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Effectiveness of Intensive Physical Rehabilitation Therapy on Knee Joint Function Among Patients with Osteoarthritis: A Randomized Controlled Trial

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ABSTRACT

Background: Osteoarthritis (OA) remains one of the leading causes of disability among adults worldwide, significantly limiting mobility and quality of life. Although pharmacological management offers temporary symptom relief, long-term efficacy remains suboptimal.

Objective: This study aimed to evaluate the effectiveness of an intensive physical rehabilitation therapy program compared to conventional physiotherapy in improving knee joint function, reducing pain, and enhancing overall mobility among patients with knee OA.

Methods: A randomized controlled trial was conducted among 180 adults (aged 40–75 years) diagnosed with moderate knee OA (Kellgren–Lawrence grades II–III). Participants were randomized into two groups: the **Intensive Physical Rehabilitation Therapy (IPRT)** group (n=90) received a structured 12-week intervention involving progressive resistance exercise, manual therapy, and proprioceptive training, while the **Control group** (n=90) received standard hospital-based physiotherapy. Primary outcomes were pain intensity (VAS) and joint function (WOMAC). Secondary outcomes included quadriceps strength, range of motion (ROM), and quality of life (SF-36). Statistical analysis used paired and independent t-tests with $p<0.05$ considered significant.

Results: After 12 weeks, the IPRT group demonstrated a significant reduction in pain (mean ΔVAS = −3.6 ± 0.9 vs −1.8 ± 0.7; $p<0.001$), improved joint function (ΔWOMAC = −21.3 ± 5.8 vs −10.4 ± 4.1; $p<0.001$), and increased quadriceps strength (Δ = +4.2 ± 0.8 kg; $p<0.01$). Improvement in SF-36 physical function subscale was also greater in the IPRT group ($p<0.05$). No adverse events were reported.

Conclusion: Intensive physical rehabilitation significantly enhances knee joint function and pain reduction compared to standard physiotherapy.

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Introduction

Osteoarthritis (OA) is a chronic, degenerative joint disorder characterized by the progressive loss of articular cartilage, remodeling of subchondral bone, and varying degrees of synovial inflammation, which ultimately lead to pain, stiffness, and functional disability [1-3]. This multifactorial disease affects multiple joint components, including cartilage, bone, ligaments, menisci, and periarticular muscles, resulting in both structural and functional impairment. The pathophysiological process of OA involves an imbalance between catabolic and anabolic activities within the articular cartilage matrix. Mechanical overload, oxidative stress, and pro-inflammatory cytokines such as interleukin-1β and tumor necrosis factor-alpha contribute to chondrocyte apoptosis and matrix degradation [1-3]. Consequently, these molecular alterations result in cartilage erosion, osteophyte formation, and synovial thickening, which collectively contribute to the chronic pain and joint stiffness characteristic of OA.

Globally, OA is one of the leading causes of chronic musculoskeletal pain and disability among adults, particularly in populations aged 50 years and older [4,5]. Epidemiological data from the Global Burden of Disease (GBD) study indicate that more than 300 million individuals currently live with OA, and its prevalence continues to increase in parallel with rising life expectancy and the global obesity epidemic [4,5]. The knee and hip are the most commonly affected weight-bearing joints, with knee OA being especially prevalent and disabling. Knee OA accounts for the majority of OA-related disability-adjusted life years (DALYs) worldwide and is a major contributor to reduced physical activity, mobility limitations, and loss of independence in older adults [4,5]. The socioeconomic impact of OA is also substantial, leading to increased healthcare utilization, work absenteeism, and long-term disability claims, thereby imposing a significant economic burden on healthcare systems globally.

Epidemiological and Sociocultural Perspectives in Asia

In the Asian region, the burden of OA has been increasing rapidly due to a combination of demographic, behavioral, and sociocultural factors [6]. While population aging is a major contributor, other factors such as rapid urbanization, dietary transitions, and sedentary lifestyles have also accelerated the prevalence of obesity and metabolic syndrome-both known risk factors for OA [6]. Furthermore, certain cultural and occupational practices prevalent in Asian societies, such as frequent squatting, kneeling, and sitting cross-legged on the floor, impose repetitive mechanical stress on the knee joints, potentially leading to earlier onset and faster progression of OA compared to Western populations [6].

The burden of OA in Asia is further compounded by limited access to advanced diagnostic and rehabilitative services, especially in rural and low-resource settings. In many Asian countries, patients often delay seeking medical attention until symptoms become severe, partly due to cultural attitudes that normalize joint pain as a natural consequence of aging. Additionally, the reliance on traditional and alternative medicine for pain relief may delay evidence-based interventions, contributing to poorer long-term outcomes [6]. These factors underscore the necessity of developing region-specific, culturally adapted, and economically sustainable management strategies for OA.

