REVIEW ARTICLE

CONTENTS

Exercise interventions for knee osteoarthritis: A narrative review of mechanisms, modalities, and clinical implementation

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ABSTRACT

Knee osteoarthritis (OA) is a chronic, multifactorial joint disorder involving cartilage degeneration, subchondral bone changes, synovial inflammation, and neuromuscular dysfunction. Exercise is first-line therapy, yet heterogeneity in modalities, dosing, and delivery limits practical guidance. A narrative review was conducted using PubMed, Scopus, Google Scholar, Frontiers, and ScienceDirect (2021–2026), focusing on aerobic, resistance, aquatic, and mind–body exercise studies. Data were extracted on type, intensity, frequency, duration, delivery, and outcomes, and synthesized narratively to provide clinically relevant insights. Exercise improves pain, function, and quality of life through enhanced muscle strength, joint stability, optimized loading, anti-inflammatory effects, and central pain modulation. Aerobic and resistance training enhance cardiovascular fitness, quadriceps and hip strength, and functional performance. Aquatic therapy reduces joint stress and improves adherence, while mind–body interventions support flexibility, balance, and stress reduction. Long-term, thrice-weekly protocols offer maximal benefit, and hybrid models combining supervised and home-based exercise optimize adherence and outcomes. Exercise is a cornerstone of knee osteoarthritis management. Individualized programs considering patient characteristics, modality-specific benefits, and delivery method are essential. Future research should refine exercise dosage, intensity, progression, and hybrid delivery strategies to maximize long-term clinical effectiveness.

KEY WORDS: exercise therapy, resistance training, aerobic exercise, aquatic therapy, mind-body interventions

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INTRODUCTION

Knee osteoarthritis (OA) is a chronic, progressive joint disorder characterized by structural and functional alterations involving articular cartilage, subchondral bone, synovium, and periarticular soft tissues. Rather than representing isolated cartilage "wear and tear," knee OA reflects a whole-joint pathology driven by the interaction of mechanical stress, low-grade inflammation, metabolic dysregulation, and neuromuscular dysfunction [1]. Pathological features include synovial activation, osteophyte formation, ligamentous remodeling, and progressive impairment of joint integrity, ultimately manifesting as pain, stiffness, and reduced mobility. Importantly, alterations in muscle strength and motor control contribute not only to symptom expression but also to abnormal joint loading patterns, providing a mechanistic basis for exercise-based interventions.

The development and clinical presentation of knee OA are influenced by multiple interacting factors, including aging, prior joint injury, repetitive mechanical loading, metabolic syndrome, and genetic predisposition [2]. These determinants shape both structural progression and symptom burden, which often do not correlate directly with radiographic severity. This discordance highlights the complex and multifactorial nature of pain generation in OA and underscores the need for comprehensive management strategies that extend beyond structural modification alone.

The global burden of knee OA continues to rise. In 2020, an estimated 595 million individuals worldwide were affected by osteoarthritis, with the knee representing the most frequently involved joint [3]. Knee OA ranks among the leading causes of years lived with disability and has demonstrated a marked increase in disability burden over recent decades. The condition commonly coexists with obesity, diabetes mellitus, and cardiovascular disease, establishing a bidirectional relationship in which reduced mobility exacerbates metabolic dysfunction, further amplifying functional

decline [4]. This convergence of musculoskeletal and systemic consequences underscores knee OA as both a clinical and public health priority.

Current pharmacological therapies primarily provide symptomatic relief and do not modify underlying disease progression. Topical nonsteroidal anti-inflammatory drugs (NSAIDs), such as diclofenac, are recommended as first-line pharmacologic treatment because of their lower systemic risk compared with oral agents. However, oral NSAIDs are associated with increased cardiovascular, gastrointestinal, and renal adverse effects, particularly in older adults with comorbidities [2, 5]. Consequently, long-term reliance on pharmacotherapy alone is insufficient for sustainable disease management.

