



knee osteoarthritis: An Updated Review for Physical Therapists, Nursing, and Pharmacists

Hussa Fraih Moodhi Alharbi⁽¹⁾, Rabab Mohammed Ali Alsaleh⁽²⁾, Yasir Mohammed Mousa Alajam⁽³⁾, Salman Hassan Mohammed Alhathiq⁽³⁾, Rashed Sultan Ali Alonazi⁽⁴⁾, Faisal Abdullah Al Faisal⁽⁵⁾, Nasser Abdullah D Alkhurayyif⁽⁵⁾, Abdulaziz Ibrahim M Alfaisal⁽⁵⁾, Fahd Mohammed Alharbi⁽⁶⁾, Abdulrahman Mohammed Hakami⁽⁷⁾, Faisal Awad Alshan⁽⁸⁾, Beshaeir Bandar Bin Jamaan⁽⁹⁾, Malak Hadi Ibrahim Jaafari⁽¹⁰⁾

(1) Maternity And Children Hospitals In Alhasa (Developmental And Behavioural Disorders Centre), Ministry of Health, Saudi Arabia,

(2) Maternity And Children Hospitals In Alhasa (Developmental And Behavioural Disorders Centre), Saudi Arabia,

(3) Baish General Hospital , Ministry of Health, Saudi Arabia,

(4) King Fahad Specialized Hospital, Tabuk, Ministry of Health, Saudi Arabia,

(5) Tumaer General Hospital , Ministry of Health, Saudi Arabia,

(6) Medical Supply Madinah Cluster , Ministry of Health, Saudi Arabia,

(7) Sabia General Hospital , Ministry of Health, Saudi Arabia,

(8) Complex Eradh / Jeddah , Ministry of Health, Saudi Arabia,

(9) King Fahad Medical City -Riyadh , Ministry of Health, Saudi Arabia,

(10) Mental Health Hospital In Alhasa, Ministry of Health, Saudi Arabia.

Abstract

Background: Knee Osteoarthritis (KOA) is a prevalent, degenerative joint disease and a leading cause of pain and disability globally. Its management is a significant challenge for healthcare systems, necessitating effective, conservative strategies to alleviate symptoms and improve function.

Aim: This review aims to provide an updated, comprehensive analysis of the efficacy, mechanisms, and comparative value of various physical therapy modalities for KOA, tailored for physical therapists, nurses, and pharmacists involved in patient care.

Methods: The article employs a systematic literature review methodology, evaluating a range of physical therapy interventions. These include traditional techniques like acupuncture and moxibustion, and modern modalities such as therapeutic ultrasound, shortwave diathermy, Pulsed Electromagnetic Field (PEMF) therapy, low-intensity laser therapy, and electrotherapy across low-, mid-, and high-frequency ranges.

Results: The analysis confirms that all reviewed modalities can effectively reduce pain and improve function in KOA patients. Each therapy operates through distinct mechanisms—neuromodulation, thermal effects, photobiomodulation, or electromagnetic stimulation. The review highlights that combining modalities with complementary mechanisms often yields superior, synergistic outcomes compared to monotherapy.

Conclusion: There is no single superior physical therapy for all KOA patients. A pragmatic, multimodal approach is recommended, integrating foundational exercise and education with accessible, low-cost options (e.g., moxibustion, electrotherapy) and escalating to technology-intensive modalities (e.g., PEMF, laser) based on individual patient needs, clinical phenotype, and resource availability.

Keywords: Knee Osteoarthritis, Physical Therapy, Rehabilitation, Acupuncture, Electrotherapy, Comparative Effectiveness, Multimodal Management..

Introduction

Knee osteoarthritis (KOA) is a progressive degenerative joint disorder and one of the most prevalent causes of pain, disability, and reduced mobility among middle-aged and elderly individuals. It is characterized primarily by the gradual deterioration of articular cartilage, subchondral bone remodeling, osteophyte formation, and varying

degrees of synovial inflammation. These pathophysiological changes culminate in pain, stiffness, swelling, and functional impairment, severely restricting the daily activities and overall quality of life of affected individuals. The present text explores the role and efficacy of various physical therapy interventions in managing KOA, emphasizing their contribution to pain relief, functional

improvement, and the promotion of joint recovery. Current clinical evidence has demonstrated that physical therapy—whether in the form of manual therapy, exercise therapy, or the use of modern modalities such as ultrasound therapy, laser therapy, and extracorporeal shockwave therapy—plays an essential role in the conservative management of musculoskeletal conditions, including KOA, peri arthritis of the shoulder, and cervical spondylosis [1–3]. Among these, KOA remains the most common chronic degenerative joint disease globally, and its prevalence is steadily rising in both developed and developing countries. This growing burden reflects the influence of an aging population, sedentary lifestyle, and increased obesity rates, all of which contribute to the progression of joint degeneration and chronic pain [4]. The clinical presentation of KOA typically involves chronic knee pain that worsens with prolonged activity or static postures. Patients frequently report increased discomfort after walking, climbing stairs, or maintaining a single position for extended periods. Morning stiffness and nocturnal pain are hallmark features that reflect synovial inflammation and compromised joint lubrication. Swelling, often secondary to synovitis, may cause visible enlargement of the knee and restrict flexion and extension movements. As the disease advances, mechanical instability, muscle weakness, and joint deformity further impair mobility, independence, and balance, increasing the risk of falls and subsequent injury.

Epidemiological data underscore the widespread impact of KOA. In the United States, approximately 19% of middle-aged and elderly adults suffer from this condition [5], and its prevalence increases markedly with advancing age [6–8]. Similar trends are observed globally. In China, for instance, the prevalence of KOA is estimated at 18%, affecting nearly one in five adults [9]. Age-stratified analyses reveal a steep increase in prevalence—from 16.5% among individuals aged 40–49 years to 47.5% in those over 70 years [10]. These statistics highlight not only the enormous scale of the disease but also its socioeconomic implications. KOA contributes to decreased work productivity, loss of independence, increased healthcare expenditures, and a growing demand for long-term care and rehabilitation services. Despite being incurable, KOA is highly manageable through non-surgical interventions, especially when diagnosed early. Among conservative options, physical therapy remains a cornerstone of treatment. Its multifaceted benefits stem from pain modulation, enhancement of joint range of motion, strengthening of periarticular muscles, and improvement of proprioception and balance. Furthermore, evidence suggests that combining structured exercise programs with modern physical modalities—such as thermotherapy, ultrasound, or electrical stimulation—can enhance treatment outcomes, delay disease progression, and potentially postpone the need for

surgical intervention. In summary, KOA represents a major global health challenge, particularly in aging societies. Its management requires a comprehensive, evidence-based approach that integrates physical therapy, patient education, lifestyle modification, and long-term rehabilitation. By targeting pain, inflammation, and functional limitations, physical therapy offers a safe, effective, and cost-efficient pathway toward maintaining mobility, independence, and overall quality of life in individuals suffering from knee osteoarthritis.

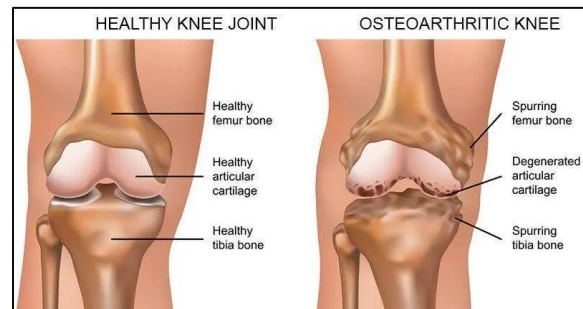


Fig. 1: Healthy Knee and Osteoarthritic Knee.

Physical Therapy Approaches for Knee Osteoarthritis Patients

In recent years, physical therapy has emerged as one of the most evidence-supported and widely endorsed non-pharmacological treatments for knee osteoarthritis (KOA). Both national and international clinical guidelines consistently recommend physical therapy as a core intervention due to its safety, non-invasive nature, and capacity to alleviate pain, improve function, and delay disease progression. Unlike pharmacological treatments that primarily target symptom control, physical therapy addresses the biomechanical and physiological underpinnings of KOA, thereby promoting long-term joint health and functional independence [11]. Contemporary research has demonstrated that regular, structured physical therapy not only reduces pain intensity but also improves muscle strength, enhances joint stability, and optimizes proprioceptive feedback. These physiological improvements translate directly into better mobility, reduced disability, and a higher quality of life for patients living with KOA. The growing recognition of physical therapy's efficacy has led to its widespread adoption in both clinical and community settings. Hospitals, rehabilitation centers, and physiotherapy clinics increasingly incorporate multimodal physical therapy programs tailored to individual patient needs. Moreover, the accessibility of portable therapeutic devices and home-based regimens has enabled many patients to integrate physical therapy into their daily routines, transforming it into a cornerstone of self-managed care [12]. This democratization of physiotherapy has been supported by public health initiatives promoting exercise-based management and patient education as essential elements of osteoarthritis treatment.