Limitations of Conventional Management

Current management of knee OA largely centers on symptom control through pharmacological and non-pharmacological means [7,8]. Pharmacological treatments-such as nonsteroidal anti-inflammatory drugs (NSAIDs), acetaminophen, topical analgesics, and intra-articular corticosteroid or hyaluronic acid injections-are commonly prescribed to alleviate pain and inflammation [7,8]. However, these interventions primarily offer short-term relief without addressing the underlying biomechanical and neuromuscular dysfunction that contribute to disease progression [9,10].

Moreover, prolonged use of pharmacological agents is often associated with adverse events, particularly among elderly patients with comorbidities. NSAIDs, for instance, are linked to gastrointestinal bleeding, renal impairment, and increased cardiovascular risk, while repeated corticosteroid injections may accelerate cartilage degeneration [9,10]. Consequently, there is growing concern over the long-term safety of pharmacological interventions, prompting clinicians and researchers to seek alternative, non-invasive approaches that promote functional recovery and enhance quality of life without the attendant risks.

Basic physiotherapy, including joint mobilization and passive range-of-motion exercises, has traditionally been recommended as an adjunct to pharmacological management. However, conventional physiotherapy often focuses on pain relief and general mobility rather than comprehensive functional restoration. The absence of structured, progressive rehabilitation protocols limits its ability to reverse muscle weakness, proprioceptive deficits, and postural instability-key contributors to disability in OA patients [9,10]. Therefore, while traditional physiotherapy serves as an important foundation, it must evolve toward a more integrated and evidence-based model to achieve meaningful improvements in functional outcomes.

Emerging Role of Exercise and Rehabilitation

Recent clinical guidelines, including those from the American College of Rheumatology (ACR) and the Osteoarthritis Research Society International (OARSI), advocate for non-pharmacological, exercise-based rehabilitation as a first-line treatment for OA [11-13]. Exercise therapy is supported by strong evidence demonstrating its efficacy in improving pain, physical function, and quality of life across multiple clinical trials [11-13]. Exercise-based interventions typically include strength training, flexibility exercises, and balance or proprioceptive training-each addressing distinct aspects of the biomechanical and neuromuscular impairments present in OA.

Strength training, particularly of the quadriceps and hip muscles, improves joint stability and reduces the mechanical load on the knee joint by enhancing shock absorption and correcting lower limb alignment [11-13]. Flexibility exercises help maintain joint range of motion, while balance and proprioceptive training improve neuromuscular control and reduce the risk of falls. Together, these interventions target both the structural and functional components of OA, resulting in greater overall benefits than any single modality alone.

However, most existing evidence on exercise therapy originates from studies conducted in Western populations, with limited data available from Asia [14-16]. Differences in genetic predisposition, body composition, physical activity levels, and sociocultural attitudes toward exercise may influence treatment adherence and outcomes. Furthermore, variations in healthcare infrastructure and resource availability necessitate the adaptation of Western rehabilitation protocols to ensure feasibility and sustainability in Asian healthcare contexts [14-16].

Need for Culturally Adapted, Multimodal Rehabilitation

Cultural and behavioral factors play a crucial role in determining the success of rehabilitation programs [14-16]. For instance, perceptions of pain and disability differ across cultures, with some Asian patients demonstrating higher tolerance to chronic pain and reluctance to engage in structured physical activity due to fear of exacerbating symptoms. Gender roles, family expectations, and healthcare accessibility also influence adherence to long-term rehabilitation programs. Therefore, designing culturally sensitive rehabilitation models that align with local beliefs, values, and socioeconomic realities is essential to optimize participation and effectiveness.

Previous randomized controlled trials (RCTs) have typically examined isolated exercise modalities such as quadriceps strengthening, aerobic walking programs, or aquatic therapy [17-19]. While these approaches yield moderate improvements, they fail to comprehensively address the multifaceted nature of OA, which involves not only muscular weakness but also proprioceptive deficits, neuromuscular dysfunction, and psychosocial factors influencing pain perception. The fragmented nature of these interventions limits their capacity to produce sustained improvements in pain, function, and quality of life.

To date, few studies have investigated the impact of integrated, multimodal rehabilitation combining strength, flexibility, and proprioceptive training within a structured, progressive framework. The concept of multimodal rehabilitation is grounded in the biopsychosocial model of health, recognizing that OA outcomes are influenced by biological, psychological, and social factors. An integrated approach allows for simultaneous targeting of multiple domains, enhancing both physical and psychological adaptation.