Major international guidelines, including those from NICE and OARSI, consistently recommend exercise as first-line therapy for knee OA across age groups and disease severities. Exercise interventions encompass aerobic conditioning, resistance training, and mind–body modalities such as Tai Chi, aiming to enhance muscle strength, improve neuromuscular control, optimize joint loading, and reduce pain [5]. Despite the expanding body of literature, heterogeneity in study design, intervention protocols, and outcome measures limits clear clinical guidance.

AIM

The current review aims to synthesize and critically evaluate current evidence on exercise-based interventions in knee osteoarthritis, integrating mechanistic rationale, comparative effectiveness across modalities, and practical considerations related to implementation and long-term sustainability in clinical practice and clinical implementation.

MATERIALS AND METHODS

REVIEW DESIGN

This review employed a narrative design to synthesize current evidence on exercise-based interventions in knee osteoarthritis (OA). A narrative approach was chosen to integrate findings from randomized controlled trials, meta-analyses, and clinical guidelines, allowing a clinically oriented synthesis across various exercise modalities, including aerobic, resistance, aquatic, and mind–body interventions. This design was preferred due to heterogeneity in study designs, outcomes, and exercise protocols, which precluded quantitative meta-analysis, while still enabling thematic integration of evidence relevant to clinical practice. As a purely narrative review, formal risk-of-bias assessment was not performed, consistent with the narrative design. Measures to minimize bias included multi-database searching, clear eligibility criteria, and iterative selection based on relevance. The findings are intended to summarize and interpret trends in evidence rather than provide pooled effect sizes.

LITERATURE SEARCH AND DATABASES

A literature search was conducted in PubMed as the primary database, with supplementary searches in Scopus, Google Scholar, Frontiers, and ScienceDirect to ensure comprehensive coverage. The search focused on publications from January 2021 to February 2026, covering studies that evaluated exercise interventions for knee OA. Each author independently conducted searches within their assigned exercise domain, followed by collaborative discussion to resolve overlap and finalize inclusion.

STUDY SELECTION

Given the narrative design, no formal title or abstract screening process was employed. Instead, studies were iteratively reviewed for relevance, clinical applicability, and alignment with the aims of the review. Selection prioritized high-quality and representative studies while excluding preclinical research, non-English publications, case reports, and studies unrelated to exercise-based interventions.

DATA EXTRACTION AND SYNTHESIS

From each included study, key information was extracted, including study design, population characteristics, exercise type, duration, frequency, intensity, and primary outcomes. Data were synthesized narratively, integrating findings across exercise modalities and clinical contexts to highlight clinically relevant evidence, practical applications, and gaps in current knowledge. No statistical pooling or meta-analysis was performed.

SCOPE AND STUDY INCLUSION

A total of 33 studies were included in the review, encompassing randomized controlled trials, meta-analyses, and clinical guidelines. This sample was considered sufficient to provide a balanced synthesis of current evidence while maintaining focus on clinically meaningful interventions. Figure 1 illustrates a flowchart outlining the process used for selecting articles included in this review.

REVIEW AND DISCUSSION

MECHANISTIC RATIONALE FOR EXERCISE IN KNEE OSTEOARTHRITIS

Exercise is recommended as a first-line therapy in knee osteoarthritis (OA) because it targets key biomechanical, physiological, and neuromodulatory factors that contribute to pain and functional limitation. Rather than acting through a single mechanism, exercise produces integrated benefits that improve joint stability, optimize loading, reduce low-grade inflammation, and modulate pain perception.

MUSCLE STRENGTHENING AND JOINT STABILITY

Quadriceps weakness is a hallmark characteristic in people with knee OA and is strongly associated with impaired physical function and altered joint mechanics. Strength deficits reduce dynamic support during weight-bearing activities such as walking, stair climbing, and standing from sitting, contributing to uneven joint loading and increased symptomatic burden. Structured resistance training enhances muscle force production and neuromuscular control, thereby improving joint stability and lowering mechanical stress at the knee.

A recent narrative review reported that strengthening exercises improve quadriceps and hip muscle performance and are consistently associated with reduced pain and improved physical function in knee OA patients. Improvements in muscle strength translate into better shock absorption and more balanced load distribution across articular surfaces [6].

