

Comprehensive Rehabilitation Strategies for Knee Joint Contractures: A Review of Contemporary Trends and Evidence

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Abstract This review summarizes research published over the past five years demonstrating the high efficacy of a multidisciplinary approach in restoring knee joint function in patients with contractures. Background: Knee joint contractures are common complications following injuries, surgical interventions, and inflammatory musculoskeletal disorders, leading to pain, reduced range of motion, and diminished quality of life. Methods: A systematized analysis of the literature was conducted, focusing on rehabilitation methods that include therapeutic exercise, mechanotherapy, and physiotherapeutic interventions, with particular emphasis on staged recovery and a personalized approach to patient management. Results: Early and comprehensive application of therapeutic exercise, mechanotherapy, and physiotherapy was found to significantly improve knee joint mobility, reduce the risk of recurrent contractures, and enhance functional outcomes. The most pronounced therapeutic effects were observed in multidisciplinary programs integrating medical, kinesiotherapeutic, and physiotherapeutic strategies. Conclusion: Current evidence demonstrates that early, personalized, and multimodal rehabilitation strategies are the most effective for managing knee joint contractures, leading to superior functional recovery and improved patient quality of life.

Keywords Review, Knee joint contracture, Rehabilitation strategies, Range of motion restoration, Mechanotherapy, Physiotherapy, Therapeutic exercise

1. Introduction

Knee joint contractures are a frequent and clinically significant complication arising from injuries, surgical interventions, or inflammatory musculoskeletal conditions. They lead to restricted joint mobility, altered biomechanics, pain, and impaired functional capacity, significantly affecting patients' quality of life. Despite advances in surgical and medical management, contractures remain a persistent challenge, highlighting the need for effective rehabilitation strategies.

Over the past decade, multiple therapeutic approaches including physical therapy, mechanotherapy, massage, and physiotherapeutic procedures have been explored to restore joint function. However, the optimal combination of interventions, timing, and individualized protocols remains a topic of ongoing investigation. Recent evidence suggests that early and multidisciplinary rehabilitation may improve

outcomes, prevent recurrence, and enhance patient quality of life.

This review aims to summarize and critically analyze current methods for the rehabilitation of knee joint contractures of various etiologies, highlighting evidence-based strategies, stages of rehabilitation, and the importance of individualized, multidisciplinary approaches.

2. Methods

A comprehensive literature search was conducted to identify studies on the rehabilitation of knee joint contractures. Electronic databases, including PubMed, Scopus, Web of Science, and Google Scholar, were searched for articles published over the last five years. Keywords used in the search included "knee joint contracture," "rehabilitation," "physical therapy," "mechanotherapy," "massage," "physiotherapy," and "multidisciplinary approach."

Inclusion criteria comprised original research studies, clinical trials, systematic reviews, and meta-analyses focusing on rehabilitation strategies for knee joint contractures of various etiologies.

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Selected studies were analyzed to extract information on rehabilitation methods, stages of treatment, timing and intensity of interventions, and patient outcomes. Data were synthesized to highlight current evidence-based approaches, the effectiveness of multidisciplinary strategies, and gaps in knowledge requiring further research.

3. Results

The knee joint is one of the most load-bearing and structurally complex joints of the human body: it simultaneously provides body stability during support and high mobility during dynamic activities such as walking, running, and turning [72]. At the same time, the biomechanics of the knee joint are determined not only by the geometry of the articular surfaces and the axes of motion, but also by the dynamics of muscle activation, the coordination of stabilizing muscles, the function of fascial and capsular structures, as well as neuromuscular regulation, including the receptors within the ligaments [1]. When injury to key ligaments occurs or when the joint anatomy is altered, this leads to significant changes in kinematics and loading patterns, which may contribute to the development of movement limitations (contractures), overload of adjacent structures, and an increased risk of subsequent injuries [2]. Thus, for a correct understanding of contracture formation following anterior cruciate ligament (ACL) reconstruction and for the development of an effective rehabilitation strategy, it is essential to begin with a thorough analysis of the anatomical, physiological, and biomechanical foundations of knee joint function.