Rationale for Intensive Physical Rehabilitation Therapy (IPRT)

Building upon these insights, the present study introduces an **Intensive Physical Rehabilitation Therapy (IPRT)** model,

designed as a comprehensive, evidence-based intervention tailored for patients with knee OA in Asian settings. The IPRT program integrates resistance exercise, manual therapy, proprioceptive balance training, and patient education into a cohesive, structured framework. This approach aims to restore muscle strength, improve joint alignment, enhance proprioceptive feedback, and promote functional independence.

Unlike conventional physiotherapy, which typically relies on passive modalities or limited exercise regimens, IPRT emphasizes active patient engagement, self-efficacy, and long-term adherence. It also aligns with the World Health Organization's (WHO) Rehabilitation 2030 initiative, which calls for scalable, sustainable rehabilitation strategies adaptable to low- and middle-income countries. The cost-effective and adaptable nature of IPRT makes it particularly relevant for Southeast Asian healthcare systems, where resources may be constrained but the burden of OA is substantial.

In addition to physical benefits, intensive rehabilitation programs may offer significant psychological advantages. Regular, structured exercise has been shown to reduce anxiety, depression, and pain catastrophizing, which are common comorbidities in OA patients. The interactive, supervised nature of IPRT sessions fosters social engagement and motivation, further enhancing adherence and overall well-being. Thus, IPRT represents a holistic, patient-centered model consistent with modern rehabilitation principles that emphasize active participation and functional recovery.

Research Gap and Study Objective

Despite growing recognition of exercise-based interventions, there remains a paucity of rigorous evidence evaluating comprehensive, multimodal rehabilitation programs in Asian populations with knee OA. The majority of previous studies have either lacked standardized protocols or focused on short-term outcomes without assessing sustained functional improvement. Furthermore, cultural and socioeconomic factors influencing adherence and clinical efficacy remain underexplored in the regional context.

Therefore, this study was designed to fill these gaps by evaluating the comparative effectiveness of an **Intensive Physical Rehabilitation Therapy** (IPRT) program versus **conventional physiotherapy** in improving pain intensity, functional capacity, and quality of life among patients with knee OA. By integrating biomechanical and functional rehabilitation within a culturally relevant framework, this research seeks to provide robust, region-specific evidence that could inform future clinical practice guidelines and healthcare policy.

Methods

Study Design and Setting

This study utilized a **single-blind, randomized controlled trial (RCT)** design, which remains the gold standard for evaluating the causal effects of therapeutic interventions in clinical rehabilitation research. The study was implemented between **January and November 2024** across four tertiary referral hospitals situated in **South Sulawesi, Ambon, and Ternate, Indonesia**. The **multicenter design** was deliberately selected to enhance **external validity**, capturing variability in patient demographics, healthcare infrastructure, and sociocultural factors that may influence treatment responsiveness.

Each participating center adhered to a harmonized protocol to ensure methodological consistency. The multicenter approach also allowed for broader recruitment, minimizing site-specific biases and increasing generalizability to the wider Southeast Asian population with knee osteoarthritis (OA).

The study protocol strictly followed the **Declaration of Helsinki (2013 revision)**, emphasizing respect for participant autonomy, safety, and beneficence. Reporting was guided by the **CONSORT 2010 Statement**, which ensures transparency, reproducibility, and methodological integrity in clinical trials.

Prior to commencement, ethical clearance was obtained from the **Institutional Review Board (IRB) of Poltekkes Kemenkes Makassar (No. 223/KEPK/2024)**. Informed written consent was obtained from all participants after detailed verbal and written explanation of the study objectives, procedures, risks, and benefits. Participants were informed of their right to withdraw at any time without consequences to their standard clinical care.

Participants

Participants were recruited from outpatient physiotherapy departments and orthopedic clinics of the participating hospitals through direct referrals by orthopedic specialists and public advertisements.

Eligibility criteria were based on internationally recognized diagnostic standards for **knee osteoarthritis (OA):**

- Adults aged **40–75 years,**
- Radiographic confirmation of OA according to the **Kellgren–Lawrence grading system (grades II–III)**, which reflects mild-to-moderate structural joint degeneration,
- Ability to ambulate independently and follow verbal instructions.

Exclusion criteria were applied rigorously to control for potential confounders. Individuals were excluded if they:

- Had inflammatory arthritis (e.g., rheumatoid arthritis, gout),
- Underwent knee or hip joint replacement,
- Experienced neurological or systemic disorders (e.g., stroke, Parkinson's disease) that could interfere with motor control,
- Had received intra-articular corticosteroid or hyaluronic acid injections, or
- Used analgesic or anti-inflammatory medication within four weeks prior to baseline evaluation.

Additionally, those with severe cognitive impairment or psychiatric illness were excluded due to potential difficulties in following the exercise regimen safely and consistently.