REDUCTION IN JOINT LOADING AND BIOMECHANICAL OPTIMIZATION

Mechanical loading contributes significantly to symptom expression in knee OA. Excessive joint contact forces, particularly in the medial compartment, are linked to pain and functional decline. Exercise improves load management through enhanced muscular support and improved movement patterns.

Low-impact aerobic activities such as cycling and controlled walking reduce joint compressive forces while enhancing cardiovascular fitness and lower-limb endurance. A scoping review confirmed that aerobic and strengthening exercises improve pain and functional performance without adverse structural outcomes [7].

Weight reduction achieved through exercise also contributes to reduced joint load per step. Clinical studies integrating exercise with behavioral lifestyle modification demonstrate meaningful reductions in pain and mechanical stress, highlighting the combined mechanical benefit of weight loss and physical activity [8].

ANTI-INFLAMMATORY EFFECTS OF PHYSICAL ACTIVITY

Osteoarthritis is increasingly recognized as having an inflammatory component in addition to mechanical degeneration. Sedentary behavior is associated with elevated systemic inflammatory markers, which may exacerbate pain sensitization and chronicity.

Moderate-intensity exercise reduces circulating pro-inflammatory mediators and improves metabolic health. Structured physical activity programs in knee OA populations have demonstrated improvements in pain and stiffness alongside reductions in inflammatory indicators, supporting a systemic anti-inflammatory effect of regular exercise [7].

PAIN MODULATION AND CENTRAL ADAPTATION

Pain in knee OA often does not correlate directly with radiographic severity, suggesting involvement of central pain processing mechanisms. Physical activity influences pain perception through both peripheral and central pathways. Peripherally, improved muscular support reduces nociceptive input from joint stress. Centrally, exercise stimulates endogenous pain inhibitory systems and reduces sensitivity to painful stimuli.

Evidence consistently supports exercise as an analgesic intervention in knee OA, producing meaningful reductions in pain intensity and improving function across diverse patient subgroups [8, 9].

These interconnected mechanisms collectively contribute to clinically meaningful improvements in pain, stiffness, and functional capacity in individuals with knee osteoarthritis. The multidimensional pathways through which exercise exerts its effects are summarized in Figure 2.

TYPES OF EXERCISE AND EVIDENCE

AEROBIC EXERCISE

Aerobic exercise elevates heart rate and oxygen consumption, forming a cornerstone of physical activity recommendations. For people with knee OA, exercises must be tailored to individual age and fitness levels. High-intensity exercise engages large muscle groups and likely enhances VO2 max. Non-

Table 1. Comparative overview of exercise modalities, dosage parameters, mechanistic effects, and clinical considerations in knee osteoarthritis

Exercise Modality	Typical Dosage / Frequency	Delivery Format	Mechanistic Benefits	Population / Clinical Considerations
Aerobic (walking, cycling, aquatic)	30 min, ≥3 days/ week, moderate intensity	Home-based / supervised	Cardiovascular fitness, lower-limb endurance, modest pain relief, reduced joint load	Suitable for most; caution in severe joint degeneration; may have minimal biomechanical improvements alone
Resistance / Strengthening	2–3 times/week; high-speed RT: 47% 1RM, 35 weeks, 640 reps/ week	Supervised / hybrid	Increased quadriceps and hip strength, improved joint stability, reduced mechanical load, functional improvements	Target quadriceps and gluteus maximus; can reverse pain-induced atrophy; may combine with hip abductor & stretching
Aquatic Therapy	30–45 min, 2–3 times/week	Supervised / aquatic facility	Reduced joint load, improved circulation, pain relief, higher adherence	Ideal for patients with pain, stiffness, or mobility limitations; accessibility & cost considerations
Mind–Body (Yoga, Tai Chi)	30–60 min, 2–3 times/week, ≥16 weeks	Home-based / supervised	Flexibility, balance, neuromuscular control, modest pain relief, stress reduction, reduced inflammation	Complementary to strengthening; less effective than high-speed RT for pain reduction; adherence depends on motivation
Exercise Dosage / Guidelines	Long-term: >16 weeks, 3x/week; Short-term: ≤16 weeks, 2–3x/ week depending on goal	N/A	Improves pain, function, and general health; supports guideline adherence	Programs should be individualized; follow international guideline recommendations
Home-Based vs Supervised	Structured sessions per above modalities	Home-based, supervised, or hybrid	Adherence, comfort, practicality, and safety	Supervised programs generally outperform home-based alone; hybrid models optimize long-term adherence