The (ACL) plays a central role in maintaining the stability of the knee joint. Anatomically, it is located within the intercondylar space of the tibia, attaching on one side to the tibial plateau and on the other to the lateral femoral condyle. Studies have shown that shortening or improper orientation of ACL fibers reduces its ability to resist anterior translation of the tibia and increases the risk of instability [4]. When the ACL is lost or damaged, significant kinematic disturbances occur: anterior translation of the tibia increases, loading on the menisci and articular cartilage intensifies, and the likelihood of developing joint instability and subsequent secondary changes rises [5]. Disruption of this system diminishes the ability of muscles and periarticular tissues to respond rapidly and adequately to external forces, further compromising stability and contributing to postoperative complications, including contracture formation [6]. If anatomical reconstruction is not fully restored to normal, even a technically successful surgery may lead to biomechanical disturbances, compensatory mechanisms, and a higher risk of complications [7].

Under normal conditions, during knee flexion, a rotation of the tibia relative to the femur occurs: at the initiation of movement from extension, the tibia rotates internally, followed by a gradual transition to external rotation or a posterior “femoral rollback” of the femur as the flexion angle increases [8]. Interestingly, studies of living, healthy knees have shown that the center of rotation is most often located on the lateral side of the joint during the stance phase of gait,

indicating the lateral pivot as a key element of normal knee kinematics [9]. Recent studies demonstrate that the properties of soft tissues their stiffness, elasticity, and pre-tension vary considerably among individuals and influence knee kinematics even in healthy joints [10]. A significant correlation has been identified between soft tissue tension or compliance (laxity) and patellar position, reflecting the impact of fascial and musculo-ligamentous elements on the trajectory of movement [11]. When soft tissue tension is impaired, this may lead to premature “locking” of the joint in a particular position or to excessive rotation, which in turn creates conditions for the development of contractures and accelerated joint wear [12]. In models with altered meniscal properties, a redistribution of loads, an increase in peak pressures, and changes in the axis of rotation have been observed, confirming the role of soft tissue structures in influencing knee joint biomechanics [13].

The first link in the chain of biomechanical alterations is the change in orientation and magnitude of anterior tibial translation loss of ACL control leads to increased displacement of the tibia relative to the femur under load, resulting in redistribution of internal joint forces [14]. In the absence of normal ACL function, the vector load transmitted through the joint ceases to be properly distributed. Under physiological conditions, the center of rotation shifts naturally during flexion and extension; however, after ACL injury, this mobility becomes limited or distorted: the axis of rotation may become “fixed” in one position or shift laterally or medially, thereby altering the trajectory of the menisci, articular surfaces, and capsuloligamentous structures [15]. It is also important to note the effect on the menisci. Following changes in kinematics due to ACL damage, the medial and lateral menisci begin to function under suboptimal conditions: the fixation of the axis is impaired, their displacement becomes restricted, and contact loading increases in specific areas, intensifying microtrauma and initiating fibroblastic reactions in the capsule and surrounding tissues. Such biomechanical overloads create a background for the development of mobility limitations, as tissues adapt to the new loading regime often in the direction of shortening and rigidity [16].

Musculofascial mechanisms. Experimental models show that a “myogenic” contracture develops as early as within the first two weeks of immobilization: the volume of muscle fibers decreases, interstitial fibrosis develops, and tissue elasticity is reduced [17]. For example, in a rat model of knee immobilization, an increase in the expression of TGF- β 1, p-Smad2/3, and α -SMA has been documented in muscles and musculofascial structures [18] all these markers are associated with tissue fibrosis. Capsular-ligamentous and articular mechanisms. In parallel with musculofascial alterations, transformations occur in intra-articular structures. The joint capsule, synovial membrane, and ligaments are exposed to hypoxic stress in the absence of movement, which activates the HIF-1 α \rightarrow NLRP3 \rightarrow caspase-1 \rightarrow GSDMD-N (pyroptosis) pathway and subsequently the TGF- β 1/Smad3 cascade, inducing capsular fibrosis and

reducing its elasticity [19]. In a rat model of knee immobilization, it was documented that the “myogenic” stage of contracture is replaced by an “arthrogenic” one after 2–4 weeks: the capsule becomes significantly thicker, collagen accumulation occurs, and pronounced fibrosis develops [20]. Neurogenic mechanisms. Following trauma or surgery, a condition known as Arthrogenic Muscle Inhibition (AMI) arises a reflex inhibition of activation of the extensor muscles (for example, *m. vastus medialis obliquus*), accompanied by a compensatory increase in the tone of the flexor or posterior group [21]. Over time, decreased activation of the quadriceps muscles and chronic shortening of the posterior capsule may consolidate the state of contracture, even when the initial cause has already been eliminated [22].