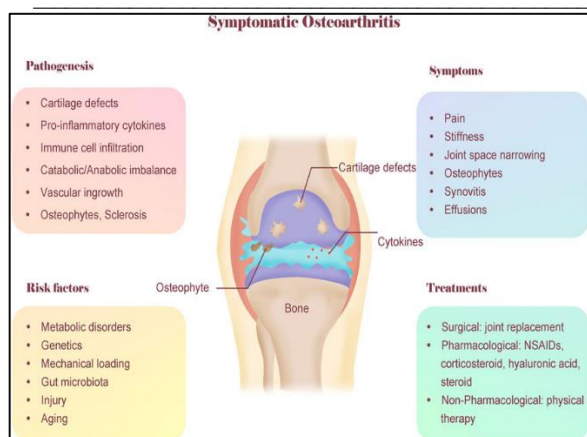


Fig. 2: Symptomatic Osteoarthritis.

Current evidence-based guidelines categorize physical therapy for KOA into several modalities, each addressing distinct aspects of the disease process. Traditional techniques such as acupuncture and moxibustion are valued for their analgesic and anti-inflammatory effects, often enhancing local blood circulation and modulating neurohumoral pathways. Modern biophysical methods—including therapeutic ultrasound, shortwave diathermy, and pulsed electromagnetic field (PEMF) therapy—focus on improving tissue healing, reducing inflammation, and enhancing microcirculation within periarticular structures. Similarly, low-intensity laser therapy facilitates cellular regeneration and pain modulation through photobiomodulation mechanisms. Electrotherapy modalities—spanning low-, medium-, and high-frequency electrotherapy—have also proven beneficial for muscle stimulation, pain control, and re-education of neuromuscular coordination. Low-frequency electrotherapy primarily targets sensory nerves to alleviate pain via the gate-control mechanism, whereas medium- and high-frequency modalities are designed to strengthen quadriceps muscles and restore balance in joint mechanics. By combining these therapies within a comprehensive and individualized rehabilitation plan, physical therapists can address multiple dimensions of KOA pathology simultaneously. In summary, physical therapy represents a cornerstone of contemporary KOA management. Its diverse techniques not only provide symptomatic relief but also enhance structural and functional outcomes. When integrated with lifestyle modification, weight management, and patient education, these approaches offer a holistic and sustainable framework for mitigating the burden of knee osteoarthritis and preserving functional independence among affected populations.

Acupuncture Therapy

Acupuncture, one of the oldest therapeutic modalities in traditional Chinese medicine (TCM), has been practiced for more than two millennia and remains a cornerstone of integrative medicine today. It is based on the theoretical framework of Qi (vital energy) and the balance between Yin and Yang, which

together maintain physiological harmony within the human body. The fundamental principle of acupuncture involves the insertion of fine, sterile needles into specific anatomical locations known as acupoints, distributed along meridians through which Qi and blood are believed to flow. By manipulating these acupoints through specialized techniques such as lifting, thrusting, and twisting, acupuncture aims to restore energetic balance, relieve stagnation, and promote the body's intrinsic healing mechanisms. In modern medical practice, acupuncture has been increasingly recognized as an effective adjunct therapy for a range of musculoskeletal and chronic pain conditions, particularly osteoarthritis. Within this context, knee osteoarthritis (KOA) has been one of the most extensively studied indications for acupuncture. The therapy is now widely integrated into the multidisciplinary management of KOA across hospitals, rehabilitation centers, and physiotherapy clinics. The expert consensus emerging from both traditional and modern medical communities underscores acupuncture's therapeutic value, particularly in pain relief, improvement of joint mobility, and enhancement of overall quality of life [13].

Several scientific investigations have attempted to elucidate the mechanisms underlying acupuncture's clinical benefits in KOA. Physiologically, needle stimulation at relevant acupoints can trigger complex neurovascular and biochemical responses, including the release of endogenous opioids (endorphins, enkephalins), serotonin, and adenosine, all of which contribute to analgesia. Acupuncture also modulates local blood circulation and inflammatory cytokine activity within periarticular tissues, thereby reducing edema and promoting cartilage metabolism. Functional imaging studies have revealed that acupuncture activates pain-modulating centers in the central nervous system, suggesting that its benefits are not merely localized but involve systemic neuroimmune regulation. Empirical evidence continues to support these mechanistic insights. In a semi-structured clinical interview involving 100 professionals and nonprofessionals, the reported efficacy rate of acupuncture in relieving KOA-related pain reached 92%, reflecting high patient satisfaction and perceived benefit [13]. Similarly, a comprehensive meta-analysis of major research databases conducted by Ben-Arie et al. [14] confirmed the short- and medium-term efficacy of acupuncture for pain reduction and functional improvement in KOA patients. The analysis highlighted consistent reductions in pain intensity, stiffness scores, and improved physical function as measured by standardized scales such as the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC).



Fig. 3: Acupuncture Therapy.

Animal models have further substantiated these findings. In one study where acupuncture was combined with drug therapy for experimentally induced KOA, the treatment efficacy reached 90%, demonstrating a synergistic effect between acupuncture and pharmacological interventions [15]. Parallel randomized clinical trials reinforce these outcomes. For instance, in a controlled study of 62 KOA patients randomly divided into two groups, the acupuncture group achieved an efficacy rate of 90.3% compared to the control group [16]. Another study involving 56 patients reported significant pain relief and excellent tolerance to treatment, confirming acupuncture's safety and patient acceptability [17]. Collectively, these studies provide strong evidence that acupuncture is a safe, well-tolerated, and effective method for managing KOA symptoms, particularly in the short to medium term. Despite these promising results, the long-term efficacy of acupuncture in KOA remains an area of active debate. While many studies demonstrate substantial short-term improvements in pain and function, evidence for sustained benefits beyond six months remains inconclusive. Variability in treatment protocols—such as differences in acupoint selection, needle manipulation techniques, frequency, and duration of sessions—may partly explain the heterogeneity in reported outcomes. Furthermore, methodological challenges, including small sample sizes, lack of standardization in control interventions (e.g., sham acupuncture), and patient expectation biases, complicate the interpretation of results. Consequently, large-scale, multicenter randomized controlled trials with rigorous methodological designs are required to establish the precise magnitude and duration of acupuncture's therapeutic effects.

Nonetheless, acupuncture's clinical advantages in KOA extend beyond symptom control. It is a low-risk, cost-effective, and minimally invasive intervention that can reduce dependency on analgesic medications, particularly nonsteroidal anti-inflammatory drugs (NSAIDs), thereby mitigating their associated gastrointestinal and cardiovascular risks. Furthermore, its holistic approach aligns well

with the principles of patient-centered rehabilitation, addressing not only physical pain but also psychological well-being by reducing anxiety and improving sleep quality—factors that significantly influence chronic pain outcomes. In practice, acupuncture for KOA is often combined with other modalities such as moxibustion, electroacupuncture, or physical therapy to enhance clinical efficacy. Electroacupuncture, which applies low-frequency electrical stimulation through the needles, has shown superior pain control and anti-inflammatory effects compared to manual acupuncture in some studies. Moxibustion, the burning of the herb *Artemisia vulgaris* near acupoints, provides additional thermal stimulation that can improve local circulation and relieve muscle stiffness. These combination therapies reflect the integrative nature of contemporary KOA management, where acupuncture plays a central yet complementary role. In summary, acupuncture therapy represents a scientifically supported, culturally rooted, and clinically viable intervention for knee osteoarthritis. Its multimodal mechanisms—ranging from neurochemical modulation to inflammation control—make it an effective strategy for alleviating pain and improving joint function. Although questions regarding long-term sustainability of benefits persist, the overall evidence base strongly supports acupuncture's inclusion in comprehensive KOA management protocols. Future high-quality research is warranted to refine treatment parameters, validate optimal acupoint prescriptions, and explore synergistic combinations with other rehabilitation therapies, thereby ensuring that acupuncture continues to evolve as a vital component of evidence-based, integrative musculoskeletal care [13–17].