Source: Developed by the authors based on literature synthesis

weight-bearing exercises, such as cycling and aquatic aerobics, reduce joint load and are preferred for low injury risk, but may provide less cardiovascular stimulus [10].

Guidelines suggest a frequency of 30-minute walks ≥3 days per week at moderate intensity, emphasizing perceived health benefits. However, these recommendations may overlook joint-specific effects; prolonged walking can increase knee joint loading and contact forces, potentially contributing to structural degeneration. Evidence shows walking alone or combined with other activities produces minimal changes in discrete biomechanical moments or impulses in mild-to-moderate knee OA. Small improvements in gait speed, spatiotemporal, and kinematic metrics are observed, but biomechanical outcomes remain largely unchanged [11].

RESISTANCE TRAINING

Resistance training is a widely prescribed rehabilitative modality in OA, improving muscle strength, joint stability, and function, while reducing joint load to slow cartilage degeneration and relieve pain. Isokinetic muscle strengthening (IKMS) is considered safe and effective for OA rehabilitation [12].

A systematic review and network meta-analysis from China found high-speed resistance training (RT) provided the greatest improvements in pain, stiffness, and function. This modality involves performing concentric contractions at maximum speed and requires symptom-specific dosing. Optimal pain reduction was achieved with 47% of 1RM over 35 weeks, with 640 repetitions per week. High-speed RT maximizes muscle activation, neuromuscular efficiency, and proprioception, enhancing joint stability and reducing mechanical load [13].

Substantial muscle mass loss and functional decline are common in OA. The painful limb shows selective reductions in knee extensors (quadriceps) and hip extensors (gluteus maximus), leading to patellofemoral pain, giving-way episodes, heaviness, focal myalgia, and fall risk. Targeted strengthening can reverse or compensate for pain-induced atrophy and fatty degeneration [14]. Studies also demonstrate additional functional benefits when stretching and hip abductor strengthening are combined with quadriceps exercises [15].