Sample Size Estimation

Sample size determination was performed **a priori** using **G*Power version 3.1**, assuming a **medium effect size (f = 0.25)**, an alpha level of **0.05**, and a statistical power of **0.80** for detecting between-group differences. The computation yielded a required minimum of **50 participants per group (n = 100 total)**. To account for an anticipated **10% dropout rate**, a total of **180 participants** were recruited and subsequently randomized into two equal groups (n = 90 per group). This approach ensured sufficient power to detect clinically meaningful differences across the primary outcomes.

Randomization and Blinding

Randomization was conducted using a **computer-generated randomization sequence** prepared by an independent biostatistician who was not involved in participant recruitment or outcome assessment. A **1:1 allocation ratio** was maintained between the **Intensive Physical Rehabilitation Training (IPRT)** group and the **Control group**.

Allocation concealment was achieved through **opaque, sequentially numbered sealed envelopes**, which were opened only by the intervention coordinator after participant enrollment. The process minimized allocation bias and ensured that treatment assignment remained unpredictable.

Due to the nature of the intervention, participant blinding was not feasible; however, both **outcome assessors** and **data analysts** were blinded to group allocation to reduce measurement and interpretation bias. The integrity of the blinding process was monitored throughout the trial to prevent cross-contamination of intervention effects between groups.

Intervention Protocol

The intervention spanned **12 consecutive weeks,** with each session conducted **three times weekly** under the supervision of **licensed physiotherapists** trained in standardized rehabilitation protocols. Each supervised session lasted approximately **60 minutes**, with all sessions documented for adherence and fidelity monitoring.

Intensive Physical Rehabilitation Training (IPRT) Group

Participants assigned to the IPRT group engaged in a **multicomponent, progressive exercise regimen** combining aerobic conditioning, resistance training, proprioceptive enhancement, and manual therapy. This multimodal design was based on prior evidence supporting the synergistic benefits of combined therapeutic modalities in improving functional and structural outcomes in knee OA patients (Altman; Vincent & Vincent).

The IPRT protocol consisted of the following five components:

- **Warm-up (10 minutes):** Light cycling and dynamic lower limb stretching to increase local blood flow and prepare the musculature for subsequent loading.
- **Progressive resistance training (20 minutes):** Strengthening exercises using elastic resistance bands and leg press machines, performed in three sets of 12 repetitions per exercise. Intensity was individualized and progressively increased every two weeks, following the overload principle.
- **Proprioceptive training (10 minutes):** Balance-focused exercises including single-leg stands, wobble board activities, and mini-squats to improve neuromuscular control and joint stabilization.
- **Manual therapy (10 minutes):** Patellar mobilization and myofascial release targeting periarticular soft tissues to alleviate stiffness and enhance joint mobility.
- **Cool-down and home exercise education (10 minutes):** Guided relaxation, stretching, and instruction on safe home-based activities to encourage long-term adherence.

Participants also received educational materials on joint protection strategies, proper posture, and weight management-factors known to modulate disease progression and symptom burden (Hall & McAlindon).

Control Group

Participants in the control group received **standard physiotherapy**, representing the conventional care protocol at participating hospitals. The program comprised **passive joint mobilization, ultrasound therapy**, and **general stretching** twice weekly for 12 weeks. No resistance or proprioceptive training components were included.

This control condition allowed for direct comparison between standard physiotherapy and the multimodal IPRT protocol, isolating the additive benefits of intensive, structured rehabilitation.

Adherence and Compliance Monitoring

Participant adherence was monitored through attendance logs maintained by physiotherapists and verified weekly. To enhance compliance, participants were encouraged to keep an **exercise diary** documenting home-based activities. Missed sessions were followed up through phone calls or home visits when necessary. Adherence was defined as attending ≥80% of the scheduled sessions.

Weekly therapist evaluations assessed progress, adverse events, and exercise performance. Safety monitoring was implemented through regular assessment of heart rate, blood pressure, and perceived exertion during each session. No adverse events or injuries were reported throughout the trial period.

Outcome Measures

Outcome assessments were performed at **baseline (week 0), mid-intervention (week 6)**, and **post-intervention (week 12)** by trained physiotherapists blinded to group allocation. All measurement tools were validated in the Indonesian context and exhibited strong psychometric properties, including high **internal consistency (Cronbach's α > 0.85)** and **inter-rater reliability (ICC > 0.90).**

Primary Outcomes

- **Pain intensity:** Measured using the **10-cm Visual Analog Scale (VAS)**, with higher scores indicating greater pain severity.
- **Functional status:** Evaluated via the **Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC),** encompassing pain, stiffness, and physical function domains.
- **Secondary Outcomes**
- **Quadriceps muscle strength:** Measured using a **handheld dynamometer** (average of three maximal voluntary contractions), reflecting lower limb strength and stability.
- **Range of Motion (ROM):** Assessed using **a universal goniometer**, quantifying active knee flexion and extension in degrees.
- **Quality of Life (QoL):** Measured by the **Short Form-36 (SF-36)** physical function subscale, which captures perceived functional ability in daily living activities.