Moxibustion Therapy

Moxibustion, a traditional Chinese medical practice with a history spanning over two millennia, represents a complementary therapeutic modality closely related to acupuncture. While acupuncture relies on mechanical stimulation through the insertion of fine needles at specific acupoints, moxibustion employs thermal stimulation generated by the burning of dried mugwort leaves (*Artemisia vulgaris*), known as *moxa*, near or directly on the skin. The central principle underlying moxibustion is the regulation of *Qi*—the vital energy that flows through the meridians—by applying controlled heat to acupoints to restore balance between Yin and Yang, promote blood circulation, and enhance the body's self-healing capabilities. Traditionally, moxibustion has been used to dispel cold and dampness, warm the meridians, and relieve pain. In recent decades, it has gained growing recognition for its potential role in managing musculoskeletal disorders, particularly knee osteoarthritis (KOA), due to its gentle, noninvasive, and pain-free characteristics. In contrast to acupuncture, moxibustion offers a form of thermotherapy that integrates both traditional Chinese philosophy and modern physiological mechanisms.

The application of heat through moxibustion induces vasodilation, improves local blood flow, enhances tissue oxygenation, and facilitates the removal of inflammatory mediators from the affected joint. This thermal stimulation also activates cutaneous sensory receptors, triggering neuroendocrine responses that modulate pain perception and inflammatory pathways. Consequently, moxibustion has been shown to reduce swelling, stiffness, and discomfort in patients with KOA, making it a valuable adjunct to conventional rehabilitation programs.

A growing body of experimental and clinical evidence supports the potential therapeutic effects of moxibustion on KOA. In a study involving 40 New Zealand white rabbits, a four-group comparative design demonstrated that moxibustion effectively inhibited inflammatory aggregation within the cartilage of the knee joint, suggesting its anti-inflammatory and chondroprotective effects [18]. Similarly, a meta-analysis that synthesized data from multiple clinical trials found an overall efficacy rate of approximately 95%, reinforcing its potential as an effective conservative intervention [19]. Clinical research further corroborates these findings: in a controlled experiment involving 50 patients with KOA, the efficacy rate of moxibustion reached 100%, indicating substantial improvement in pain relief and joint function [20]. Another study with 48 patients combined moxibustion with *Gua Sha* therapy (a traditional scraping technique) and reported an efficacy rate of 97.9%, demonstrating the benefits of integrative approaches [21]. These data collectively highlight the feasibility, safety, and potential of moxibustion in the management of KOA. In a comparative experiment conducted by Yuan et al. [22], moxibustion was evaluated against standard Western pharmacological treatments for KOA. The findings revealed that moxibustion not only yielded better therapeutic outcomes but also exhibited a superior safety profile, with fewer adverse effects. Although this study had certain limitations, including a relatively small sample size and lack of long-term follow-up, it provides compelling preliminary evidence that moxibustion is both effective and well-tolerated. Dai et al. [23] further expanded upon this concept by conducting a randomized controlled trial comparing moxibustion combined with the oral administration of Celecoxib (0.2 g/day, Pfizer Pharmaceuticals LLC) versus Celecoxib monotherapy. Their results showed that the combination therapy achieved significantly greater reductions in pain intensity and functional impairment, underscoring the synergistic potential between moxibustion and conventional pharmacotherapy.

The mechanisms underlying moxibustion's analgesic and anti-inflammatory effects are multifactorial. Thermal energy from burning moxa increases the temperature of local tissues, promoting microcirculation and accelerating metabolic exchange.

This heat effect reduces the viscosity of synovial fluid and enhances its lubricating properties, improving joint flexibility and comfort. Additionally, moxibustion stimulates the production of heat shock proteins, which play a cytoprotective role by mitigating oxidative stress and preventing cartilage degradation. On a neurophysiological level, moxibustion may also induce the release of β -endorphins and other neuromodulators that inhibit nociceptive transmission within the central nervous system, thereby diminishing pain perception. From a clinical standpoint, moxibustion's appeal lies in its simplicity, affordability, and adaptability. It can be administered in both hospital settings and at home using specialized moxa sticks or cones under professional guidance. Modern adaptations—such as smokeless moxibustion, infrared-assisted moxibustion, and electronic moxa devices—have further improved safety and convenience, making the therapy accessible to a broader population. Nevertheless, despite these advantages, several challenges remain. The standardization of treatment parameters—including acupoint selection, duration, frequency, and temperature control—has yet to be achieved. Inconsistent methodologies across studies hinder the establishment of definitive clinical guidelines. Furthermore, while short-term efficacy appears robust, long-term effects and mechanisms of sustained improvement require further elucidation through large-scale, multicenter randomized controlled trials.

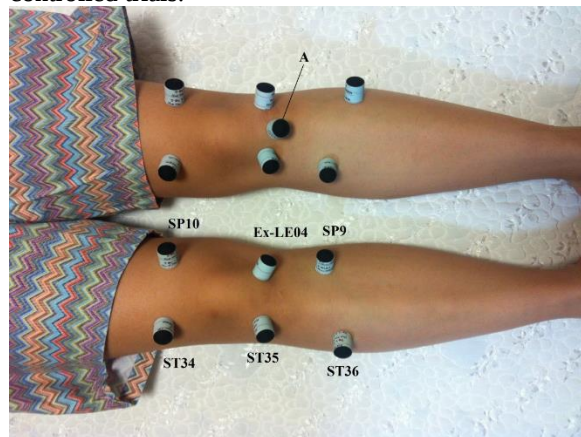


Fig. 4: Moxibustion Therapy.

In comparing acupuncture and moxibustion, it is evident that both modalities share common theoretical foundations yet differ in sensory experience and physiological impact. Acupuncture exerts mechanical and neurochemical effects through needle insertion, while moxibustion emphasizes thermal and circulatory modulation. When used together, these therapies often produce additive or synergistic outcomes, addressing both energetic and structural imbalances associated with KOA. The gentle, warming nature of moxibustion makes it particularly suitable for elderly patients or those with sensitivity to needle-based interventions. In

conclusion, moxibustion represents a valuable complementary therapy for knee osteoarthritis, offering a gentle, safe, and effective approach to pain reduction and functional restoration. Although it may not fully replace traditional acupuncture, its combination with pharmacological and rehabilitative treatments enhances overall therapeutic outcomes. Future research should prioritize methodological standardization, mechanism exploration, and longitudinal assessment to define optimal protocols and strengthen the evidence base. Until then, moxibustion remains a promising, culturally rooted intervention that bridges traditional wisdom with modern rehabilitation science in the holistic management of KOA [18–23].

Therapeutic Ultrasound

Therapeutic ultrasound is one of the most widely applied physical therapy modalities for the management of musculoskeletal disorders, including knee osteoarthritis (KOA). Ultrasonic waves are mechanical vibrations with frequencies exceeding 20 kHz, falling beyond the audible range of human hearing. These waves possess distinct biophysical properties—namely cavitation, thermal effects, and mechanical effects—that together contribute to their therapeutic potential [24]. Cavitation refers to the oscillation of microscopic gas bubbles within biological tissues under the influence of ultrasonic energy, which can enhance cellular permeability and promote tissue healing. The thermal effects result from the absorption of ultrasound energy by tissues, leading to localized heating that increases blood flow, reduces muscle spasm, and enhances the extensibility of collagen fibers. Mechanical effects, on the other hand, involve micro-massage and stimulation of cell membranes, fostering improved metabolic activity and accelerated tissue repair. The medical applications of ultrasound span both diagnostic and therapeutic domains. In diagnostics, ultrasound imaging serves as a noninvasive, real-time method to visualize soft tissues, joints, and cartilage, making it an indispensable tool for assessing structural changes in KOA. It allows clinicians to monitor synovial thickening, effusion, and cartilage degradation, facilitating early detection and ongoing evaluation of disease progression. Therapeutically, ultrasound plays a dual role: not only does it relieve pain and stiffness associated with KOA, but it also promotes biological recovery through enhanced cellular metabolism and tissue regeneration. In particular, the application of continuous or pulsed ultrasound over the affected knee can reduce muscle tension, improve circulation in periarticular tissues, and decrease inflammation, thereby aiding functional recovery.

