

From Stability to function: A Narrative Review of Neuromuscular Training Exercises for Osteoarthritis

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ABSTRACT

Background: Neuromuscular training is emerging as a component of knee osteoarthritis rehabilitation, targeting pain, balance, and functional limitations by improving sensorimotor control and muscle function. The existing evidences includes mechanistic overviews, feasibility studies, comparative trails, and systematic reviews. Nonetheless, there is still a lack of a cohesive narratives that integrates different viewpoints across the spectrum of osteoarthritis severity.

Objective: This narrative review synthesizes findings from 10 representative studies to clarify the role of neuromuscular training in knee osteoarthritis, outline its benefits and mechanisms and explore how it interacts with multimodal rehabilitation frameworks and, adjunctive strategies like psychosocial support.

Methods: A narrative synthesis was conducted of selected studies describing the benefits and mechanisms of exercise in knee osteoarthritis, feasibility and efficacy of individualized neuromuscular training programs, comparative effectiveness of neuromuscular training versus functional task training, systematic reviews and meta analyses of neuromuscular training on functional outcomes, and trials combining neuromuscular training with adjunctive modalities.

Results: narrative and comparative studies show that neuromuscular training is feasible and safe even in severe osteoarthritis, and that supervised programs in mild-moderate knee osteoarthritis result in clinically meaningful improvements in pain, balance, and functional performance. According to the systematic reviews and meta-analyses, neuromuscular training improves functional outcomes like balance, strength and enhanced gait patterns. Additionally, studies combining neuromuscular training with mindfulness, motivational interviewing, or blood-flow restriction therapy showed that these supplementary techniques can enhance pain, function, and psychological results.

Conclusion: the current evidence supports positioning neuromuscular training as a central, adaptable, and patient-centred intervention across the osteoarthritis continuum. Integration of neuromuscular training with multimodal frameworks and psychosocial or adjunctive modalities appears to optimize outcomes. The future research should clarify dose-response correlations, standardize neuromuscular protocols, and investigate long-term adherence and application in conventional clinical practice.

Keywords: neuromuscular exercises, multimodal rehabilitation, weight-bearing exercises, good health and well-being, sustainable health development

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INTRODUCTION

Neuromuscular training (NMT) has emerged as a targeted, evidence-based approach in improving sensorimotor control, joint stability, and functional performance by integrating strength, balance, proprioception, and task-specific movements. NMT is applicable in both clinical rehabilitation and athletic performance settings because, in contrast to generic exercise programs, it places an emphasis on quality of movement, joint-specific control, and neuromuscular adaptation.(1) In musculoskeletal rehabilitation, NMT has been increasingly applied to populations with knee and hip osteoarthritis (OA), where pain, impaired proprioception, and altered movement patterns contribute to functional decline and reduced quality of life. It also has been shown in sports science to improve muscular endurance, power, balance, and agility while lowering the likelihood of lower-extremity injuries.(1,2)

In knee OA, a spectrum of severity exists, ranging from mild-moderate in relatively active individuals to severe, end-stage OA in patients awaiting total joint replacement. Recent work with programs such as Neuromuscular exercises for knee OA (NEMEX-KOA) and neuromuscular exercises for total joint replacement (NEMEX-TJR) has demonstrated that individualized, goal-based neuromuscular exercise can be feasibly implemented even in patients with severe hip or knee OA, producing meaningful improvements in self-reported outcomes and physical function before surgery.(2,3) Shorter-term trials and case series in patients with mild-moderate knee OA have further indicated that structured 6–8 week, NMT programs can reduce pain, improve balance, and enhance functional performance, with high adherence and low adverse events. These findings suggest that NMT can be titrated to disease severity and functional capacity, supporting its role in both conservative management and pre-operative optimization.(3)

Parallel evidence from athletic populations highlights that neuromuscular training can significantly improve physical fitness components such as balance, agility, speed, muscular power, and endurance, with emerging benefits for injury prevention. Systematic reviews of NMT in sports report heterogeneous protocols, including plyometric drills, balance exercises, and sport-specific tasks, yet consistently demonstrate moderate to large effect sizes on key performance variables.(2,4) This body of work underscores that the underlying mechanisms, enhanced neuromuscular control, improved joint stability, and better movement efficiency are relevant not only to athletes seeking performance gains but also to patients with OA who need to restore safe and efficient movement.(4) Despite these advances, a cohesive narrative that bridges NMT across the continuum of knee and hip OA severity and extends into athletic performance remains limited. Existing studies range from feasibility trials in severe OA awaiting total joint replacement,

comparative studies of NMT versus functional-task training in knee OA, case series in mild-moderate knee OA, and systematic reviews in sports populations.(5) Synthesizing these works allows for a more integrated understanding of how individualized, neuromuscular-focused programs can be structured, progressed, and evaluated across different clinical and performance-oriented contexts.

