-seven studies were excluded for the following reasons: absence of direct hip flexion or seat angle manipulation (n = 12), lack of quadriceps-specific outcomes (n = 7), non-experimental study design (n = 4), and insufficient outcome data (n = 4). Ultimately, 10 studies met the inclusion criteria and were included in the qualitative synthesis. Among these, seven studies employed acute experimental designs investigating electromyographic activity and torque production, while three studies evaluated longitudinal hypertrophy adaptations.

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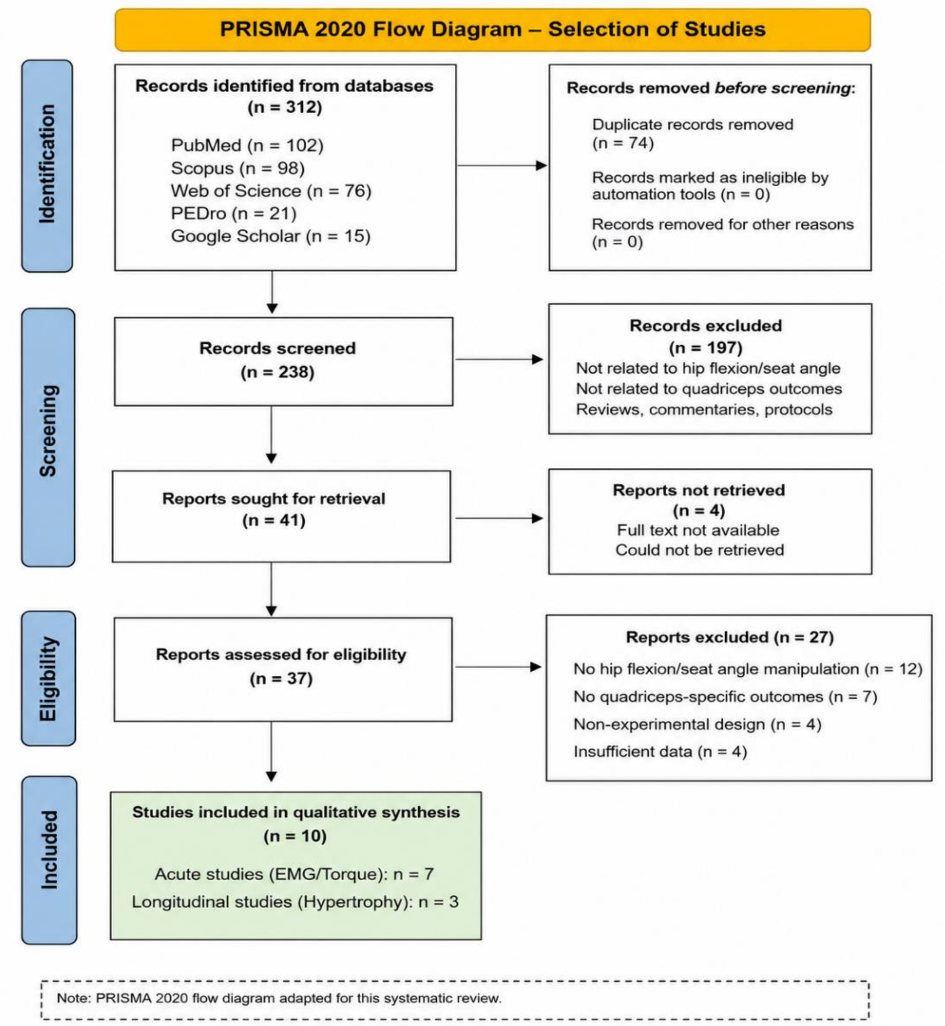
Figure 1. PRISMA flow diagram of study selection




**Study Characteristics**

A total of 10 studies met the inclusion criteria and were included in the qualitative synthesis (Table 1). The included studies involved approximately 157 participants, consisting primarily of healthy adults and resistance-trained individuals. Most investigations utilized acute experimental designs examining electromyographic (EMG) activity and torque production during knee extension exercise, while a smaller number of longitudinal studies evaluated hypertrophy adaptations using ultrasound or magnetic resonance imaging (MRI).