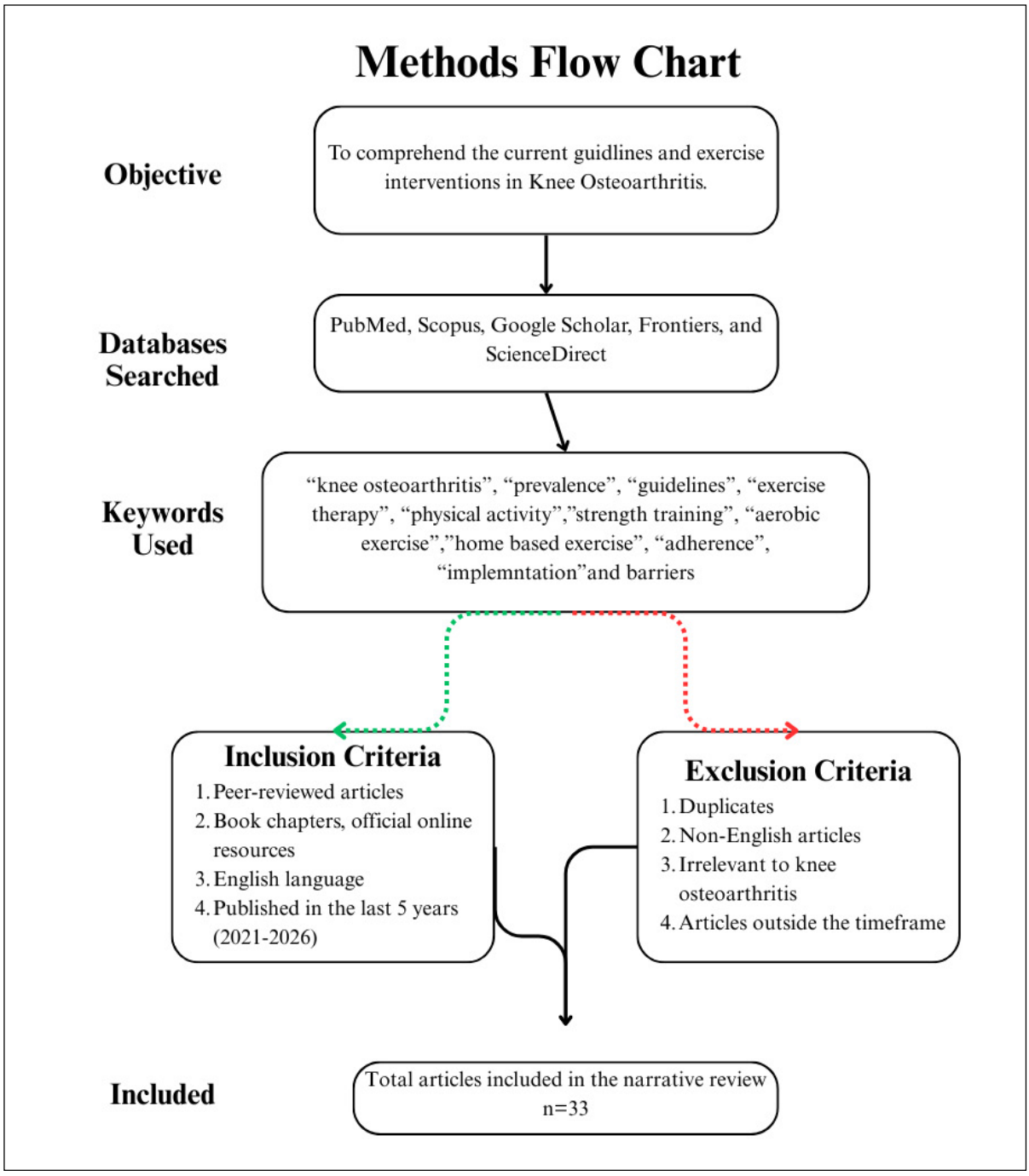

Fig. 1. Methodology flowchart summarizing literature search strategy, inclusion/exclusion criteria, and data synthesis steps used in the review
Source: Developed by the authors

AQUATIC PHYSICAL THERAPY

Aquatic therapy is ideal for patients with pain, stiffness, or weakness during land-based exercises. Buoyancy reduces joint load, while warmth and water pressure improve circulation and reduce discomfort. Compliance is higher than with other modalities [16]. Recommendations are conditional on accessibility and cost. Optimal water parameters (temperature, depth, composition) remain unclear, affecting exercise outcomes [17].

MIND–BODY EXERCISES:

Strengthening exercises focus on knee joint muscle power, stability, and mechanical pain reduction. Yoga combines postures, mindfulness, and breathing techniques, offering modest pain relief through flexibility and stress reduction. A randomized trial (2025) showed yoga outcomes were modest compared to strength training [18].

Tai Chi, an aerobic mind–body practice, incorporates mindful movement and abdominal breathing. It im-