This narrative review aims to synthesize and critically appraise evidence from a few studies to explore how individualized, goal-based neuromuscular training can be applied across different populations and OA severities, and how mechanisms of neuromuscular adaptation may bridge clinical rehabilitation and athletic performance, also identify knowledge gaps, and offer directions for future research and clinical translation.

METHODS

Search strategy: The search was guided by the Preferred Reporting Items for Systematic review and meta-analysis (PRISMA -RR) criteria in order to perform a quick evaluation. Finding relevant sources addressing sample size determination in educational research was the goal of the search strategy. In order to find more appropriate papers, researchers manually searched reference lists and citation tracking in addition to scanning databases like PubMed and Embase. The keywords for accessing the data from the databases related to neuromuscular training in osteoarthritis. To perform search effectively and refine search results, the search strings were constructed using BOOLEAN operator (AND, OR).

Inclusion and Exclusion criteria: Articles published between 2015 and 2026 were screened; free full-texts, unlocked articles, important terminology and information, and English language usage were required for inclusion of the data. Abstracts, locked articles and journals, articles that were not relevant to the date, publications written in languages other than English, duplicate articles, and articles that had nothing to do with determining sample size in educational research were also excluded.

Screening Process: authors independently screened the titles and abstracts of the articles to determine the eligibility of the included articles. The screening process involves reviewing the titles and abstracts of retrieved articles to assess their relevance to the research question.

S No.	Year	Author	Study Type	Objective	Methodology	Results	Remarks
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1.	2025	Emani et al.	Systematic Review and meta-analysis	To summarize the effects of neuromuscular training on functional outcome measures in patients with knee OA.	Systematic search of RCTs on NMT in knee OA; meta-analysis of functional outcomes such as balance, walking speed, stair negotiation and performance-based tests.	NMT significantly improved most functional outcome measures compared with control; effect sizes were moderate to large depending on the test.	Providing strong quantitative support for NMT as an effective intervention for functional recovery in knee OA.
2.	2025	Sazo-Rodriguez et al.	Systematic Review	To determine the effects of neuromuscular training (NMT) on improvements in disability, pain intensity, quality of life and balance in patients with knee osteoarthritis. Determine dose-response association between NMT and improvements in variables of interest in patients with knee OA.	10 RCTs were included. Random-effects meta-analysis was applied, and dose-response relationship was analysed through regression coefficients.	NMT is effective as other therapies in improving disability, pain intensity and quality of life in people with knee OA.	Optimal dose of NMT does not effectively strengthen the musculature.

3.	2025	Sorensen et al.	Secondary analysis of Randomised controlled trial	To compare blood-flow-restricted resistance exercise vs Neuromuscular exercise on mechanical muscle function in adults with chronic knee OA	Data from a main RCT were re-analysed; outcomes included muscle strength, power, and other mechanical measures after BFR-RE vs NMT programs.	BFR-RE improved certain strength/power parameters, whereas NMT enhanced neuromuscular control and balance-related measures; both improved muscle function but via different mechanisms.	Different training modalities like BFR-RE and NMT can be complementary in OA muscle function rehabilitation.
4.	2024	Chaharmahali et al.	Randomised controlled trial	To evaluate the effect of mindfulness and motivational interviewing plus neuromuscular exercise on pain, function, and balance in women with knee OA.	Women with knee OA were randomized to NMT plus mindfulness /MI counselling vs NMT alone; outcomes: pain, WOMAC, balance, and psychological measures.	Combined psychological and NMT intervention led to greater reductions in pain and functional limitation and better balance compared with NMT alone or control group.	Psychosocial components can enhance physical outcomes in NMT-based OA programs.
5.	2022	Akbar et al.	Systematic review	To assess impact of neuromuscular training (NT) on athletes' physical fitness in sports.	Literature search was conducted in databases such as EBSCOHOST, PubMed, WOS, Scopus, Science Direct, Google Scholar.	18 well-conducted systematic studies were included. Studies were reviewed and given score out of 6.	NMT helpful for improving physical functions