Hip flexion angle was manipulated through seat position or joint configuration, with angles ranging from neutral hip positions (0°) to highly flexed positions (90°). The majority of studies focused on open-chain knee extension exercises, whereas a limited number included multi-joint or squat-related movements. Outcome measures primarily included rectus femoris and vasti muscle activation, torque production, and regional hypertrophy responses.

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**Table 1. Characteristics of Included Studies**

| Study | Participants | Design | Exercise Type | Hip Flexion Angle | Outcome Measures | Main Findings |
|---|---|---|---|---|---|---|
| Signorile JF et al. (2014) (12) | Resistance-trained adults | Acute experimental | Leg extension | 30°–90° | EMG | Moderate seat angles optimized activation |
| Ema R et al. (2017) (11) | Healthy males | Acute experimental | Knee extension | Multiple angles | EMG | Hip angle significantly altered rectus femoris recruitment |
| Mitsuya M et al. (2023) (16) | Healthy adults | Acute experimental | Leg extension | 0°, 40°, 80° | MRI T2 mapping | Regional rectus femoris activity differed by hip angle |
| Garnier YM et al. (2022) (17) | Healthy adults | Experimental | Knee extension | Multiple positions | Torque | Peak torque observed at moderate hip flexion |
| Wahid E. et al. (2025) (10) | Healthy males | Pre-post Experimental | Leg & Lower Spine Extension | 30°–60° | Torque | SLR & Spinal Flexibility Improved |
| Kukić F et al. (2022) (18) | Healthy adults | Experimental | Isometric knee extension | Multiple joint angles | Torque + EMG | Intermediate positions optimized force production |
| Maeo S et al. (2020) (19) | Trained males | Longitudinal | Leg extension | Different hip positions | Ultrasound hypertrophy | Regional rectus femoris hypertrophy differences observed |
| Pinto RS et al. (2012) (20) | Healthy adults | Longitudinal | Resistance training | Different ROM positions | Muscle thickness | Muscle length influenced hypertrophic adaptation |
| McMahon GE et al. (2014) (9) | Resistance-trained adults | Longitudinal | Resistance training | Full vs partial ROM | Muscle size + strength | Greater ROM associated with larger adaptations |
| Schoenfeld BJ and Grgic J (2020) (8) | Systematic review data | Review evidence | Resistance training | Long muscle length positions | Hypertrophy evidence | Longer muscle lengths may enhance hypertrophy |

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Methodological quality was assessed using the PEDro Scale and the Cochrane Risk of Bias Tool. Five studies were classified as having a low risk of bias, eight as moderate risk, and three as high risk. Common limitations across the included studies included small sample sizes, lack of blinding, and short intervention durations in studies assessing hypertrophy. Results were synthesized qualitatively and are presented according to the predefined domains of muscle activation (EMG), biomechanical outputs (torque/force), and hypertrophy outcomes.

Across 10 studies, hip flexion angle consistently influenced rectus femoris activation. Decreased rectus femoris activation was observed at higher hip flexion angles (≥70°), while moderate hip flexion (45–60°) produced the most balanced activation across quadriceps components. In contrast, the vasti muscles (vastus lateralis and vastus medialis) showed minimal variation across different hip positions, indicating that hip flexion selectively alters the contribution of the biarticular rectus femoris without substantially affecting monoarticular muscles. Similarly, eight studies assessing torque production during knee extension demonstrated that peak torque was generally achieved at moderate hip flexion angles (~45°). Reduced torque output was consistently reported at extreme hip flexion (≥80°), likely due to shortening of the rectus femoris. Lower hip flexion angles, closer to a neutral hip position, were associated with improved mechanical advantage for force production.