Knee joint contracture remains one of the most frequent and clinically significant complications following anterior cruciate ligament (ACL) reconstruction, substantially affecting limb function recovery and long-term treatment outcomes. According to modern research, the incidence of postoperative contracture varies from 2% to 35%, depending on the surgical technique used, the timing of mobilization, and the characteristics of the rehabilitation protocol [23].

Experimental studies have shown that movement restriction after ACL reconstruction triggers local activation of the TGF- β /Smad signaling pathway and promotes fibrotic transformation of the capsule and synovial membrane [24]. Additionally, individual biological factors play a significant role including the intensity of the inflammatory response, tendency toward hyperfibrosis, and hormonal or metabolic influences that affect tissue repair and remodeling. Other contributors include intra-articular hemorrhage and scar formation in the intercondylar notch region (Cyclops syndrome), which mechanically impede full knee extension [25]. Current evidence suggests that the optimal window for initiating early mobilization is within the first 7–14 days after surgery, provided that the graft fixation is stable [26]. On the other hand, imbalanced rehabilitation protocols, lack of neuromuscular activation of the quadriceps (especially the *m. quadriceps femoris*), and chronic pain syndromes contribute to the development of persistent pathological movement patterns, which further reinforce motion restriction and contracture formation [27].

Classification and clinical forms of contractures: For the proper selection of treatment strategy and prognosis, it is important to differentiate between the main clinical forms: muscular, fibrotic, arthrogenic, and mixed contractures. The muscular form is characterized by predominant involvement of the musculofascial component. The fibrotic form develops as a result of prolonged adaptation of soft tissue structures to movement restriction or inflammation. As noted in recent studies, fibrotic transformation may involve not only the joint capsule but also intra-articular folds, leading to a pronounced loss of both flexion and extension [28]. The arthrogenic form primarily involves intra-articular alterations: adhesion formation, synovial membrane scarring, posterior capsular thickening, and movement restriction due to

mechanical blockage (for example, cyclops-like syndrome) or incorrect positioning of the ACL graft [29]. These changes require not only physiotherapy but often surgical correction as well. The mixed form is the most common variant in clinical practice, where musculofascial, fibrotic, and intra-articular mechanisms coexist simultaneously. In addition, modern classifications suggest considering the severity of motion limitation, for example: mild — loss of $<10^\circ$ of extension or flexion $>120^\circ$; moderate — loss of $10\text{--}20^\circ$ or flexion between $90\text{--}120^\circ$; severe — loss of $>20^\circ$ or flexion $<90^\circ$ [30].

Biomechanical alterations in contracture: Studies indicate that in cases of contracture or following ACL reconstruction, the center of joint rotation (CJR) may shift laterally, medially, or in the anteroposterior direction, thereby altering the moment arm of the muscles, increasing contact pressure forces, and modifying the load transmission pathway across the joint [31]. When knee joint mobility is restricted, compensatory mechanisms are activated: the load on the hip joint, ankle joint, and the constitutional stabilizing muscles of the thigh and lower leg increases. These alterations not only lead to muscle fatigue and imbalance but also contribute to secondary pathologies such as fascial hypertrophy, fascial adhesions, and functional instability beyond the area of the primary lesion.

Diagnosis and assessment of contracture: An important marker is the alteration of passive and active range of motion, particularly the loss of full extension (“zero degrees”), which is associated with an increased risk of developing osteoarthritis [33]. These assessment methods enable quantitative evaluation of tissue changes and allow differentiation from simple muscular rigidity [34]. A study analyzing the six degrees of freedom of the knee joint after ACL reconstruction demonstrated that, even when the range of motion is restored, rotational and translational abnormalities of the tibia often persist, which may indicate underlying contracture-related changes or load redistribution [33].

Modern Approaches to Rehabilitation After ACL Reconstruction: The evolution of concepts regarding postoperative recovery has led to a shift from prolonged immobilization toward early mobilization, the use of neuromuscular stimulation, isokinetic training, and 3D motion control. These strategies have significantly reduced the incidence of contractures and improved functional outcomes [36].