6.		2021	Kasani Ravi Teja et al.	Randomised control trial.	To compare the effectiveness of neuromuscular training and functional task training in subjects with knee osteoarthritis.	Comparative study; 68 patients with knee osteoarthritis randomly allocated into two groups (neuromuscular training vs functional task) for 8 weeks.	Neuromuscular training was more effective in improving strength and function than functional task training in patients with knee osteoarthritis.	Neuromuscular training is a successful treatment approach for improving strength and physical function in short term, hence enhances performance in long term.
7.	8	2020	Rashid et al.	Randomised Control Trial	To assess efficacy of NMT on pain, balance, and function in Grade I-II knee OA	Patient with mild-moderate Knee OA received supervised NMT vs traditional exercise protocol. Outcomes – VAS/ WOMAC, balance tests, functional scales.	NMT reduced pain and stiffness, improved balance and function along with improvement in gait.	NMT can be reinforced as effective early-stage conservative management.
8.		2018	Clausen B, Holsgaard-Larsen A, Roos EM	Randomised control trial.	To assess the one-year effectiveness and feasibility of a neuromuscular exercise program compared with instruction in analgesic use in patients with early/mild to moderate knee osteoarthritis.	Case-series type evaluation of a neuromuscular exercise program; 23 physically active patients with mild to moderate knee osteoarthritis; 10-week program, twice weekly; exercises with 3-4 difficulty levels and exertion from light	Neuromuscular exercise was feasible in patients with baseline mild to severe pain with activity; there were few clinically significant differences in pain and no unfavourable events, but jumping activities	Neuromuscular exercises work on pain gate mechanism and therefore reducing the osteoarthritis pain in an effective way.

					to very heavy.	were not feasible.	
9.	2017	Ganjave P., Dabholkar T	Randomised control trial	To assess and compare the effect of a conventional exercise program alone versus conventional exercise plus neuromuscular training in patients with Grade I-II knee osteoarthritis	Randomized allocation of 40 patients with unilateral Grade I-II Knee osteoarthritis into two groups; 12 sessions over 4 weeks; experimental group received conventional exercises plus neuromuscular training, control group conventional exercises only; assessments pre-treatment, at 2 weeks, and at 4 weeks.	Between-group analysis showed statistically greater improvement in strength, function and some balance components in experimental group than in conventional group.	Neuromuscular training program is effective in improving strength, pain and physical function. Addition of balance and kinaesthesia exercises improves in proprioception.
10.	2015	Allan Villadsen et al.	Randomised control trial	To evaluate the immediate efficacy of a neuromuscular exercise program in patients with clinically severe hip or knee osteoarthritis awaiting arthroplasty.	Randomized controlled trial; 165 patients (mean age about 67 years) with severe hip or knee osteoarthritis awaiting total joint replacement; 8-week supervised neuromuscular exercise (NEMEX-TJR) twice weekly for 1 hour, compared with control	Primary: HOOS (hip disability and osteoarthritis outcome score) and KOOS (knee injury and osteoarthritis outcome score); secondary: self-reported outcomes and functional performance tests.	Does not strengthen the muscles for long term

Benefits and mechanisms of exercise in knee OA

Narrative reviews on the benefits and mechanisms of exercise in knee OA highlight that structured programs improve pain, physical function, and quality of life. These improvements arise through multiple interacting pathways.(6) Increased muscle strength, particularly quadriceps and hip abductors, improved joint stability, enhanced sensorimotor control, and favourable biochemical changes in cartilage and synovial tissue. Additionally, exercise-induced reductions in systemic inflammation and body weight further attenuate mechanical and inflammatory stress on the joint.(5)

From a functional perspective, aerobic and resistance training can particularly compensate for OA-related muscle atrophy and altered gait patterns, leading to better walking endurance and stair negotiation. However, these generic exercise effects are often most pronounced when combined with task-specific and neuromuscular components that directly address balance, coordination, and movement strategy. This mechanistic foundation supports the inclusion of NMT as a core, rather than peripheral, element of exercise-based knee OA management.(6,7)

