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THE ROLE OF THERAPEUTIC EXERCISE IN KNEE JOINT CREPITUS DURING SQUATTING: A NARRATIVE REVIEW OF BIOMECHANICAL AND BEHAVIORAL FACTORS

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ABSTRACT

Background: Knee joint crepitus frequently occurs during functional activities such as squatting and is commonly reported by individuals with patellofemoral pain syndrome (PFPS). Although often considered a benign phenomenon, knee crepitus may influence movement-related beliefs, confidence, and activity participation. Therapeutic exercise represents a cornerstone of conservative PFPS management; however, its potential role in modifying knee joint crepitus and related movement behaviors remains insufficiently synthesized.
Aim: To narratively review and synthesize current evidence regarding the potential effects of therapeutic exercise on knee joint crepitus during squatting, with particular consideration of biomechanical, neuromuscular, and psychosocial factors.
Methods: A structured literature search was conducted in PubMed and Google Scholar for studies published up to February 2025. Randomized controlled trials, cohort studies, systematic reviews, and biomechanical analyses evaluating exercise-based interventions in PFPS populations were included. Given heterogeneity in study design and outcome measures, a narrative review methodology was adopted.
Results: Exercise-based interventions consistently improved pain, function, and lower limb biomechanics in individuals with PFPS, a population in which knee crepitus is commonly reported. Hip and quadriceps strengthening combined with neuromuscular training improved movement control, reduced dynamic knee valgus, and optimized patellofemoral joint loading during squatting. Although knee crepitus was rarely assessed directly, these adaptations may influence mechanical and perceptual contributors to joint sound generation and movement confidence.
Conclusions: Therapeutic exercise improves clinically meaningful outcomes in individuals reporting knee crepitus during squatting. While crepitus alone is not a reliable indicator of structural pathology, addressing it through exercise and patient education may reduce fear-avoidance behaviors and enhance functional participation. Further studies employing objective measures of knee joint crepitus are required to clarify direct intervention effects.

KEYWORDS

Knee Crepitus, Patellofemoral Pain, Therapeutic Exercise, Hip and Quadriceps Strengthening, Squat Biomechanics

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1. Introduction

Knee joint crepitus—commonly described as popping, grinding, cracking, or clicking—is a frequently observed phenomenon during knee flexion and extension, particularly during functional movements such as squatting. In many individuals, knee crepitus is considered a physiological and benign finding; however, accumulating evidence suggests that in certain populations it may coexist with, or result from, altered patellofemoral mechanics, muscle imbalances, or increased joint loading.(Alba-Martín et al. 2015, Waiteman,et al. 2021)

Among knee disorders, patellofemoral pain syndrome (PFPS) is one of the most prevalent conditions affecting young and physically active adults. PFPS is characterized by anterior or peripatellar knee pain that is typically exacerbated during activities involving loaded knee flexion, including squatting, stair ambulation, running, jumping, or prolonged sitting. (4) Importantly, knee joint crepitus and sensations of clicking, popping, or abnormal joint movement are commonly reported by individuals with PFPS. (3)

Therapeutic exercise—encompassing quadriceps strengthening, hip abductor and external rotator strengthening, neuromuscular training, and movement retraining—is widely recognized as a first-line conservative intervention for PFPS. A substantial body of evidence demonstrates that exercise-based rehabilitation improves pain, function, and muscle strength in this population. In particular, combined strengthening of the knee extensors and hip musculature appears to be more effective than isolated knee-

focused programs, likely due to improved proximal control, optimized patellar tracking, and reduced abnormal joint stress. (5)

Despite this growing body of evidence, the literature lacks a focused synthesis evaluating whether therapeutic exercise specifically influences knee joint crepitus during functional tasks such as squatting. Most studies prioritize pain intensity, functional outcomes, muscle strength, or kinematic variables, while crepitus is rarely examined as a primary outcome. This gap limits our understanding of whether exercise-based rehabilitation can modify the mechanical or neuromuscular factors underlying audible or palpable knee joint sounds.

Therefore, the aim of this narrative review is to summarize and critically evaluate the current evidence regarding the role of therapeutic exercise—particularly hip and knee strengthening and movement retraining—in reducing knee joint crepitus in individuals performing squats. By addressing this topic, the review seeks to clarify whether exercise interventions, beyond alleviating pain and improving function, may influence joint sound phenomena and thereby contribute to more comprehensive rehabilitation strategies.