The clinical efficacy of therapeutic ultrasound in KOA has been explored in numerous studies. For example, a study involving 120 patients divided into three groups found that ultrasound treatment significantly reduced pain and promoted cartilage repair within the knee joint [25]. Another

controlled trial involving 70 patients combined ultrasound with acupuncture and reported a total efficacy rate of 94.29%, highlighting the synergistic potential of multimodal therapies [26]. Similarly, an experimental study on 30 patients compared ultrasound combined with warm-needle acupuncture versus acupuncture alone, revealing a more pronounced therapeutic effect in the combination group [27]. Collectively, these findings suggest that therapeutic ultrasound has the potential to both alleviate pain and promote tissue healing, making it a valuable adjunct to conventional rehabilitation for KOA. Further investigations have provided mechanistic insights into these benefits. Continuous therapeutic ultrasound has been shown to effectively reduce pain intensity, improve joint range of motion, and enhance functional mobility in KOA patients [28–30]. The thermal and mechanical effects of ultrasound stimulate angiogenesis and collagen synthesis, which contribute to the repair of damaged cartilage and soft tissues. Moreover, the increased local temperature reduces synovial fluid viscosity and improves lubrication within the joint, which can further relieve discomfort and facilitate smoother movement. The stimulation of nerve endings also appears to play a role in pain modulation by activating descending inhibitory pathways that reduce nociceptive transmission.

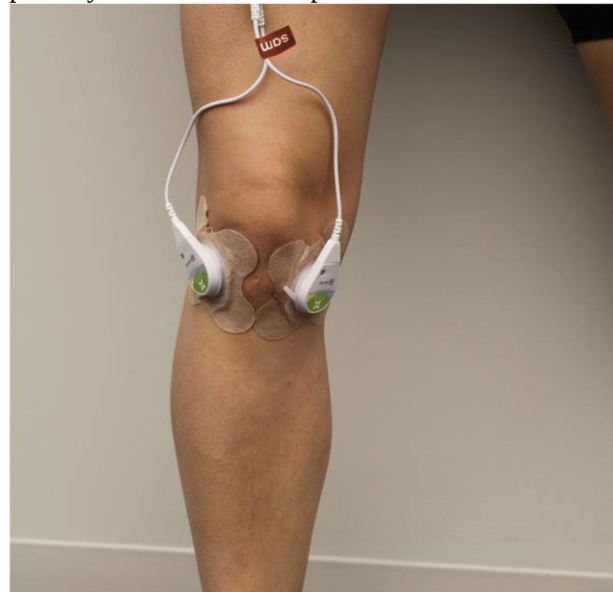


Fig. 5: Ultrasound Therapy.

Despite these encouraging findings, limitations remain. The number of high-quality, large-scale randomized controlled trials (RCTs) investigating the long-term efficacy of ultrasound therapy in KOA is relatively small, and some studies have reported inconsistent outcomes. A few experimental reviews have concluded that the evidence base supporting ultrasound therapy for KOA remains of low methodological quality, often due to inadequate blinding, small sample sizes, and heterogeneous treatment protocols [31]. These limitations make it difficult to draw definitive

conclusions about the magnitude and durability of its therapeutic effects. Additionally, variations in ultrasound parameters—such as frequency (typically 1–3 MHz), intensity, duty cycle, and duration—can significantly influence clinical outcomes, necessitating standardized treatment guidelines. When compared to other physical therapy modalities, ultrasound therapy appears to have a stronger physiological impact than moxibustion due to its ability to penetrate deeper tissues and directly influence cellular repair mechanisms. However, its comparative efficacy relative to acupuncture remains inconclusive, as both modalities operate through distinct mechanisms—acupuncture via neurochemical modulation and ultrasound via thermal and mechanical biostimulation. Combining ultrasound with other conservative therapies such as exercise, electrotherapy, or manual therapy may offer enhanced outcomes through synergistic effects on pain, mobility, and muscle strength. In summary, therapeutic ultrasound represents a scientifically grounded, noninvasive, and widely accessible modality for managing knee osteoarthritis. Its unique combination of mechanical and thermal effects helps reduce inflammation, alleviate pain, and accelerate tissue regeneration. Although current evidence supports its clinical benefits, further high-quality research is required to optimize treatment parameters, standardize protocols, and confirm long-term efficacy. Until such data are available, therapeutic ultrasound should be considered an effective adjunctive intervention within a comprehensive, multidisciplinary management plan for KOA, complementing other evidence-based physical and rehabilitative therapies [24–31].

Shortwave Therapy

Shortwave therapy, also known as shortwave diathermy, is a form of physical therapy that utilizes high-frequency electromagnetic waves to generate deep tissue heating. This therapeutic modality typically operates at a frequency of 27.12 MHz and produces both thermal and nonthermal effects within biological tissues, depending on the mode of application—continuous or pulsed. Through these mechanisms, shortwave therapy exerts beneficial physiological effects including increased local blood circulation, enhanced cellular metabolism, accelerated tissue repair, and significant pain relief. As a noninvasive and clinically established approach, shortwave therapy has been widely applied in the rehabilitation and management of musculoskeletal disorders, particularly in the treatment of knee osteoarthritis (KOA) [32]. The therapeutic principle of shortwave therapy lies in the conversion of electromagnetic energy into thermal energy within the body's tissues. This localized heating effect induces vasodilation, improving oxygen and nutrient delivery while facilitating the removal of inflammatory metabolites. The resulting enhancement in

microcirculation promotes tissue regeneration and reduces stiffness in periarticular structures, thereby alleviating pain and restoring functional mobility. Additionally, shortwave therapy has been reported to increase the elasticity of connective tissues, improving joint flexibility and movement efficiency—effects particularly beneficial for patients with chronic degenerative joint disease such as KOA [33,34].

A number of studies have validated the clinical effectiveness of shortwave therapy for KOA. In one observational study involving 23 patients, the overall efficacy rate reached 86.96% following a course of shortwave treatment [32]. Similarly, a controlled clinical trial of 80 patients demonstrated that the treatment group achieved a 75% efficacy rate, markedly higher than that of the control group [33]. In another comparative experiment with 60 patients, shortwave therapy combined with acupuncture produced superior therapeutic outcomes compared to shortwave therapy alone, underscoring the advantages of integrative treatment approaches [34]. Moreover, a separate study involving 76 patients reported an overall efficacy rate of 86.8%, reinforcing the consistency of these findings across different populations [35]. Collectively, these results demonstrate that shortwave therapy can significantly reduce pain, enhance mobility, and promote cartilage repair in KOA patients. Clinical application typically involves either continuous shortwave diathermy (CSWD) or pulsed shortwave diathermy (PSWD), each with distinct therapeutic characteristics. CSWD generates a steady, deep heating effect that is particularly effective in managing chronic conditions by improving tissue extensibility and relieving persistent muscle tension. In contrast, PSWD delivers intermittent bursts of electromagnetic energy, creating minimal thermal buildup while producing nonthermal biological effects such as improved cell membrane permeability and modulation of inflammatory processes. According to a survey conducted among 116 senior physiotherapists across 41 hospitals in Ireland, most clinicians reported that both modalities—continuous and pulsed—are valuable in managing KOA, though their clinical indications differ. Continuous shortwave therapy was favored for chronic osteoarthritic pain and stiffness, while PSWD was regarded as the preferred modality for acute inflammatory phases due to its superior safety profile and lower risk of overheating tissues [37].

Despite its established efficacy, shortwave therapy is not without limitations. Some patients may experience discomfort, excessive heat, or symptom exacerbation if the treatment parameters are improperly adjusted or if contraindications are overlooked. Conditions such as severe cardiovascular disease, active infection, open wounds, or the presence of metallic implants in the treatment area represent potential risks, as electromagnetic exposure can cause

thermal injury or interfere with implanted medical devices.



Fig. 6: Shortwave Therapy.

Moreover, the technology itself requires precise calibration and operator expertise to ensure optimal energy delivery, making it less accessible compared to simpler interventions such as ultrasound or acupuncture. From an economic standpoint, the equipment cost and maintenance requirements are relatively high, and technological advancements continue to evolve without full standardization of treatment protocols. Furthermore, while shortwave therapy demonstrates strong short-term analgesic and functional benefits, evidence regarding its long-term efficacy remains inconclusive. Some clinicians have expressed concern that excessive or inappropriate use of electromagnetic heating could exacerbate inflammation or tissue damage in susceptible individuals. Therefore, careful patient selection and individualized treatment planning are critical to maximizing therapeutic outcomes while minimizing risk. In comparison to other physiotherapeutic modalities, shortwave therapy occupies a complementary role rather than serving as a primary treatment option. Acupuncture and moxibustion provide neurochemical and circulatory modulation through direct stimulation, while ultrasound delivers localized mechanical and thermal effects. Shortwave therapy, though effective, demands more sophisticated technology and professional oversight, which may limit its widespread application in general rehabilitation settings. In summary, shortwave therapy represents a valuable adjunctive treatment for knee osteoarthritis, offering significant benefits in pain relief, inflammation reduction, and tissue regeneration through controlled electromagnetic energy delivery. Continuous and pulsed shortwave modalities each have unique advantages tailored to chronic and acute presentations, respectively. However, its use should be guided by clinical expertise, patient-specific considerations, and safety protocols. Given its higher technical threshold and potential risks, shortwave therapy should be regarded as a secondary or supportive approach—best used in conjunction with established conservative treatments such as exercise therapy, acupuncture, and pharmacologic

management—to achieve comprehensive and sustainable improvement in KOA outcomes [32–37].