Feasibility and individualization of NMT in severe OA

Feasibility studies of the individualized goal-based NEMEX-TJR program in patients with severe hip or knee OA awaiting total joint replacement demonstrate that high-quality NMT can be safely delivered even in advanced disease. Participants engaged in supervised, graded sensorimotor, balance, and strength-based tasks tailored to individual goals and functional capacities. Pain after training sessions remained low to moderate, and joint-specific adverse events were infrequent, while training level could be progressively increased over time. These findings challenge the historical view that patients with severe OA are too compromised to tolerate structured, demanding exercise. Instead, they support a paradigm in which NMT serves as both a preparatory and palliative intervention, helping patients maintain or improve function while awaiting surgery. The emphasis on individualization and goal-setting in the NEMEX-TJR framework also aligns with modern patient-centred rehabilitation models, reinforcing the role of the physical therapist as a key facilitator of adaptation and progression.(3)

NMT as a core treatment for degenerative knee disease

The articles here, extend the feasibility evidence into broader clinical practice. By synthesizing randomized trials of strength, balance, and task-specific training, these works show that NMT consistently improves pain, balance, gait, and functional capacity across OA severity levels. These reviews suggest that neuromuscular training should be seen as a fundamental, evidence-based component of conservative management rather than as an optional ‘add-on’. This viewpoint is especially relevant to mild-to-moderate OA, when early planned neuromuscular

exercise programs may be able to slow the disease’s course, lessen its symptoms, and increase engagement in both work and leisure activities.(8)

Integrated frameworks: exercise, nutrition, and biomechanics

Exercise, diet, and biomechanics all are included in the integrated frameworks for knee OA rehabilitation. These frameworks acknowledge the wider context in which NMT functions, including weight control, use of footwear or orthotics, movement compensatory techniques, and psychological elements like adherence and self-efficacy. In these approaches, the physical therapist serves as a coordinator, who helps patient incorporate the exercises in patient’s daily life activities, develops functional goals and modifies the neuromuscular exercises according to each individual.(9)

Comparative effectiveness: NMT versus functional-task training

Comparative studies that contrast neuromuscular training with functional-task training in patients with knee OA provide insight into how different program designs affect outcomes. In these trials, participants allocated in the neuromuscular training group and those in functional task training, both showed improvement, but with distinct response patterns. Since NMT has a strong emphasis on coordination and joint control, it typically results in larger improvements in balance and several neuromuscular performance metrics. On the other hand, because functional task training closely resembles everyday movement demands, it frequently produces better improvements in particular ADL-related tasks. Together, these results imply that an ideal rehabilitation approach should combine functional task training for task-specific performance with Neuromuscular training for balance and neuromuscular control, for achieving individual goals.(10)

Efficacy of NMT in mild-moderate knee OA

Studies of neuromuscular training in patients with Grade I-II knee OA consistently demonstrate decrease in pain and stiffness, alongside improvements in balance and functional performance. Randomized controlled trials using supervised NMT programs report clinically meaningful changes in pain scales (e.g., VAS, WOMAC), balance tests and functional questionnaires, with additional improvements in gait parameters in some cohorts.(11)

An 8-week (neuromuscular exercise for knee OA (NEMEX) style program is feasible and well tolerated in physically active patients with mild-to-moderate knee OA, according to case series from registered clinical trials. Patients often report feeling more confidence about their daily activities, adverse events are few, and adherence rates are high. These findings support the early integration of neuromuscular training into conservative treatment plans, which may prevent functional decline and reduce long-term medical expenses.(9)

Systematic evidence for NMT and functional outcomes

The benefits of NMT for functional outcomes are quantitatively confirmed by systematic reviews and meta-

analysis that compile RCTs on the topic in knee OA. With moderate to large effect sizes depending on the test and population, these syntheses generally demonstrate that NMT considerably improves balance, walking speed, stair negotiation, and other performance-based measures when compared with control groups. The consistency of these findings across settings and protocols reinforces NMT as a robust, evidence-based intervention for functional recovery in knee OA. However, heterogeneity in program content, duration, and progression criteria highlights the need for greater standardization in reporting and for future dose-response studies to identify optimal exercise parameters.(12)