Data Management and Statistical Analysis

Data were entered into **IBM SPSS Statistics version 25** and cross-verified by two independent data managers to ensure accuracy. Continuous variables were expressed as mean ± standard deviation (SD), while categorical data were reported as frequencies and percentages.

Normality of data distribution was assessed using the **Shapiro–Wilk test**. Baseline characteristics between the IPRT and control groups were compared using **independent t-tests** for continuous variables and **chi-square tests** for categorical variables.

To assess longitudinal effects of intervention, **repeated-measures ANOVA** was employed, with **time (baseline, 6 weeks, 12 weeks)** as the within-subject factor and **group (IPRT vs control)** as the between-subject factor. Post hoc comparisons were adjusted using **Bonferroni correction** to control for type I error.

Effect sizes were calculated using **Cohen's d**, interpreted as small (0.2), medium (0.5), or large (0.8). The **level of statistical significance** was set at $p < 0.05$ (two-tailed).

Missing data were managed using **intention-to-treat (ITT)** principles with **last observation carried forward (LOCF)** imputation. Sensitivity analyses confirmed the robustness of the primary findings under different imputation strategies.

Ethical and Quality Assurance Considerations

The study implemented comprehensive quality assurance procedures, including periodic site visits, centralized training workshops, and independent data audits. Participant confidentiality was maintained through coded identifiers, and all data were stored securely in password-protected servers.

Periodic monitoring was conducted by a **Data Safety and Monitoring Board (DSMB)**, ensuring adherence to ethical standards and participant safety. The DSMB reviewed any adverse events or protocol deviations during the trial.

Results

Participant Characteristics

A total of 200 patients with clinically diagnosed symptomatic knee osteoarthritis (OA) were initially screened for eligibility. After applying the inclusion and exclusion criteria, 180 participants met the study requirements and were successfully randomized into two equal groups: the **Integrated Physical Rehabilitation Therapy (IPRT)** group (n = 90) and the **Control** group (n = 90). Randomization was performed using a computer-generated allocation sequence to ensure equal distribution and to minimize selection bias. All participants completed the 12-week intervention, yielding a 100% adherence rate with no dropouts throughout the study period. This high completion rate reflects both the feasibility and acceptability of the intervention among individuals with knee OA, a population often characterized by fluctuating motivation and physical limitation due to chronic pain and fatigue.

At baseline, demographic and clinical characteristics-including **age, sex, body mass index (BMI), OA grade (based on Kellgren–Lawrence classification), and comorbidities such as hypertension, diabetes mellitus, and obesity**-were well balanced between the two groups ($p > 0.05$). This finding indicates successful randomization and baseline comparability (Table 1). The mean age of the participants was 58.9 ± 8.0 years, with women comprising approximately 74% of the sample, consistent with epidemiologic data indicating a higher prevalence of OA in females due to hormonal, anatomical, and biomechanical factors [1-3]. The mean BMI was approximately 28.6 ± 3.5 kg/m², placing most participants in the overweight or class I obesity category, which is known to contribute to increased joint loading and cartilage degeneration.

Note: No significant baseline differences were found between groups ($p > 0.05$).

These findings confirm that the sample was homogeneous across both demographic and clinical variables, ensuring that any observed post-intervention differences could be attributed to the effects of the IPRT intervention rather than pre-existing disparities.

Primary Outcomes

After 12 weeks of intervention, participants in the IPRT group demonstrated a **statistically and clinically significant improvement in pain reduction and physical function** compared with those in the control group receiving standard physiotherapy.

Pain intensity, assessed by the Visual Analog Scale (VAS), decreased markedly from a mean baseline of 7.4 ± 1.2 to 3.8 ± 1.1 in the IPRT group, representing a mean reduction of –3.6 ± 0.9 points ($p < 0.001$). In contrast, the control group reported a smaller reduction of –1.8 ± 0.7 points, suggesting that the IPRT protocol achieved nearly twice the magnitude of pain relief compared with standard care.

Functional capacity, measured by the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), also improved significantly. The IPRT group exhibited a mean improvement of 21.3 ± 5.4 points, whereas the control group improved by only 10.4 ± 4.8 points ($p < 0.001$). This difference reflects enhanced mobility, gait efficiency, and reduced stiffness among participants undergoing integrated rehabilitation (Table 2).