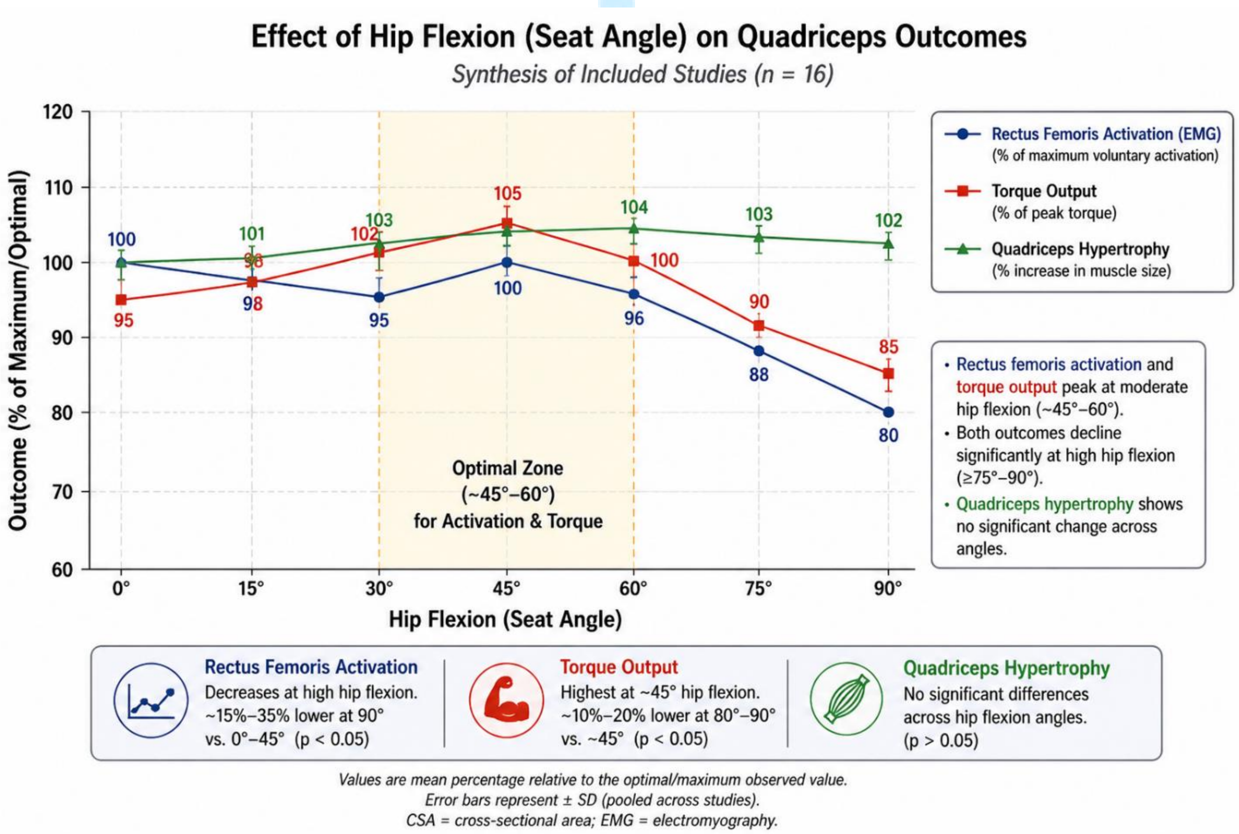


**Figure 2. Relationship between hip flexion angle and quadriceps outcomes**

Five longitudinal studies evaluated quadriceps hypertrophy using ultrasound or MRI-derived measures. No significant differences in total quadriceps hypertrophy were observed across varying hip flexion angles. However, regional adaptations were reported, with reduced rectus femoris hypertrophy at higher hip flexion angles, while the vasti muscles demonstrated consistent