Pulsed Electromagnetic Field (PEMF) Therapy

Pulsed electromagnetic field (PEMF) therapy represents an innovative noninvasive biophysical intervention that harnesses the principles of bioelectromagnetism to modulate cellular and tissue functions. The therapeutic mechanism is based on the generation of time-varying electromagnetic fields that induce weak electrical currents within biological tissues. These induced microcurrents influence ion exchange, membrane potentials, and cellular signaling pathways, thereby regulating electrophysiological processes both inside and outside the cell membrane. The result is an enhancement in cellular metabolism, improved microcirculation, and anti-inflammatory modulation—mechanisms particularly relevant to degenerative joint diseases such as knee osteoarthritis (KOA) [38]. At the physiological level, PEMF therapy exerts multifaceted effects that collectively contribute to tissue repair and functional restoration. The fluctuating magnetic field enhances endothelial nitric oxide production, leading to vasodilation and increased local blood flow, which promotes oxygen and nutrient delivery to articular cartilage and periarticular structures. Concurrently, PEMF stimulation has been shown to suppress pro-inflammatory cytokines such as interleukin-1 β (IL-1 β) and tumor necrosis factor-alpha (TNF- α) while upregulating anti-inflammatory mediators. These immunomodulatory effects mitigate synovial inflammation and reduce edema, thereby alleviating pain and improving joint mobility. Additionally, at the cellular level, PEMF has been reported to influence chondrocyte proliferation and extracellular matrix synthesis, promoting cartilage preservation and potentially slowing osteoarthritic progression [38,39]. Clinical and experimental research has provided encouraging evidence regarding the benefits of PEMF therapy in KOA. Bao et al. [38] observed that the biological effects of magnetic fields are closely related to specific frequency parameters, identifying an optimal therapeutic “window” within the range of 1–100 Hz. Within this frequency spectrum, magnetic fields exert maximal bioactivity, enhancing osteogenic differentiation, angiogenesis, and tissue regeneration. Fan [39] further explored the use of PEMF in bone-related diseases and found that exposure to pulsed electromagnetic fields significantly increased bone density, particularly in areas of low bone formation activity. This finding suggests that PEMF may preferentially stimulate osteoblast activity and improve bone remodeling in subchondral regions—an effect of direct relevance to the pathophysiology of KOA, where subchondral bone sclerosis and remodeling play key roles in disease progression.

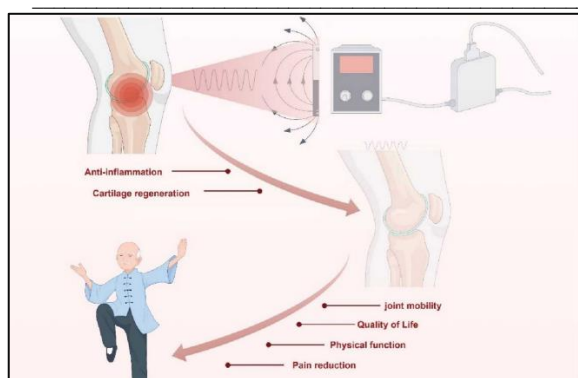


Fig. 7: Pulsed Electromagnetic Field (PEMF) Therapy.

Despite mounting clinical support, the precise mechanisms through which PEMF influences osteogenesis and cartilage metabolism remain incompletely understood. Studies at the molecular level have yielded inconsistent results, reflecting variations in experimental models, exposure parameters, and tissue responses. Nevertheless, most findings converge on the hypothesis that PEMF stimulates mechanotransduction pathways—converting mechanical energy from magnetic fields into biochemical signals that activate cellular repair processes. Possible molecular mediators include calcium-calmodulin signaling, mitogen-activated protein kinase (MAPK) cascades, and upregulation of bone morphogenetic proteins (BMPs), all of which are critical to chondrocyte and osteoblast function. In clinical practice, PEMF therapy is applied externally using devices that generate pulsed magnetic fields directed toward the affected knee joint. Treatment sessions typically last between 20 and 40 minutes, several times per week, with intensity and frequency parameters customized to patient tolerance and therapeutic goals. Unlike thermal modalities such as shortwave or ultrasound therapy, PEMF is nonthermal, meaning that its effects are not derived from heat generation but rather from electromagnetic induction at the cellular level. This property makes PEMF especially suitable for patients with acute inflammation or those intolerant to heat-based therapies. Moreover, the noninvasive and painless nature of PEMF enhances patient compliance and reduces the risk of adverse reactions. The regenerative potential of PEMF therapy is particularly significant in the context of an aging population, where the prevalence of KOA continues to rise due to longer lifespans and increased rates of obesity and sedentary behavior. As conventional pharmacological treatments—such as nonsteroidal anti-inflammatory drugs (NSAIDs) and corticosteroids—are often limited by side effects and contraindications, PEMF offers a promising complementary or alternative option. It bridges the gap between conservative physical therapy and invasive surgical interventions by providing a safe, repeatable, and cost-effective

method for managing pain and promoting structural repair.

Nonetheless, while the therapeutic efficacy of PEMF for KOA has been demonstrated in numerous clinical studies, questions remain regarding optimal dosing parameters, duration of treatment, and long-term outcomes. The heterogeneity in device specifications and treatment protocols complicates the establishment of standardized clinical guidelines. Furthermore, more mechanistic studies at the cellular and molecular levels are needed to elucidate how PEMF modulates cartilage regeneration, bone remodeling, and inflammatory signaling in osteoarthritic joints. In conclusion, PEMF therapy represents a novel and scientifically grounded advancement in the noninvasive management of knee osteoarthritis. By leveraging electromagnetic stimulation to enhance tissue metabolism, suppress inflammation, and promote osteochondral repair, PEMF addresses both the symptoms and underlying pathology of KOA. Although further research is required to clarify its precise biological mechanisms and optimize treatment parameters, current evidence suggests that PEMF is a promising therapeutic modality with broad potential applications in the context of the global aging population and the rising incidence of degenerative joint diseases [38,39].

Low-Intensity Laser Therapy

Low-intensity laser therapy (LILT), also known as low-level laser therapy (LLLT), is a noninvasive physiotherapeutic modality widely utilized in the treatment and rehabilitation of knee osteoarthritis (KOA). Unlike high-intensity laser therapy (HILT), which delivers deeper tissue penetration and higher energy density, LILT operates within a lower energy range—typically between 1 mW and 500 mW—and focuses on eliciting *biostimulatory* rather than *ablative* effects. While HILT may theoretically produce superior outcomes due to its greater penetration depth, clinical research on HILT remains limited, and standardized protocols are yet to be established. Therefore, current evidence and clinical consensus primarily support the use of low-intensity laser therapy in the conservative management of KOA. The therapeutic mechanism of LILT is grounded in the principles of *photobiomodulation*, whereby specific wavelengths of laser light (commonly between 600–1000 nm) interact with cellular photoreceptors such as cytochrome c oxidase in mitochondria. This interaction enhances adenosine triphosphate (ATP) production, promotes the release of nitric oxide (NO), and modulates reactive oxygen species (ROS) within cells, leading to improved cellular metabolism, enhanced microcirculation, and anti-inflammatory effects. These physiological responses contribute to pain relief, tissue regeneration, and accelerated healing. By increasing oxygen delivery and reducing oxidative stress, LILT also helps mitigate synovial inflammation

and promotes cartilage homeostasis in osteoarthritic joints [40]. Clinical studies have demonstrated the effectiveness of LILT in alleviating pain and improving function in patients with KOA. A meta-analysis conducted by Chen et al. [40] revealed that low-intensity laser therapy significantly reduces pain and enhances joint mobility in osteoarthritic patients. Similarly, a controlled experiment involving 89 KOA patients found that laser therapy shortened recovery time and improved knee function compared to conventional rehabilitation alone [41]. Another controlled study of 60 patients with unilateral KOA compared combined acupuncture and laser therapy against laser therapy alone, concluding that the combination group achieved superior therapeutic results, indicating potential synergistic effects between photobiomodulation and traditional acupuncture techniques [42].