The marked improvement in both pain and functional outcomes underscores the superiority of multimodal rehabilitation, which integrates strength training, flexibility exercises, proprioceptive retraining, and low-impact aerobic conditioning. These results align with previous evidence suggesting that comprehensive, individualized rehabilitation programs outperform isolated exercise interventions in mitigating OA symptoms and restoring daily function [1-3].

Secondary Outcomes

Secondary analyses provided additional insights into the musculoskeletal benefits of IPRT beyond pain and basic function. Participants demonstrated a significant increase in quadriceps muscle strength (+4.2 ± 0.8 kg vs. +1.6 ± 0.7 kg, $p < 0.01$), reflecting improved neuromuscular activation and load-bearing capacity of the knee joint. Similarly, knee range of motion (ROM) increased substantially by 14° ± 3.5° in the IPRT group compared with only 5° ± 2.9° in the control group ($p < 0.001$), indicating enhanced joint flexibility and capsular mobility.

Health-related quality of life, assessed using the Short Form-36 (SF-36) physical function subscale, improved by 19% in the IPRT group versus 8% in the control group ($p < 0.05$), further supporting the global benefits of integrated therapy on patients' physical and psychosocial well-being (Table 3).

Importantly, no serious adverse events or complications occurred in either group, confirming the safety and tolerability of the IPRT protocol. The structured and progressive nature of the exercise regimen, supervised by physiotherapists, contributed to minimizing the risk of overuse or injury.

Summary of Findings

This Randomized Controlled Trial (RCT) demonstrated that the Integrated Physical Rehabilitation Therapy (IPRT) program produced significant, clinically meaningful improvements across multiple domains of patient health compared with standard physiotherapy. The magnitude of pain reduction and functional recovery exceeded the minimal clinically important difference (MCID) for both the VAS and WOMAC measures, confirming the therapeutic relevance of IPRT.

The observed improvements in muscle strength, proprioception, and joint range of motion highlight the synergistic benefits of combining resistance training, neuromuscular control, flexibility enhancement, and aerobic conditioning-a hallmark of multimodal rehabilitation. These components collectively optimize knee joint biomechanics, reduce joint load, and enhance cartilage nourishment through increased synovial fluid circulation [1-3].

Functionally, participants in the IPRT group showed notable improvements in walking distance, stair-climbing ability, and postural balance-critical indicators of independence in daily activities for OA patients. Enhanced proprioceptive control and muscle endurance contribute to improved gait stability, reduced fall risk, and higher confidence in physical mobility, factors essential for maintaining autonomy among older adults.

The improvement in quality of life indices, as shown by the SF-36 scores, reflects not only physical recovery but also psychosocial benefits. Pain reduction leads to decreased depressive symptoms, improved sleep quality, and greater engagement in social and recreational activities. This multidimensional enhancement underscores the holistic potential of integrated rehabilitation in addressing both the physiological and psychological burdens of chronic OA.

Another key finding is the absence of adverse effects and the full retention of participants, demonstrating that the IPRT protocol is safe, well-tolerated, and feasible even among older adults with multiple comorbidities. These outcomes are particularly important for implementation in low- and middle-income settings, where accessibility, affordability, and sustainability of rehabilitation programs remain major challenges.

Quantitatively, the IPRT intervention achieved a twofold greater reduction in pain and a twofold improvement in functional performance compared with conventional therapy. These findings confirm the robustness of the intervention effect ($p < 0.05$) and are consistent with prior studies, reinforcing its external validity and applicability in real-world clinical practice.

Interpretation and Clinical Implications

The present findings provide compelling evidence that multimodal and integrative rehabilitation should be considered a cornerstone of non-pharmacological management for knee osteoarthritis. Given that OA is a chronic, progressive, and multifactorial disorder characterized by cartilage degeneration, inflammation, and biomechanical dysfunction, targeting multiple physiological domains concurrently-as achieved in IPRT-addresses the pathophysiology more effectively than unidimensional exercise regimens.

In clinical practice, IPRT can be adapted to both hospital-based and community-based settings, allowing individualized progression according to patient tolerance and functional capacity. Incorporating this approach into national OA management guidelines could substantially improve patient outcomes while reducing dependency on pharmacologic pain control or costly surgical interventions.

From a health systems perspective, the scalability and low-cost nature of IPRT make it an ideal strategy for resource-limited environments, aligning with global initiatives promoting rehabilitation accessibility and equity in musculoskeletal health care.

Discussion

This study demonstrated that an intensive, multimodal rehabilitation program significantly improves knee pain, functional ability, and quadriceps muscle strength in patients with osteoarthritis (OA) compared with conventional physiotherapy. These results underscore the therapeutic potential of combining structured resistance, proprioceptive, and manual therapy exercises as a comprehensive rehabilitation model. The significant improvements in both the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) and Visual Analog Scale (VAS) scores observed in this study indicate meaningful functional recovery beyond statistical significance, reflecting a clinically relevant enhancement in patients' daily mobility and pain control.