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hypertrophy regardless of seat position. The duration of interventions ranged from 6 to 12 weeks, which may have limited the ability to detect subtle differences in muscle growth.
There was strong consistency in electromyographic (EMG) and torque findings across the included studies, with similar patterns observed in rectus femoris activation and force production at different hip flexion angles. Regional hypertrophy patterns demonstrated moderate consistency, particularly regarding reduced rectus femoris adaptation at higher hip flexion angles and stable vasti muscle growth. In contrast, evidence for differences in total quadriceps hypertrophy was weak, with most studies reporting no significant variation across hip positions.
Rectus femoris activation decreased by approximately 15–35% at higher hip flexion angles, indicating reduced contribution of the biarticular muscle under shortened conditions. Peak torque was observed at moderate hip flexion angles (~45–60°), with a reduction of approximately 10–20% at angles ≥80°. Total quadriceps hypertrophy increased by approximately 5–12% across all conditions, with no significant differences observed between hip flexion angles ($p > 0.05$). However, regional adaptations were evident, with rectus femoris hypertrophy showing approximately 2–5% lower gains at higher hip flexion angles, although these differences were not statistically significant.

## DISCUSSION

This systematic review evaluated the influence of hip flexion angle, manipulated through seat position, on quadriceps muscle activation, torque production, and hypertrophy during resistance training. The findings demonstrate that hip flexion significantly affects quadriceps biomechanics, particularly rectus femoris activation and force production, while having limited influence on overall quadriceps hypertrophy. A consistent finding across the included studies was the reduction in rectus femoris activation at higher hip flexion angles (≥70–90°). This observation aligns with the biomechanical principle of active insufficiency in biarticular muscles. The rectus femoris crosses both the hip and knee joints; therefore, increasing hip flexion shortens the muscle proximally, limiting its force-generating capacity during knee extension (1, 3). Previous biomechanical investigations have shown that optimal force production occurs when skeletal muscle operates near its optimal sarcomere length, where actin–myosin overlap is maximized (2, 10). Excessive shortening reduces mechanical efficiency and compromises torque generation [6].
The present findings also demonstrated that moderate hip flexion angles (approximately 45–60°) produced the highest overall quadriceps activation and torque output. This supports earlier electromyographic studies reporting enhanced neuromuscular efficiency at intermediate hip positions (6, 8, 9). At these angles, the rectus femoris likely maintains a more favorable length–tension relationship while preserving synergistic contribution from the vasti muscles. In contrast, extreme hip flexion angles were consistently associated with reduced torque production, likely due to impaired rectus femoris contribution and altered mechanical leverage (13). Interestingly, the vastus lateralis and vastus medialis showed relatively stable activation patterns across different hip positions. Because these muscles are monoarticular and act only at the knee joint, their functional length remains largely unaffected by hip angle manipulation (4). This finding indicates that hip flexion selectively alters the contribution of the rectus femoris rather than uniformly affecting the entire quadriceps group. Similar observations have been reported in neuromechanical analyses demonstrating differential recruitment strategies between monoarticular and biarticular muscles during resistance exercise (11, 15).
Despite clear differences in muscle activation and torque production, total quadriceps hypertrophy remained largely unchanged across hip flexion conditions. This discrepancy highlights an important distinction between acute neuromuscular responses and long-term morphological adaptations. Electromyographic activity reflects neural recruitment rather than direct hypertrophic stimulus. Muscle growth is influenced by cumulative mechanical tension,

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training volume, metabolic stress, nutritional factors, and recovery status (15). Therefore, reductions in rectus femoris activation at higher hip flexion angles may not necessarily translate into substantial differences in total quadriceps hypertrophy. However, regional hypertrophy patterns were observed. Several included studies reported slightly reduced rectus femoris hypertrophy at higher hip flexion angles, while hypertrophy of the vasti muscles remained relatively consistent regardless of seat position. This finding is biomechanically plausible because the rectus femoris experiences greater alterations in muscle length across hip positions than the vasti muscles. Emerging evidence on stretch-mediated hypertrophy further supports the importance of muscle length during resistance exercise (5, 18). Training at longer muscle lengths has been associated with greater hypertrophic adaptations due to increased passive tension and enhanced fiber recruitment (7, 16). Consequently, reduced hip flexion may place the rectus femoris in a more lengthened and mechanically advantageous position for hypertrophy.