2. Methods

A structured literature search was conducted to identify scientific publications examining the relationship between therapeutic exercise and knee joint crepitus, with particular emphasis on individuals performing squatting movements. The search was performed using the electronic databases PubMed and Google Scholar and included all relevant publications available up to February 2025.

The search strategy incorporated a combination of free-text keywords and Medical Subject Headings (MeSH). Primary keywords included: “knee crepitus,” “patellofemoral pain,” “knee joint sounds,” “squat biomechanics,” “exercise therapy,” “hip strengthening,” “quadriceps strengthening,” and “movement retraining.” Additionally, the following MeSH terms were applied when appropriate: “Knee Joint,” “Patellofemoral Pain Syndrome,” “Exercise Therapy,” and “Biomechanics.”

Boolean operators (AND, OR) were used to enhance search sensitivity and specificity. Reference lists of eligible articles were also screened to identify additional relevant studies.

Studies were included if they: investigated knee joint crepitus, patellofemoral pain, or biomechanical aspects of squatting, evaluated therapeutic or exercise-based rehabilitation interventions, included randomized controlled trials (RCTs), cohort studies, systematic reviews, or biomechanical analyses, were published in peer-reviewed journals, were written in English.

Studies were excluded if they: focused exclusively on knee crepitus associated with advanced knee osteoarthritis, investigated non–exercise-based interventions (e.g., surgery, injections, pharmacological treatments), were case reports, expert opinions, or conference abstracts without full-text availability.

Titles and abstracts were screened for relevance, followed by full-text review of eligible articles. Approximately 10–15 high-quality studies were selected for qualitative synthesis based on methodological rigor, relevance, and contribution to understanding the biomechanical, neuromuscular, and behavioral effects of therapeutic exercise in populations reporting knee crepitus or patellofemoral pain. Owing to heterogeneity in study designs, intervention protocols, and outcome measures, a narrative review approach was employed, with an emphasis on clinical interpretation and theoretical integration rather than quantitative synthesis.

3. Results

The reviewed literature identified several consistent and clinically relevant themes regarding the effects of therapeutic exercise on pain, function, and biomechanical parameters in individuals with patellofemoral pain syndrome (PFPS), a condition frequently accompanied by knee joint crepitus during squatting and other activities involving loaded knee flexion.

Multiple systematic reviews and clinical trials demonstrate that exercise programs targeting the hip and knee musculature effectively reduce pain and improve function in individuals with PFPS. Strengthening interventions focusing on the hip abductors and external rotators are associated with significant reductions in pain intensity and improvements in functional performance. Similar benefits have been reported for multimodal programs combining hip and knee strengthening with neuromuscular training, which are particularly relevant for functional tasks such as squatting. (Alba-Martín et al. 2015)

More recent meta-analytic evidence indicates that combined hip and knee strengthening programs are more effective than knee-focused programs alone. Halabi et al. (2025) reported that interventions integrating strengthening of the hip abductors and external rotators with quadriceps training lead to greater pain reduction and superior functional improvement compared with isolated knee strengthening. These findings are

particularly relevant to squatting, which places substantial mechanical demands on both the hip and patellofemoral joints.

Although knee crepitus was rarely assessed as a primary outcome, several studies have demonstrated its high prevalence in PFPS populations. de Oliveira Silva et al. (2018) showed that knee crepitus is common in women with PFPS, although it is not directly associated with pain intensity, physical activity level, or functional status. This suggests that crepitus represents a phenomenon that may coexist with PFPS but is not necessarily a marker of symptom severity. Complementary findings were reported by Couch et al. (2025), whose systematic review and meta-analysis demonstrated that knee crepitus is prevalent across both symptomatic and asymptomatic populations and is not consistently associated with structural pathology. These observations reinforce the concept that crepitus alone is not a reliable indicator of joint damage but remains clinically relevant due to its impact on patient perception and movement behaviour.