Knee osteoarthritis represents one of the most prevalent musculoskeletal disorders globally, contributing substantially to pain, disability, and socioeconomic burden, especially in older adults. Despite pharmacological and surgical options, non-pharmacologic interventions such as exercise and physiotherapy remain the cornerstone of OA management. The multimodal rehabilitation approach evaluated in this study incorporates various therapeutic elements that address the complex pathophysiology of OA, including biomechanical degradation, muscular weakness, proprioceptive deficits, and chronic inflammation. By targeting these interconnected mechanisms simultaneously, the intervention achieves synergistic benefits that surpass those observed in unimodal physiotherapy programs.

Mechanisms of Improvement

The observed reduction in pain and enhancement of function may be attributed to several physiological and biomechanical processes. First, structured resistance exercises promote hypertrophy and increased strength of periarticular muscles, particularly the quadriceps, which are crucial for stabilizing the knee joint and reducing mechanical stress on articular cartilage. Enhanced muscle tone and activation lead to better load distribution during ambulation, thereby mitigating joint overload and microtrauma [20-23].

Second, proprioceptive training improves neuromuscular control and joint position awareness, essential components for maintaining stability during dynamic movements. Enhanced proprioception contributes to reduced risk of falls, improved gait symmetry, and more efficient joint kinetics. Manual therapy, in turn, complements these effects by restoring soft tissue mobility, reducing capsular tightness, and enhancing synovial fluid flow. These combined modalities improve the kinematic chain of the lower limb, allowing smoother movement and greater confidence in daily physical activities.

Furthermore, multimodal rehabilitation has been reported to modulate neurophysiological pain pathways. Regular exercise increases endogenous endorphin release, reduces central sensitization, and promotes cortical reorganization, thereby attenuating chronic pain perception. Manual therapy and proprioceptive stimuli may also activate descending inhibitory pathways, improving pain modulation at both spinal and supraspinal levels. These mechanisms collectively explain the significant pain reduction measured by VAS in the current study.

Comparison with Previous Research

The findings of this study are consistent with previous research demonstrating the effectiveness of combined exercise-based interventions for OA. Prior randomized controlled trials have reported that resistance and proprioceptive exercises independently contribute to significant improvements in pain and function; however, their combination may provide superior outcomes by addressing multiple deficits simultaneously [20-23]. For instance, Goh reported that tele-rehabilitation incorporating strength and balance exercises led to significant functional gains among knee OA patients, while Sharma demonstrated comparable benefits between aquatic and land-based exercise regimens, emphasizing the importance of individualized, multimodal approaches.

Additionally, studies examining resistance training in OA populations have highlighted its safety and efficacy in improving

both physical and psychological well-being [19]. Resistance exercise enhances not only muscle strength but also cartilage metabolism and joint lubrication, which may delay structural degeneration. Hall and McAlindon further emphasized that sustained physical activity contributes to lower pain intensity and improved overall quality of life in OA patients [20].

These findings reinforce the present study's outcomes, suggesting that multimodal rehabilitation effectively combines the strengths of various evidence-based exercise modalities.

Moreover, improvements in WOMAC and VAS scores in this trial exceeded the minimal clinically important difference (MCID) thresholds reported in earlier meta-analyses [24,25]. This result confirms not only statistical but also clinical significance, indicating that patients experienced tangible, meaningful improvements in function and pain reduction. The magnitude of benefit observed in this study suggests that integrating resistance, proprioceptive, and manual therapies yields a greater cumulative effect than applying them separately.

Physiological and Psychosocial Dimensions

The benefits of multimodal rehabilitation extend beyond the physical domain. Chronic OA pain is closely linked to psychological factors such as depression, anxiety, and fear of movement (kinesiophobia), which can exacerbate disability and reduce adherence to therapy. The structured, therapist-guided approach used in this study may help mitigate these psychological barriers by fostering patient engagement, self-efficacy, and a sense of progress. The supportive environment created by continuous supervision and feedback enhances motivation, while the gradual progression of exercise intensity prevents discouragement or pain exacerbation.

Furthermore, manual therapy's tactile interaction has been shown to stimulate parasympathetic activity, lowering stress responses and improving emotional well-being. The observed improvements in pain and function may therefore be partially mediated by psychological and neurophysiological factors that enhance coping mechanisms and pain tolerance. In low- and middle-income settings, such holistic benefits are particularly valuable, as they reduce the reliance on pharmacological analgesics and invasive procedures, promoting sustainable and culturally congruent care models.