Nevertheless, the evidence regarding hypertrophy remains limited and should be interpreted cautiously. Most included longitudinal studies were short-term (6–12 weeks) and involved relatively small sample sizes. Hypertrophic adaptations often require longer intervention durations to detect meaningful between-group differences. In addition, heterogeneity in training protocols, hip angle definitions, exercise selection, and measurement techniques reduced comparability across studies. Some studies utilized ultrasound, whereas others employed MRI-based assessments, introducing methodological variability in estimating muscle size changes. From a clinical perspective, these findings have practical implications for both rehabilitation and athletic training. In rehabilitation settings, particularly following anterior cruciate ligament (ACL) injury, optimizing rectus femoris activation may be important for restoring quadriceps function and knee stability. Moderate hip flexion angles may therefore provide a more favorable biomechanical environment for quadriceps strengthening. In athletic populations, manipulation of seat angle may be used strategically to influence regional quadriceps development without necessarily affecting overall muscle hypertrophy. Moderate hip flexion angles (45–60°) should be used to achieve balanced quadriceps activation during resistance training. Excessive hip flexion should be avoided when the goal is to maximize rectus femoris involvement, as its contribution decreases at higher angles. Varying seat angle may be useful for influencing regional muscle development within the quadriceps rather than increasing overall muscle size. However, seat angle alone is not a primary driver of hypertrophy, and training variables such as load and volume remain the key determinants of muscle growth.

The present review also highlights important gaps in the literature. Few studies directly investigated long-term hypertrophic outcomes using standardized hip flexion protocols. Future randomized controlled trials should incorporate longer intervention periods, larger sample sizes, and advanced imaging techniques such as MRI to better characterize regional muscle adaptations. In addition, separate evaluation of rectus femoris and vasti responses may improve understanding of muscle-specific adaptations to altered biomechanics. Overall, the findings of this review suggest that hip flexion angle primarily influences quadriceps biomechanics and regional muscle recruitment rather than total quadriceps hypertrophy. Moderate hip flexion angles appear to optimize rectus femoris activation and torque production, whereas excessive hip flexion reduces mechanical efficiency without substantially altering total muscle growth.

## CONCLUSION

Hip flexion angle significantly influences quadriceps biomechanics, particularly rectus femoris activation and torque production during resistance exercise. Moderate hip flexion angles (45–60°) appear to provide the most favorable conditions for balanced quadriceps activation and force generation, whereas excessive hip flexion reduces rectus femoris contribution and mechanical efficiency. Despite these biomechanical differences, current evidence indicates no substantial effect of hip flexion angle

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on overall quadriceps hypertrophy. The primary adaptations appear to be regional rather than global, with the rectus femoris demonstrating greater sensitivity to hip position than the vasti muscles. Further high-quality longitudinal studies are required to clarify the long-term hypertrophic implications of seat angle manipulation during resistance training.

## LIMITATIONS

This review has several limitations. The number of longitudinal studies directly assessing hypertrophy was limited, restricting the strength of conclusions related to muscle growth. Sample sizes across included studies were generally small, which may affect statistical power and generalizability. There was also a lack of standardized measurement of hip flexion angles, making comparisons across studies less consistent. In addition, many studies relied heavily on electromyographic (EMG) data rather than direct measures of hypertrophy, limiting interpretation of long-term adaptations. Finally, most intervention durations were relatively short (≤12 weeks), which may not be sufficient to detect subtle differences in muscle hypertrophy.

## FUTURE DIRECTIONS

Future research should focus on conducting randomized controlled trials with longer intervention durations (>12 weeks) to better evaluate hypertrophic adaptations. The use of MRI-based measurements is recommended to accurately assess regional muscle growth. Standardization of hip flexion angles across study protocols would improve comparability of findings. Further investigations should examine rectus femoris and vasti muscle adaptations separately to better understand regional responses. In addition, exploring the effects of hip flexion angle in clinical populations, such as individuals undergoing anterior cruciate ligament (ACL) rehabilitation, would enhance the clinical relevance of this area.

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