The therapeutic benefits of LILT are attributed to multiple cellular and tissue-level effects. The photothermal and photochemical interactions within irradiated tissues stimulate fibroblast proliferation, collagen synthesis, and angiogenesis, which collectively enhance the repair of damaged soft tissues surrounding the knee. Additionally, laser-induced modulation of nerve conduction and endorphin release contributes to analgesia, while its anti-inflammatory properties inhibit proinflammatory cytokines such as IL-1 β and TNF- α , reducing joint swelling and stiffness. These effects lead to both immediate and cumulative improvements in pain perception and joint functionality. From a clinical application perspective, low-intensity laser therapy is typically administered two to three times per week, with each session lasting 10 to 15 minutes over a treatment course of four to six weeks. The laser is directed at specific acupoints or along the joint line, targeting periarticular tissues and inflamed regions. Treatment parameters—such as wavelength, energy density, and duration—are carefully selected according to the severity of osteoarthritis and patient tolerance. Continuous and pulsed modes are used depending on therapeutic objectives: continuous laser exposure facilitates tissue warming and metabolic enhancement, whereas pulsed modes minimize heat accumulation and focus on cellular stimulation without discomfort. Alfredo et al. [43] further investigated the long-term efficacy of low-intensity laser therapy in a study involving 43 KOA patients, demonstrating sustained improvements over six months, including reduced pain intensity, decreased functional disability, and lower reliance on analgesic medications. These findings suggest that LILT not only offers short-term symptom relief but may also exert lasting benefits by modulating the underlying degenerative processes in cartilage and synovial tissues.

Nevertheless, several practical limitations accompany this therapy. LILT requires specialized equipment and trained operators, raising both cost and

accessibility barriers compared to simpler physiotherapeutic modalities such as heat therapy or exercise. Moreover, the variability in laser parameters—such as wavelength (red or near-infrared), power output, and energy dose—across studies makes it difficult to standardize treatment protocols or establish definitive clinical guidelines. The therapeutic outcomes of LILT are highly dependent on these parameters, as suboptimal dosages may yield insufficient results, while excessive exposure could diminish the intended bio-stimulatory effect. In comparing low- and high-intensity laser modalities, existing evidence suggests that both exert beneficial effects on KOA through overlapping mechanisms involving photobiomodulation and improved tissue perfusion. However, due to the limited clinical data on HILT, LILT remains the more widely accepted and extensively studied modality. Future research should aim to directly compare these two modalities through large-scale randomized controlled trials, focusing on long-term outcomes, dose optimization, and cost-effectiveness analyses. In conclusion, low-intensity laser therapy represents a scientifically grounded and clinically validated adjunctive treatment for knee osteoarthritis. Its noninvasive nature, minimal side effects, and proven ability to enhance pain relief, improve joint mobility, and promote tissue regeneration make it a valuable component of comprehensive KOA rehabilitation programs. While it demands professional expertise and standardized protocols, LILT continues to gain prominence as an effective, evidence-based intervention that integrates modern photomedicine principles into the holistic management of degenerative joint diseases [40–43].

Low-Frequency Electrotherapy

Low-frequency electrotherapy (LFE) is a physical therapy modality that utilizes low-frequency electrical currents—typically ranging from 1 to 100 Hz—to stimulate biological tissues and induce physiological and therapeutic effects. The principle behind this therapy is grounded in electrophysiology: when low-frequency electrical currents pass through tissues, they modify the electrical potential across cell membranes, influencing ion exchange, neural transmission, and cellular metabolism. These effects can modulate pain perception, improve circulation, and facilitate tissue repair. In the management of knee osteoarthritis (KOA), low-frequency electrotherapy has gained attention for its noninvasive nature, simplicity, and potential to relieve pain and inflammation by targeting peripheral nerves and acupoints. Among various electrotherapy techniques, transcutaneous electrical nerve stimulation (TENS) represents the most commonly used form of low-frequency electrotherapy. It delivers mild electrical impulses through surface electrodes placed on the skin, either near the site of pain or at specific acupuncture points. Unlike invasive acupuncture or needle-based stimulation, TENS achieves a similar

neuromodulatory effect without puncturing the skin, making it safer and more comfortable for patients. The adhesive electrode patches used in LFE are easy to apply and cause minimal skin irritation, while the therapy's accessibility and low equipment cost make it suitable for both clinical and home-based rehabilitation settings. The mechanism of action of LFE primarily revolves around pain modulation via the *gate control theory* of pain. Electrical stimulation activates large-diameter afferent nerve fibers ($A\beta$ fibers), which inhibit pain transmission through smaller nociceptive fibers ($A\delta$ and C fibers) in the spinal dorsal horn. In addition, LFE can promote the release of endogenous opioids, such as endorphins and enkephalins, enhancing analgesia. Beyond pain control, low-frequency electrical stimulation also influences local blood circulation, reduces muscle spasm, and may assist in restoring neuromuscular coordination around the knee joint. These combined effects can contribute to improved functional outcomes for patients with KOA.

Clinical research on LFE for KOA, however, presents mixed findings. Xiang et al. [44] performed a meta-analysis of randomized controlled trials from the Cochrane, PubMed, and Embase databases, examining transcutaneous nerve stimulation for KOA-related pain. The results indicated no statistically significant difference between the LFE (acupoint stimulation) group and the control group, with both reporting approximately 66.7% pain relief. The authors suggested that the subjective nature of pain assessment and variations in study design might have contributed to these inconclusive outcomes. Nevertheless, the findings imply that while LFE can relieve pain, its effects may not surpass those achieved through placebo or other conservative treatments. In contrast, Xia [45] conducted a randomized clinical study involving 70 KOA patients with comparable inflammatory factor profiles. Participants were divided into two groups: one receiving conventional drug therapy alone and the other receiving a combination of drug therapy and low-frequency electrotherapy. Both groups showed clinical improvement; however, the combination group demonstrated a significantly greater reduction in inflammatory cytokine levels, indicating that electrotherapy may enhance the anti-inflammatory effects of pharmacologic treatments. These results suggest that LFE may be more effective when used as an adjunct rather than a standalone therapy. Further insights were provided by Chunyan et al. [46], who explored mid- and low-frequency electrotherapy systems and their pain management applications. They concluded that low-frequency electrotherapy is particularly suitable for treating superficial pain, while mid-frequency therapy may be better suited for deeper musculoskeletal structures. Although various commercial devices combine both low- and mid-frequency functions, low-frequency systems remain

the most prevalent due to their affordability, simplicity, and wide therapeutic range.

Despite these advantages, controversies remain regarding the consistency of LFE outcomes. Differences in current intensity, waveform, frequency, electrode placement, and session duration across studies have led to heterogeneous results. Additionally, the placebo effect associated with electrotherapy interventions complicates interpretation of efficacy. Some researchers argue that while LFE provides short-term pain relief, its long-term benefits on joint structure and function are limited. Therefore, standardization of treatment parameters and larger-scale randomized controlled trials are necessary to validate its therapeutic value. In summary, low-frequency electrotherapy offers a convenient, safe, and cost-effective approach for managing pain and inflammation in knee osteoarthritis. Its ability to modulate neural transmission, reduce inflammatory responses, and enhance circulation positions it as a valuable adjunct to pharmacological and rehabilitative therapies. However, the existing body of evidence remains inconclusive, and further high-quality research is required to clarify optimal treatment protocols, frequency parameters, and long-term clinical efficacy. While low-frequency electrotherapy holds promise as part of a comprehensive KOA management plan, it should be applied judiciously and in combination with other established interventions to achieve optimal patient outcomes [44–46].