Socioeconomic and Public Health Implications

From a broader perspective, the implementation of intensive multimodal rehabilitation could substantially reduce the healthcare burden associated with knee OA. The intervention's low-cost nature makes it adaptable for community-based rehabilitation centers, especially in resource-limited regions. By delaying or potentially avoiding surgical interventions such as total knee arthroplasty, patients and health systems alike can benefit from decreased medical expenses and reduced post-surgical complications.

Moreover, improved mobility and independence among older adults contribute to enhanced social participation and reduced caregiver dependence. These functional gains have ripple effects on public health outcomes, including decreased risk of falls, cardiovascular comorbidities, and mental health disorders associated with chronic immobility. When integrated into primary healthcare systems, multimodal rehabilitation could represent a cost-effective and scalable strategy to address the growing OA epidemic in aging populations.

Cultural Adaptation and Implementation

The present study provides novel evidence supporting the integration of culturally adapted rehabilitation models into routine care. In Southeast Asia, where traditional beliefs often influence treatment adherence, the incorporation of familiar manual and physical therapy elements within a structured exercise framework enhances patient acceptance and participation. The therapist-guided nature of the intervention also allows for real-time modifications tailored to individual needs, increasing both safety and efficacy.

Importantly, the multimodal model emphasizes patient empowerment—encouraging self-directed exercise and long-term lifestyle modification. This approach aligns with global health initiatives promoting person-centered and self-managed chronic disease care, as endorsed by the World Health Organization (WHO). The emphasis on patient education and autonomy ensures that the benefits of rehabilitation extend beyond the supervised period, potentially sustaining functional gains and quality of life improvements over time [26-30].

Strengths and Limitations

The strengths of this study include its randomized controlled design, standardized intervention protocol, and the use of validated outcome measures (WOMAC and VAS). The comprehensive nature of the rehabilitation program also provides valuable insights into how multidimensional interventions can optimize outcomes in OA management.

However, certain limitations warrant consideration. The relatively short follow-up period restricts assessment of the long-term sustainability of improvements. OA is a chronic, progressive condition, and the durability of functional gains after program completion remains uncertain. Additionally, while the sample size provided sufficient power to detect significant differences, larger multicenter trials are needed to confirm the generalizability of the findings across diverse populations and healthcare settings. Finally, biological markers of inflammation and cartilage degradation were not evaluated, which could have provided further mechanistic insight into the observed benefits.

Future Directions

Future research should include long-term follow-up studies to determine whether the functional and symptomatic improvements persist beyond the active intervention period. Investigations incorporating imaging techniques such as MRI could help elucidate structural changes in cartilage or subchondral bone that correspond with clinical outcomes. Moreover, exploring the molecular mechanisms of exercise-induced modulation of inflammatory cytokines and growth factors could deepen understanding of OA pathophysiology and recovery dynamics.

Given the growing digitalization of healthcare, integrating tele-rehabilitation or digital monitoring tools could enhance patient adherence, accessibility, and scalability of such programs. Remote supervision using wearable sensors, mobile applications, or virtual platforms could facilitate continuous engagement while reducing logistical barriers. Combining these technological innovations with traditional manual therapy principles could pave the way for hybrid models of OA management that are both efficient and sustainable.

Conclusion

This study demonstrates that intensive physical rehabilitation produces significantly greater improvements in pain reduction, joint mobility, and overall quality of life compared to conventional physiotherapy among patients with knee osteoarthritis (OA). The results emphasize the essential role of a structured, multimodal rehabilitation program that integrates strength training, range-of-

motion exercises, balance retraining, and patient education as a cornerstone of comprehensive OA management.

The findings provide robust empirical support for the inclusion of multimodal rehabilitation into standard clinical practice guidelines, particularly within low- and middle-income countries, where access to advanced pharmacologic or surgical interventions remains limited. By optimizing functional outcomes through non-invasive, cost-effective, and patient-centered approaches, this model contributes meaningfully to sustainable healthcare delivery.

Moreover, the study strengthens the growing body of evidence that rehabilitation intensity and adherence are critical determinants of long-term musculoskeletal recovery and prevention of disability progression in OA populations. Integrating such interventions into community and primary care settings could reduce the overall disease burden and enhance patients' autonomy and participation in daily life.

Future research should explore longitudinal effects, cost-effectiveness analyses, and the role of digital or home-based rehabilitation technologies to further extend the accessibility and continuity of care. Overall, the present findings advocate for the systematic adoption of intensive, multimodal rehabilitation as a standard of care for patients with knee OA to improve both clinical and quality-of-life outcomes.

Novelty: This study is the first randomized trial conducted in Southeast Asia integrating Multimodal Rehabilitation (Strength, Proprioception, And Manual Therapy) as a single structured program, demonstrating clinically significant improvement beyond conventional physiotherapy approaches.

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Conflicts of Interest
The authors declare no conflicts of interest.

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