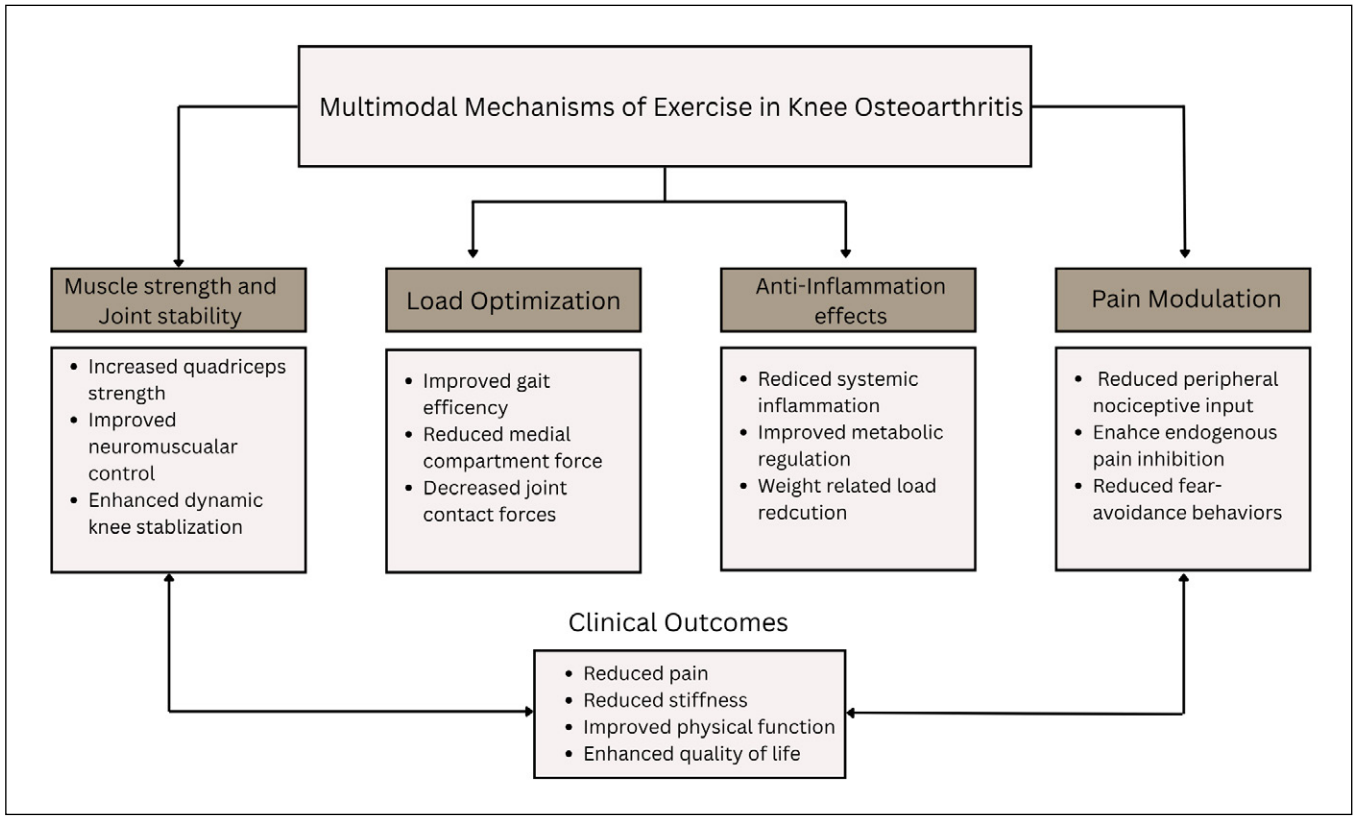

Fig. 2. Multidimensional mechanisms underlying the effects of exercise in knee osteoarthritis
Source: Developed by the authors based on literature synthesis

proves alignment, strengthens lower limbs, stabilizes the knee, and reduces local and systemic inflammation, facilitating healing [19].

EXERCISE DOSAGE AND GUIDELINES

Preliminary evidence (2025) suggests long-term (>16 weeks)/three-times-weekly protocols improve pain and function; short-term (≤16 weeks)/three-times-weekly protocols alleviate stiffness; short-term (≤16 weeks)/twice-weekly protocols enhance general health [20].

Multiple international guidelines recommend therapeutic exercise as first-line for knee OA, highlighting benefits and cost-effectiveness. However, delivery is often sub-optimal, with insufficient guidance for healthcare professionals on best practice [21].