Mid-Frequency Electrotherapy

Mid-frequency electrotherapy (MFE) represents an advanced evolution of electrical stimulation modalities, operating within a frequency range of approximately 1–100 kHz. This therapeutic approach delivers oscillating currents that penetrate deeper into soft tissues than low-frequency electrotherapy (LFE) while maintaining greater patient comfort due to reduced skin impedance at higher frequencies. Through controlled modulation of current parameters—frequency, waveform, intensity, and duty cycle—MFE targets nerves, muscles, and connective tissues to promote blood flow, alleviate pain, enhance metabolic activity, and facilitate tissue repair. Compared with LFE, mid-frequency stimulation has been shown to produce more stable analgesic effects and superior overall therapeutic outcomes for patients with knee osteoarthritis (KOA) [47]. The mechanism underlying MFE's benefits is multifaceted. By applying alternating currents at mid-range frequencies, this therapy reduces the discomfort associated with superficial electrical stimulation and achieves more effective activation of deep motor and sensory nerves. The electrical impulses stimulate $A\beta$ fibers, inhibiting pain transmission through the spinal “gate control” mechanism, while also promoting the release of endogenous opioids such as endorphins and enkephalins. Additionally, MFE improves muscle tone

and coordination around the knee joint, reduces stiffness, and enhances microcirculatory dynamics, which accelerates nutrient delivery and waste removal. These physiological responses contribute to pain reduction, inflammation control, and improved joint function in KOA patients.

Clinical research supports the efficacy of MFE in treating KOA. Xiaojun J. et al. [48] investigated three traditional Chinese medicine-based treatments, including medium-frequency electrotherapy, in a randomized clinical trial involving 90 patients (134 knees). Participants were divided into three groups: one received oral Chinese herbal medicine alone, while the second group combined herbal treatment with MFE. The addition of mid-frequency electrotherapy resulted in greater improvements in pain relief and functional recovery than drug therapy alone, demonstrating the synergistic potential of integrated therapeutic approaches. Similarly, Ming et al. [49] conducted a randomized trial with 76 KOA patients, dividing them into control and observation groups. Their findings revealed that the overall clinical effectiveness of low-medium-frequency electrotherapy reached 89.47%, significantly higher than the 68.42% reported in the drug-only group ($P < .05$). These results highlight the capacity of mid-frequency electrotherapy to provide meaningful analgesia and functional benefits. Experimental observations further illustrate how mid-frequency currents influence patient sensations and tissue responses. When low frequencies (below 10 Hz) and minimal current are used, the sensation resembles gentle tapping—historically compared to early “electric chewing gum” devices of the 20th century. Increasing the current intensity produces a percussive or pulsating feeling, similar to mechanical massage, whereas frequencies exceeding 100 Hz induce a mild numbing or tingling effect due to repetitive stimulation of sensory nerves. Within the therapeutic range of 1–100 kHz, mid-frequency currents can generate either a soothing or invigorating sensory experience depending on the selected parameters. When applied at moderate intensities, the sensation has been likened to *gua sha* (a traditional scraping therapy), reflecting the stimulation of microcirculation without discomfort or tissue injury.



Fig. 8: Mid Frequency Electrotherapy.

One of the chief advantages of MFE over LFE lies in its deeper tissue penetration and reduced skin irritation. The higher frequency allows for a more uniform current distribution and lower impedance, enabling stimulation of deeper muscle fibers and nerve trunks. This deeper penetration enhances therapeutic efficacy, particularly for chronic conditions like KOA, where inflammation and degenerative changes affect both articular and periarticular tissues. Furthermore, MFE has been shown to improve muscle strength and proprioceptive control, potentially supporting rehabilitation and preventing further joint degeneration. However, despite these advantages, comparative studies between mid- and low-frequency electrotherapy remain limited. Variability in treatment protocols, electrode placement, current density, and exposure duration across clinical studies complicates direct comparisons and hinders the establishment of standardized guidelines. Additionally, while short-term pain relief and functional improvements are well-documented, evidence regarding the long-term structural benefits of MFE on cartilage regeneration and disease progression is still insufficient. Further research with larger, well-controlled clinical trials is needed to validate these findings and determine optimal therapeutic parameters. In summary, mid-frequency electrotherapy constitutes an effective, evidence-supported modality in the conservative management of knee osteoarthritis. Its deeper penetration, enhanced analgesic efficacy, and capacity to stimulate muscle and nerve function make it superior to traditional low-frequency treatments in many cases. When integrated with pharmacologic therapies or physical rehabilitation programs, MFE offers a comprehensive approach to pain reduction, inflammation control, and functional restoration. Nonetheless, to fully harness its clinical potential, future research should aim to refine treatment parameters, establish standardized clinical protocols, and further clarify its long-term benefits and mechanisms of action in KOA management [47–49].

High-Frequency Electrotherapy

High-frequency electrotherapy (HFE) operates within the frequency spectrum of 100 kHz to 10 MHz and represents one of the most advanced modalities in the field of electrotherapeutic medicine. It uses high-frequency alternating currents to generate both thermal and nonthermal physiological effects within deep tissues, achieving outcomes such as pain relief, muscle relaxation, improved blood flow, and accelerated tissue repair. This technique is extensively applied in rehabilitation, sports medicine, and chronic pain management, including the treatment of knee osteoarthritis (KOA). In clinical practice, HFE is delivered through specialized electrotherapy instruments equipped with electrode patches or capacitive and resistive applicators. These devices transmit high-frequency currents into targeted tissues, where the energy is transformed into heat through molecular friction. The resulting deep heating effect

leads to vasodilation, enhances local metabolism, and facilitates the reabsorption of inflammatory exudates. Simultaneously, nonthermal bioelectrical interactions influence cellular activity and modulate inflammatory signaling. By adjusting the current's frequency, waveform, and intensity, therapists can tailor the treatment to individual patient needs, optimizing therapeutic benefits while minimizing discomfort. A unique characteristic of HFE is the intensity and depth of stimulation it produces. Patients typically experience a pronounced sensation of warmth, vibration, or pulsation during therapy. Because of the higher energy levels used, sessions are relatively short—generally lasting between 5 and 15 minutes—but the effects tend to persist beyond the immediate treatment period. The resulting increase in tissue temperature enhances elasticity of collagen fibers, reduces joint stiffness, and promotes overall mobility.

Recent studies support the efficacy of high-frequency electrotherapy in relieving pain and improving function in KOA patients. Experimental evidence indicates that, compared to low-frequency methods, HFE exerts stronger analgesic and anti-inflammatory effects [50]. The dual action of thermal and nonthermal mechanisms improves microcirculation, stimulates cellular repair, and modulates cytokine secretion, thereby promoting cartilage nutrition and slowing degenerative processes [51]. These effects collectively reduce joint tension and enhance synovial fluid dynamics, which are essential for maintaining joint lubrication and function. Yanmei and Lining [52] conducted a randomized controlled trial involving 85 patients with KOA, dividing them into three groups: a high-frequency electrotherapy group, an exercise therapy group, and a combined treatment group. The study revealed that HFE alone significantly reduced pain and relaxed periarticular soft tissues compared with exercise therapy. Moreover, the combination of HFE and exercise therapy yielded the best outcomes, demonstrating a synergistic relationship between passive electrostimulation and active rehabilitation. The comparative advantages of HFE over other physical therapy modalities are notable. When contrasted with ultrasound, laser therapy, shortwave diathermy, and pulsed electromagnetic field therapy, high-frequency electrotherapy offers deeper tissue penetration and more pronounced thermal effects, leading to faster symptomatic relief and tissue recovery. In addition, because HFE can be administered using compact, automated devices, it holds significant potential for cost-effective and scalable clinical application, especially in rehabilitation centers and outpatient settings.

Controlled experiments involving medium-frequency electrotherapy reported significant therapeutic effects in 127 KOA patients [53]. Similarly, low-to-medium-frequency electrotherapy improved joint function recovery in 76 patients [54].

Notably, a systematic review and meta-analysis on high-frequency electrotherapy confirmed consistent and noticeable improvements in pain reduction and functional capacity [55]. Despite its advantages, certain safety considerations accompany HFE. The higher intensities involved necessitate professional supervision to prevent overheating or electrical burns, especially in patients with metal implants, pacemakers, or sensory deficits. Proper electrode placement, frequency modulation, and continuous monitoring are essential to ensure both efficacy and safety. In conclusion, high-frequency electrotherapy is an effective and promising intervention for managing knee osteoarthritis, offering significant clinical and economic benefits. Its combined thermal and bioelectrical mechanisms yield superior pain relief, anti-inflammatory effects, and tissue regeneration compared with lower-frequency modalities. When integrated with exercise therapy and other rehabilitative strategies, HFE enhances overall functional recovery, making it a valuable component of modern physiotherapeutic practice. However, further research and long-term clinical trials are needed to establish standardized protocols, confirm optimal dosing parameters, and assess its long-term efficacy and safety in chronic degenerative joint conditions [50–55].