Kinematic studies further highlight the relationship between knee crepitus, PFPS, and altered movement patterns. Waiteman et al. (2021) found that women with PFPS and knee crepitus exhibited reduced knee flexion angles during stair ascent, suggesting a protective or avoidance strategy that may increase joint loading elsewhere in the kinetic chain. Similarly, Pazzinatto et al. (2018) demonstrated that women with PFPS and knee crepitus display distinct kinematic alterations during stair ascent and descent, including changes in knee and hip motion that may reflect impaired movement control and altered patellofemoral joint mechanics.

Biomechanical investigations emphasize the role of altered lower limb alignment and muscle activation patterns in increasing patellofemoral joint stress during squatting. Straub and Powers (2024) reported that insufficient hip control, excessive femoral internal rotation, and dynamic knee valgus substantially increase patellofemoral joint compressive forces. Such biomechanical conditions are hypothesized to contribute not only to pain development but also to irregular joint surface contact and soft tissue interactions that may underlie knee joint crepitus.

The importance of hip biomechanics in PFPS is further supported by a systematic review and meta-analysis by Xie et al. (2022), which demonstrated that individuals with PFPS exhibit increased hip adduction and internal rotation during functional tasks. Strengthening of the gluteus medius and gluteus maximus improves femoral control, reduces dynamic valgus, and optimizes patellar tracking, thereby potentially modifying mechanical contributors to both patellofemoral pain and joint sound generation.

Randomized controlled trials comparing hip-focused and knee-focused strengthening programs confirm that both approaches improve muscle strength and movement patterns. Saad et al. (2018) found that hip strengthening was at least as effective as quadriceps strengthening in reducing pain and improving function in women with PFPS, with additional benefits in dynamic knee alignment. These findings support a combined proximal and local approach to rehabilitation, particularly for activities such as squatting that require coordinated control of the entire lower limb.

Interventions incorporating neuromuscular retraining and movement re-education have also shown beneficial effects on movement quality. Manickaraj (2018) reported that squatting re-education emphasizing lumbo-pelvic-thigh muscle co-contraction improved functional performance in individuals with PFPS. Although this was a case presentation, it provides clinically relevant evidence that modifying squat technique and enhancing neuromuscular coordination may influence mechanical factors associated with patellofemoral joint loading and potentially with knee crepitus.

Clinical guidelines and expert consensus further support exercise-based rehabilitation as the foundation of PFPS management. Barton et al. (2015) emphasized that best-practice conservative treatment should include targeted strengthening, movement retraining, and patient education. Similarly, the international consensus statement by Crossley et al. (2016) highlighted the importance of individualized exercise therapy focusing on hip and knee musculature, combined with education and load management strategies. Although neither guideline directly addresses crepitus as a primary outcome, both recognize the importance of addressing biomechanical and neuromuscular deficits that may contribute to abnormal joint mechanics and patient concern regarding knee sounds.

Overall, the evidence consistently supports the effectiveness of therapeutic exercise in improving pain, functional performance, and lower limb biomechanics in individuals with PFPS. However, direct evidence quantifying changes in knee joint crepitus following exercise interventions remains limited. Most available studies infer potential effects on crepitus indirectly through improvements in kinematics, muscle strength, and patellofemoral joint loading parameters.

This highlights a significant gap in the literature and underscores the need for future randomized controlled trials that:

- include standardized and objective methods for assessing knee joint crepitus,
- evaluate changes in crepitus alongside clinical and biomechanical outcomes,
- investigate whether improvements in squat biomechanics translate into measurable reductions in the frequency or intensity of joint sounds.

Such studies would strengthen the mechanistic link between therapeutic exercise and knee joint crepitus and provide more precise clinical guidance for the management of patients who report audible or palpable knee sounds during functional activities.

4. Discussion

From a broader health and social functioning perspective, knee joint crepitus represents not only a biomechanical phenomenon but also a perceptual and behavioral factor that may influence how individuals engage in physical activity. Audible or palpable joint sounds during squatting are frequently interpreted by patients as signs of joint damage, potentially leading to fear-avoidance behaviors, altered movement strategies, and reduced participation in occupational, recreational, or exercise-related activities. Within this context, therapeutic exercise may play a dual role by addressing both mechanical contributors to patellofemoral joint loading and psychosocial factors related to movement confidence and symptom interpretation.