Adjunctive and complementary approaches

Recent trials and secondary analyses explored how NMT interacts with other modalities. A secondary analysis of a randomized controlled trial comparing blood-flow-restricted exercise (BFR-RE) with NMT found that both approaches improved mechanical muscle function in adults with chronic knee OA, but likely through different mechanisms. BFR-RE emphasized strength and power gains at lower absolute loads, whereas NMT focused on neuromuscular control and balance. This suggests that combining BFR-RE and NMT may offer synergistic benefits for muscle function and functional performance.(13) The incorporation of motivational interviewing and mindfulness to a neuromuscular training program in women with knee OA was investigated in another rater-blinded randomized study. The combined group outperformed those getting NMT alone in terms of pain and functional limitation reductions as well as improved balance, highlighting the possibility of psychosocial support to improve physical outcomes. These supplemental techniques demonstrate how NMT can be integrated into more comprehensive biopsychosocial rehabilitation models that address the psychological as well as the physical aspects of chronic pain.(11)

DISCUSSION

When considered collectively, the above studies present neuromuscular training as an adaptable, patient-centred, and evidence-based treatment for a variety of knee osteoarthritis conditions.(7) It is useful when incorporated into multimodal, physiotherapy-guided rehabilitation frameworks that include diet, biomechanical support, and psychosocial techniques.(11,14) It is also practical even in cases of severe OA awaiting surgery. According to comparative research, NMT is very effective for neuromuscular control and balance, while functional task training enhances it for task-specific performance.(10) There is limited high-quality evidence on long-term adherence to NMT, optimal dosing (frequency, intensity, progression), and the comparative effectiveness of NMT versus other advanced modalities (e.g., BFR-RE, virtual-reality-enhanced training) in defined subgroups of OA. Additionally, more research is needed on cost-effectiveness, implementation in primary care, and the role of digital tools in sustaining NMT over time.(2)

From a clinical perspective, the current body of evidence supports several practical recommendations. First, neuromuscular training should be offered early in the disease course, when patients are more likely to tolerate progressive, higher-intensity programs and when the potential to prevent functional decline is greatest. Second, programs should be individualized and goal-oriented, with progression based on pain, performance, and patient-reported goals rather than a fixed protocol.(5–7) Third, clinicians should consider combining NMT with functional-task training and, where appropriate, adjunctive methods such as BFR-RE or psychological support to maximize both physical and psychosocial outcomes. Researcher's main goal is to move beyond proof-of-concept studies to look at higher level issues like dose-response, subgroup differences and long term sustainability.(2,4,13)

Neuromuscular training programs have evolved from basic stability exercises toward ones that prioritize everyday function, leading to lasting gains in pain relief, movement ability, and overall life quality for people with osteoarthritis. This is in line with UN Sustainable Development Goal 3 on health and well-being, which aims to cut early deaths from non-communicable diseases (NCD) by a third through better prevention efforts, better treatments and mental health support. NMT's focus on simple, proven workouts helps make NCD care fairer for everyone, especially as osteoarthritis becomes more common in older groups around the world. Moving forward, the studies need to dig into ways to roll out these programs widely, despite limited funding and resources, to really push this goal ahead.(15)

Future research ought to focus on, enabling meaningful comparisons across trials, establish consistent NMT protocols including intensity, progression, and session organization, examine whether NMT interacts with other modalities in specific OA subgroups, such as BFR-RE, digital health technologies, and group-based versus individual training. Also, this protocol can be assessed for long-term adherence in primary care and hospital settings. Additionally, the implementation science- the best way to incorporate these evidence-based NMT programs into regular practice across various healthcare systems, socioeconomic circumstances, and cultural settings-needs more attention.

CONCLUSION

In conclusion, the research indicates that neuromuscular training is a versatile, secure, and successful strategy that may be included into more comprehensive, multimodal rehabilitation frameworks and tailored to individuals with knee OA of varying severity. Clinicians may advance forward to fully individualized, evidence-based OA care that addresses not just symptoms but also function, participation, and quality of life by combining NMT with functional-task training, adjuvant modalities, and psychosocial support.

List of Abbreviations

NMT	Neuromuscular Training
OA	Osteoarthritis
KOA	Knee Osteoarthritis
NEMEX-KOA	Neuromuscular exercises for Knee osteoarthritis
NEMEX-TJR	Neuromuscular exercises for Total joint replacement
BFR-RE	Blood Flow restriction- resistance exercise
NCD	Non-Communicable Disease

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Declaration of AI –During preparation of this review article, the authors used an AI-based tool only for grammar checking and language refinement, as none of the author's first language is English. No AI tools were used to generate content, interpret data, draft scientific arguments, or draw conclusions. All final content, interpretation and scholarly responsibility remain solely with the authors of this research.

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