Main stages of rehabilitation after ACL reconstruction. Modern rehabilitation protocols are structured according to a phase-based rather than a time-based approach, where progression to the next stage is determined by clinical and functional criteria rather than the number of weeks post-surgery [37]. The acute phase (0–2 weeks) focuses on pain and inflammation control, prevention of contracture, and restoration of full passive extension range of motion. The subacute phase (2–6 weeks) aims to restore active motion control, normalize gait, and gradually increase the range of motion to the physiological limit [38]. The recovery phase (6–12 weeks) involves rebuilding strength, flexibility, and

lower limb symmetry. The key criterion for progressing to full recovery is achieving at least 90% strength of the knee extensors and flexors compared to the contralateral limb, symmetry in landing mechanics, and absence of kinematic asymmetries during motion analysis [39].

The role of early mobilization and contracture prevention. Early mobilization after ACL reconstruction is considered a key element of the rehabilitation process, aimed at preventing contracture and preserving functional knee joint mobility. Numerous studies have demonstrated that prolonged immobilization leads to both structural and functional impairments [40]. It has been shown that restoring full knee extension during the early stages of rehabilitation is a predictor of reduced risk of arthrofibrosis and improved long-term functional outcomes [41]. At the same time, researchers emphasize the importance of strict individualization of loading parameters, depending on the graft type, fixation stability, and condition of the periarticular tissues [42].

Traditional Rehabilitation Methods. Traditional methods including kinesitherapy, manual therapy, physiotherapy, myostimulation, and hydro-kinesitherapy remain key components in restoring postoperative knee joint function [43]. Kinesitherapy serves as the main element of the recovery process, aimed at restoring range of motion, strength, and lower limb control [44]. Recent studies emphasize that the early inclusion of graded exercises focused on isometric contractions and closed kinetic chain movements accelerates functional recovery and reduces the risk of contracture development [45]. Manual therapy, including soft-tissue and joint mobilization techniques, targets the reduction of capsuloligamentous rigidity, decreases hypertonicity in synergistic muscles, and improves fascial gliding quality [46]. Several clinical reports have noted that combining manual therapy techniques with active exercises accelerates the achievement of full extension and promotes normalization of the knee joint movement axis [47]. Physiotherapy is traditionally used as an adjunctive method to reduce inflammation, pain, and edema. The most commonly applied modalities include low-frequency magnetotherapy, ultrasound therapy, laser therapy, and local cryotherapy [48]. However, recent systematic reviews highlight the necessity of personalizing physiotherapeutic interventions according to the stage of graft healing and the condition of soft tissues [49]. Myostimulation is employed as a preventive measure against quadriceps atrophy, particularly during the early postoperative period when active movements are limited [50]. Optimal stimulation parameters frequency 35–50 Hz and pulse modulation 300–400 μ s — ensure physiological activation without inducing excessive muscle fatigue [51]. Hydro-kinesitherapy is considered one of the safest and most physiologically favorable rehabilitation methods following ACL reconstruction [52]. Exercises in water not only facilitate gait correction and improve venous return but also accelerate tissue regeneration [53].

Limitations of traditional approaches from a biomechanical perspective: Standard rehabilitation protocols are often focused primarily on restoring range of motion and

muscle strength, but they insufficiently account for the dynamic axis of knee rotation and shifts in the center of rotation, which may lead to asymmetric loading of articular surfaces and redistribution of forces to adjacent joints [54], [55]. Secondly, many traditional techniques do not allow for quantitative control of three-dimensional kinematic parameters of movement [56]. Furthermore, while myostimulation and hydro-kinesitherapy have proven effective in restoring strength and range of motion, they do not always ensure optimal proprioceptive and sensorimotor activation of the knee extensors and stabilizers [57]. Physiotherapeutic modalities aimed at reducing pain and inflammation also have limitations their effects are often localized and fail to consider the interconnection between soft-tissue structures, the joint capsule, and the biomechanics of the entire lower limb [58]. Thus, the biomechanical limitations of traditional methods underscore the need to integrate modern technologies such as 3D motion analysis, robot-assisted therapy, and sensorimotor training to correct subtle kinematic disturbances and prevent contracture formation after ACL reconstruction [59].