This narrative review aimed to synthesize and critically appraise the current evidence regarding the role of therapeutic exercise in reducing knee joint crepitus during squatting, with particular emphasis on individuals presenting with patellofemoral pain syndrome (PFPS). Although the direct assessment of knee crepitus as a primary outcome remains limited within the existing literature, the accumulated body of evidence suggests that exercise-based rehabilitation exerts a favorable influence on a range of clinical, biomechanical, and neuromuscular parameters that are commonly associated with both the generation and perception of knee joint sounds. From an evidence-based medicine (EBM) perspective, these findings reinforce the concept that knee crepitus should be interpreted within a multifactorial framework that integrates structural, biomechanical, neuromuscular, and psychosocial contributors, rather than being viewed as an isolated indicator of joint pathology or treatment failure.

Therapeutic exercise has consistently demonstrated efficacy in reducing pain and improving functional outcomes in individuals with PFPS, as supported by multiple systematic reviews, meta-analyses, and randomized controlled trials. These improvements are observed across a wide range of exercise interventions, including hip and quadriceps strengthening, neuromuscular training, and movement retraining strategies. While knee crepitus alone is not considered a reliable marker of underlying structural pathology, its presence frequently contributes to heightened patient concern, fear of movement, and activity avoidance. Such psychosocial responses are clinically relevant, as they may negatively influence rehabilitation adherence, alter movement strategies, and ultimately compromise long-term functional recovery. Consequently, addressing knee crepitus as a symptom of patient concern—despite its weak association with tissue damage—is clinically justified within a patient-centered rehabilitation framework. Improvements in pain and functional capacity achieved through therapeutic exercise may positively modify patients' interpretation of joint sounds, reduce symptom-related distress, and enhance confidence during functional activities such as squatting.

From a mechanistic standpoint, therapeutic exercise is likely to influence knee joint crepitus indirectly by modifying key biomechanical and neuromuscular factors implicated in patellofemoral joint loading. Strengthening of the hip abductors and external rotators plays a central role in controlling excessive femoral internal rotation and hip adduction, movement patterns frequently observed in individuals with PFPS during weight-bearing tasks. These proximal adaptations contribute to improved frontal and transverse plane knee alignment, thereby reducing dynamic knee valgus during squatting and other functional activities. Improved lower limb alignment is associated with more optimal patellar tracking and a reduction in abnormal patellofemoral joint stress, which may decrease irregular joint surface contact, frictional forces, and aberrant soft tissue interactions that are hypothesized to contribute to the generation of audible or palpable knee joint sounds.

Quadriceps strengthening further enhances dynamic stabilization of the patella by improving force transmission through the extensor mechanism and promoting more uniform load distribution across the patellofemoral joint. Enhanced quadriceps function may also facilitate smoother knee flexion–extension patterns during squatting, potentially reducing abrupt changes in joint contact forces. In addition, neuromuscular retraining strategies, including movement re-education and technique modification during squatting, aim to improve motor control, coordination, and timing of muscle activation. These adaptations may

lead to more controlled joint motion, improved shock absorption, and increased movement efficiency. Collectively, such changes are consistent with contemporary biomechanical models of patellofemoral joint loading and provide a plausible mechanistic basis through which therapeutic exercise may indirectly influence knee crepitus, even in the absence of direct structural change.

Importantly, clinical improvements in pain and function frequently occur even when knee crepitus persists. This observation reinforces the notion that crepitus should not be interpreted as a direct surrogate marker for disease progression, biomechanical dysfunction, or treatment ineffectiveness. Instead, knee crepitus should be contextualized alongside clinically meaningful outcomes such as pain intensity, functional capacity, movement quality, and patient-reported measures of confidence and participation. From an EBM perspective, therapeutic decision-making should prioritize outcomes with established clinical relevance and prognostic value, while recognizing knee crepitus as a secondary phenomenon that is often benign and weakly associated with structural pathology.

From a clinical standpoint, the evidence supports the implementation of individualized, exercise-based rehabilitation programs for patients reporting knee crepitus during squatting, particularly when crepitus is accompanied by pain, functional limitation, or fear of movement. Rehabilitation programs should emphasize the correction of modifiable biomechanical deficits, enhancement of hip and knee muscle strength, and optimization of neuromuscular control during dynamic, task-specific movements. Rather than attempting to eliminate knee crepitus directly, clinicians should focus on improving movement efficiency and joint loading patterns, thereby addressing the underlying contributors to both symptomatic presentation and dysfunctional biomechanics.