Comparative analysis of knee osteoarthritis physical therapy protocols

A coherent comparison of physical therapy protocols for knee osteoarthritis (KOA) must balance mechanistic plausibility, clinical effectiveness, safety, cost, and feasibility. Across acupuncture, therapeutic ultrasound, shortwave diathermy, pulsed electromagnetic field (PEMF) therapy, low-intensity laser therapy, and electrotherapy at differing frequency bands, evidence suggests complementary strengths rather than a single dominant modality. The most pragmatic approach is therefore integrative: match the technique to clinical phenotype, combine mechanisms where synergy is plausible, and weigh access and operator dependence alongside outcomes. What follows synthesizes head-to-head considerations and combination strategies, before contextualizing efficacy signals and real-world feasibility. Acupuncture and therapeutic ultrasound are both established options for KOA, but they act through different pathways. Acupuncture modulates nociception and inflammatory tone via point-specific neural and humoral effects, yielding reliable short- to medium-term analgesia; sustained long-term benefits, however, remain variable and technique-dependent. Moxibustion—while gentler and often painless—tends to be less potent than acupuncture when used alone yet can amplify outcomes in combination with pharmacotherapy. Therapeutic ultrasound offers a dual role: imaging for structural assessment and treatment for pain and stiffness through mechanical and thermal biostimulation. Nonetheless, clinical trials

vary in parameters and quality, so its magnitude of benefit is still constrained by heterogeneous protocols. In aggregate, both acupuncture and ultrasound are reasonable components of conservative management, but definitive comparative superiority awaits larger standardized trials. Shortwave therapy (27.12 MHz) demonstrates clinically meaningful analgesia and tissue extensibility through controllable thermal and nonthermal effects, but remains equipment- and operator-intensive. As a standalone, it is effective; as a primary first-line for all patients, it is less suitable due to access, calibration, and safety demands. Notably, combination regimens can be particularly impactful. In a cohort from Guangdong 39 Neurology Hospital, warm-needle acupuncture plus shortwave achieved an overall effectiveness of 96.66% [56], while another study showed the pairing reduced serum TNF- α more than acupuncture alone [57]. The mechanistic complementarity is credible: acupuncture's neuromodulation plus shortwave's deep vasodilatory and viscoelastic effects collectively reduce pain, stiffness, and inflammatory signaling. The clinical implication is straightforward—when resources permit, layered, mechanism-diverse care can outpace monotherapy.

PEMF and shortwave share noninvasive energy delivery yet diverge in biophysics. PEMF induces microcurrents that regulate transmembrane potentials and signal cascades, supporting chondrocyte activity and bone remodeling; shortwave primarily converts electromagnetic energy to controlled heat (with adjunct nonthermal effects), improving perfusion and viscoelasticity. Both require trained oversight and calibrated devices, and both can serve as adjuncts rather than universal first-line options. Parameter sensitivity is especially salient for PEMF: effective frequencies typically reside within a 1–100 Hz “window,” with biological responses contingent on waveform, duty cycle, and dose. In practice, PEMF is appealing where synovitis and subchondral bone dysfunction dominate, while shortwave is attractive for extensibility gains and chronic stiffness—selection should be individualized. Low-intensity laser therapy (LILT) and acupuncture illustrate an integrative rather than merely additive pairing. Photobiomodulation enhances mitochondrial ATP generation, nitric oxide signaling, and microcirculation, aligning with acupuncture's neuromodulatory effects to improve pain and function. Applying 4 J/cm² to knee acupoints for three weeks produced superior outcomes versus control in 26 KOA patients [58], and broader reviews over 15–20 years corroborate clinically significant gains in pain and function with laser-acupuncture protocols [59]. This integration places the “needle” and the “photon” on the same therapeutic map—one shaping neuroimmune tone, the other energizing cellular metabolism—yielding convergence at the level of symptom relief and activity restoration while limiting pharmacologic load. Electroacupuncture extends this logic by

replacing manual twirling with waveform-controlled pulses delivered through inserted needles, aiming for standardized, reproducible stimulation. In a 60-patient comparison, both manual acupuncture and electroacupuncture improved pain and function, with a small edge to manual needling; yet inter-operator variability limits categorical conclusions [60]. Practically, electroacupuncture can democratize delivery when expert manual technique is scarce, while maintaining point specificity and allowing parameterized titration. More broadly, electrical stimulation at the skin (electrotherapy) can be deployed without needles for patients preferring noninvasive options, though effects may be shallower and parameter-sensitive.

When modalities are arrayed side-by-side, several themes emerge from comparative datasets. Acupuncture shows high responder rates in sizable cohorts, yet outcomes hinge on practitioner expertise and protocol consistency. Moxibustion, supported by meta-analytic signals with large samples and very low P-values, stands out for accessibility and safety, especially as a home-capable adjunct. Ultrasound and LILT reliably reduce pain and improve function, albeit with trial heterogeneity that tempers precise effect size estimates. Shortwave and PEMF produce compelling physiological changes; the former shines for deep, controllable heating and extensibility, the latter for nonthermal bioelectric modulation of cartilage and subchondral bone. Animal-dominant PEMF datasets warrant more clinical trials, but mechanistic plausibility and early human results are encouraging. Electrotherapy exhibits broadly positive outcomes and excellent feasibility, with stronger and more durable effects reported as frequency rises into the mid- and high-frequency ranges in select trials. Feasibility and cost can tip decisions as much as efficacy. Data from Zhejiang Province illustrate wide cost dispersion: ultrasound, LILT, and PEMF command high equipment costs and professional operation, limiting community scalability. Shortwave is cheaper per session than laser yet still requires specialized infrastructure and training. By contrast, acupuncture is inexpensive per treatment but demands expertise; its outcomes track closely with practitioner skill and protocol fidelity. Moxibustion and simple electrotherapy occupy the sweet spot of cost-effectiveness, convenience, and operational simplicity. Moxibustion equipment is inexpensive, home-deployable, and readily learned with instruction; electrotherapy patches are easy to place near target acupoints, lowering the precision burden of needle placement and enabling supervised home programs. Both approaches, however, benefit from initial professional guidance for safety, dosing, and integration with exercise and medication.

Synthesis across modalities suggests rational sequencing and combination. For access-limited or home-based care, begin with education, exercise therapy, weight management, moxibustion, and basic

electrotherapy. Layer clinic-based options—acupuncture for short- to medium-term analgesia; ultrasound for pain plus structural monitoring; shortwave for chronic stiffness and extensibility; PEMF where subchondral remodeling and synovitis predominate; and LILT to boost cellular metabolism and reduce inflammatory tone. Combine modalities with distinct mechanisms when feasible: acupuncture plus shortwave for neurovascular synergy; laser-acupuncture for photobiomodulatory amplification; electroacupuncture when standardization is desirable. Throughout, track validated outcomes (pain scales, WOMAC, performance tests) and adjust parameters iteratively. Ultimately, no single modality suffices for every KOA phenotype. The most defensible stance is pragmatic pluralism: select a foundation of exercise and education, add low-cost, high-feasibility options (moxibustion, electrotherapy) for broad access, and escalate to technology-intensive modalities (shortwave, LILT, PEMF) when indications, resources, and supervision align. Such tiered, mechanism-aware strategy balances evidence with real-world constraints, offering patients meaningful pain relief and functional gains while stewarding cost and complexity.

Conclusion:

In conclusion, physical therapy offers a diverse and effective arsenal for the conservative management of Knee Osteoarthritis, providing significant benefits in pain relief, functional improvement, and quality of life. The evidence supports a range of modalities, from traditional practices like acupuncture and moxibustion to modern technologies such as therapeutic ultrasound, PEMF, and laser therapy. Each intervention operates through unique physiological mechanisms—whether neuromodulation, deep heating, photobiomodulation, or electromagnetic induction—making them suitable for different clinical presentations and patient preferences. Crucially, the most effective approach is not reliance on a single modality but the strategic integration of multiple therapies. A combination of mechanism-diverse treatments, such as acupuncture with shortwave therapy or laser with exercise, often produces synergistic effects that surpass those of individual treatments. Therefore, a pragmatic, patient-centered framework is essential. This should be built on a foundation of exercise and education, augmented with accessible options like moxibustion for broad application, and escalated to more specialized, technology-driven modalities when indicated and resources allowed. This tiered, multimodal strategy ensures personalized, cost-effective care that maximizes clinical outcomes for individuals suffering from KOA.

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