HOME-BASED VS SUPERVISED EXERCISE

Hospital-based programs do not provide long-term advantages over home-based exercise (HBE), which is cost-effective, practical, highly compliant, comfortable, and low-risk [22]. Supervised exercises outperform HBE in achieving patient goals due to structured guidance, real-time feedback, and tailored progression. HBE may lack supervision, leading to inconsistent adherence and limited progression. Hybrid models combining supervised and home-based exercise may optimize outcomes and engagement [23].

Table 1 provides a consolidated summary of exercise modalities for knee osteoarthritis, including typical dosage, delivery methods, mechanistic benefits, and clinical considerations, offering a practical reference for evidence-based implementation.

CLINICAL IMPLEMENTATION AND ADHERENCE CHALLENGES

PATIENT-LEVEL FACTORS

Long-term adherence often declines after supervised care ends. Secondary analysis of an RCT found higher adherence with physiotherapist-supervised exercises than app-based instruction. Higher education and self-efficacy promoted adherence, while fatigue reduced it [24].

Sustaining engagement requires more than simple prescriptions. Exercise adherence frequently declines after therapist contact ceases, emphasizing the need for behavioral strategies [25].

Cognitive, social, and environmental factors strongly influence participation. Fear of pain or self-doubt may cause avoidance, whereas encouragement and favorable conditions support continued engagement.

PROVIDER AND SYSTEM-LEVEL FACTORS

Healthcare provider and system barriers include limited awareness of physiotherapy services, difficulty accessing affordable care, and perceptions of patient non-adherence [25]. Even when exercise is recognized as first-line, structural issues such as accessibility, funding, and referral processes may hinder effective implementation.

STRATEGIES TO IMPROVE ADHERENCE

Patient expectations, such as believing surgery is inevitable or fearing exercise-induced pain, impact adherence [26]. Clear education about benefits and reassurance regarding manageable discomfort are critical.

Exercise adherence reporting remains inconsistent across trials, complicating interpretation and tailoring strategies [27]. Effective programs should integrate behavioral support, accessible delivery methods (supervised, hybrid, app-based), and motivational strategies. Programs must be tailored to individual beliefs, social contexts, and lifestyle factors for long-term engagement.

CLINICAL IMPLICATIONS AND FUTURE DIRECTIONS

Exercise remains the cornerstone of knee osteoarthritis management. Current guidelines recommend individualized programs incorporating strengthening, aerobic, and neuromuscular training for all patients, irrespective of disease severity [28]. Meta-analytic evidence indicates that exercise provides pain relief comparable to oral NSAIDs and paracetamol, while avoiding the long-term systemic risks associated with pharmacotherapy [29]. Programs combining aerobic and resistance training confer broader functional benefits, though variability in dosage, intensity, and progression may influence clinical outcomes [30].

Despite strong evidence, exercise is underutilized in routine practice. Inconsistent prescription, limited monitoring, and lack of structured progression or follow-up are commonly reported [31]. Long-term adherence often declines once clinician supervision ceases, highlighting the need for behavioral support, patient education, and structured follow-up to maintain engagement [32]. Home-based exercise programs are accessible, practical, and cost-effective, whereas supervised interventions generally achieve superior improvements in pain, function, and adherence. Hybrid models combining supervised initiation with ongoing home-based programs may offer a pragmatic approach to optimize patient outcomes [33].

CONCLUSIONS

Exercise is a foundational, evidence-based intervention for managing knee osteoarthritis, yielding substantial improvements in pain, physical function, and overall quality of life. Despite robust guideline support, implementation in routine practice remains suboptimal, underscoring the need for innovative delivery strategies and sustained patient engagement.

FUTURE DIRECTIONS

Future research should define optimal exercise dosage, intensity, and progression across diverse patient populations and identify subgroups most likely to benefit from tailored interventions. Evaluating hybrid models that integrate supervised initiation with ongoing home-based programs, alongside behavioral support strategies, will be critical to enhance long-term adherence and clinical effectiveness. Strengthening implementation frameworks within primary care and community settings is essential to ensure that these evidence-based interventions translate into meaningful, real-world benefits for the growing population affected by knee osteoarthritis.

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