Patient education emerges as a critical component of effective management. Providing clear, evidence-based explanations regarding the generally benign nature of knee crepitus and its limited association with structural damage may help reduce fear-avoidance behaviors and catastrophic interpretations of joint sounds. Reassurance, when combined with a structured and progressive exercise program, has the potential to enhance patient engagement, improve adherence to rehabilitation protocols, and support sustained functional recovery. This approach aligns with contemporary biopsychosocial models of musculoskeletal rehabilitation, which emphasize the integration of physical, psychological, and contextual factors in treatment planning.

Despite these promising clinical implications, several limitations within the current body of evidence must be acknowledged. The most prominent limitation is the scarcity of studies that directly quantify knee crepitus as a primary or secondary outcome following exercise-based interventions. Furthermore, substantial heterogeneity exists across studies with respect to exercise protocols, intervention duration, training intensity, and outcome measures, limiting the comparability and generalizability of findings. The predominantly subjective nature of crepitus assessment further complicates interpretation, as individual perception of joint sounds may vary widely and be influenced by psychological and contextual factors.

Future research should prioritize the development and validation of standardized, objective methods for assessing knee joint sounds, such as acoustic emission analysis or vibration-based measurement tools, used in conjunction with validated patient-reported outcome measures. Well-designed randomized controlled trials are needed to determine whether targeted exercise interventions can directly influence the frequency, intensity, or perception of knee crepitus during functional tasks such as squatting. Integrating biomechanical, clinical, and psychosocial outcomes within a unified research framework would provide a more comprehensive understanding of the mechanisms through which therapeutic exercise impacts knee joint function and symptom perception.

In conclusion, while direct evidence linking therapeutic exercise to reductions in knee joint crepitus remains limited, the available EBM strongly supports exercise-based rehabilitation as an effective strategy for improving pain, function, and biomechanical efficiency in individuals with PFPS. These improvements likely create a joint environment that is less conducive to the mechanical and perceptual factors associated with knee crepitus, thereby indirectly addressing this clinically relevant but often misunderstood symptom.

5. Conclusions

Therapeutic exercise plays a central and well-supported role in improving pain, physical function, movement confidence, and lower limb biomechanics in individuals experiencing knee joint crepitus during squatting, particularly within the context of patellofemoral pain syndrome (PFPS). Although knee crepitus is infrequently evaluated as a primary outcome measure in intervention studies, a consistent body of evidence from randomized controlled trials, systematic reviews, and biomechanical investigations demonstrates that strengthening of the hip and quadriceps musculature, when combined with neuromuscular training and

movement retraining, favorably modifies key factors associated with patellofemoral joint loading, alignment, and dynamic stability during functional tasks. These adaptations contribute to improved movement quality and more efficient load distribution across the patellofemoral joint, which may indirectly influence the mechanical conditions underlying the generation and perception of knee joint sounds.

Importantly, knee crepitus in isolation is not indicative of structural joint pathology nor a reliable marker of disease severity or progression. However, the presence of audible or palpable knee joint sounds frequently influences patient beliefs, fear of movement, and activity-related confidence. Addressing these concerns through evidence-based patient education, reassurance, and individualized exercise-based rehabilitation may reduce maladaptive movement strategies, limit fear-avoidance behaviors, and support sustained engagement in physical activity. By targeting modifiable biomechanical and neuromuscular deficits rather than attempting to eliminate crepitus directly, clinicians can prioritize clinically meaningful outcomes such as pain reduction, functional improvement, and participation in daily and sporting activities.

Despite the favorable clinical implications of exercise-based rehabilitation, significant gaps remain within the current evidence base. In particular, there is a need for high-quality research employing standardized and objective methods for the assessment of knee joint crepitus, including acoustic or vibration-based measurement techniques, alongside validated patient-reported outcome measures. Future well-designed randomized controlled trials should aim to determine whether specific exercise parameters, intervention dosages, or movement retraining strategies can directly influence the frequency, intensity, or perceptual impact of knee joint sounds during squatting. Such research would enhance mechanistic understanding, strengthen the evidence base, and inform the development of more precise, evidence-based clinical guidelines for the management of individuals who report knee crepitus during functional activities.

Disclosure

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