Biomechanical technologies and innovations in contracture rehabilitation: Robotic kinesitherapy and exoskeletal systems enable precise control over range of motion, velocity, and applied force, thereby creating optimal conditions for safe loading of the graft and surrounding soft tissues [60]. The combination of visual and tactile feedback allows patients to adjust their movements in real time, reducing the risk of structural overload and accelerating the recovery of functional joint kinematics [61]. This integrative approach simultaneously targets muscle-fascial, capsular, and neurogenic components of contracture, minimizing the risk of chronicity [62]. Moreover, artificial intelligence-based technologies provide a personalized rehabilitation strategy that takes into account each patient's anatomical and physiological characteristics, graft condition, and biomechanical parameters [63].

Biomechanical Motion Analysis: Biomechanical motion analysis is a modern tool for quantitative assessment of functional impairments and rehabilitation efficacy following ACL reconstruction. Motion capture systems utilize optical or inertial sensors to record, with high precision, the position of markers placed on the bones and soft tissues of the patient during functional movements [64]. Motion capture is also applied to analyze knee extension dynamics in the early postoperative period, which is crucial for contracture prevention and optimization of graft loading [65]. This technique enables evaluation of load distribution between limbs, detection of excessive or insufficient torque moments in the knee joint, and identification of compensatory strategies that may contribute to secondary contracture formation or meniscal injury [66]. Recent studies demonstrate that the integration of gait analysis into rehabilitation protocols enhances the precision of exercise personalization and improves functional outcomes [67].

Use of Feedback Sensors: Review and empirical studies indicate that wearable devices enable quantitative monitoring

of the range of motion, gait symmetry, and load parameters, making them valuable tools for both clinical and home-based rehabilitation [68]. Evidence from randomized and controlled trials demonstrates that training with load-based or centrifugal feedback improves both strength and gait performance [69]. Recent studies show that modern IMU systems and “smart” knee braces exhibit good agreement with optical motion capture systems during walking and controlled movements; however, accuracy may decrease during high-speed or complex multi-segmental maneuvers [70]. Integration with telemedicine is also advancing—remote monitoring and software dashboards for physiotherapists are making therapy more accessible [71]. Several studies emphasize the need for hybrid approaches, combining objective sensor data with clinical assessment and individualized physiotherapy to achieve optimal rehabilitation outcomes.

4. Discussion

Knee joint contractures remain a significant challenge in clinical practice due to their high prevalence, multifactorial etiology, and profound impact on patients’ functional abilities and quality of life. The review of recent literature highlights that early intervention and individualized rehabilitation programs are critical for achieving optimal outcomes.

Physical therapy remains the cornerstone of treatment, with exercises targeting flexibility, strength, and range of motion. Mechanotherapy and physiotherapeutic procedures, including electrotherapy and hydrotherapy, complement traditional approaches by enhancing tissue remodeling and joint mobility. Massage contributes to pain reduction, improvement of circulation, and relaxation of periarticular tissues, supporting other rehabilitation modalities.

A consistent finding across studies is the importance of a multidisciplinary approach, involving physiotherapists, physicians, and sometimes occupational therapists. Such programs not only improve functional recovery but also reduce the risk of relapse and accelerate the return to daily activities. Evidence suggests that protocols tailored to the patient’s etiology, severity of contracture, and overall health status are more effective than standardized programs.

Despite progress, several challenges remain. There is a lack of large-scale randomized controlled trials directly comparing different rehabilitation strategies, and long-term follow-up data are limited. Additionally, optimal timing, intensity, and combination of interventions are still subjects of ongoing research. Future studies should focus on standardized protocols, patient-centered approaches, and the integration of novel technologies to enhance outcomes.

5. Conclusions

Contemporary evidence supports a comprehensive, individualized, and multidisciplinary approach for the rehabilitation of knee joint contractures. Early intervention, combined therapies, and ongoing evaluation of functional

outcomes are key elements for improving recovery and quality of life in affected patients. Physical therapy, mechanotherapy, massage, and physiotherapeutic procedures, when applied in combination, demonstrate the highest effectiveness in restoring joint function and preventing relapse.

Despite progress, further research is needed to establish standardized protocols, optimal timing, and intensity of interventions, as well as to evaluate long-term outcomes. Overall, a patient-centered and evidence-based approach remains the cornerstone of successful rehabilitation of knee joint contractures.

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