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Effect of combined intrinsic foot muscle strengthening and foot core stabilization training on knee joint loading and functional outcomes in individuals with knee osteoarthritis: A quasi experimental study

Bafna Pranjal Santosh[1], Dr. Manikandan P[2]
[1] Intern, Rashtrasant Janardhan Swami College of Physiotherapy Kokamthan, Maharashtra University of Health Sciences, Maharashtra, India
[2] HOD, Department of Musculoskeletal Physiotherapy, Rashtrasant Janardhan Swami College of Physiotherapy Kokamthan, Maharashtra University of Health Sciences, Maharashtra, India
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Abstract
Background: Knee osteoarthritis (KOA) is a prevalent chronic musculoskeletal disorder associated with pain, reduced mobility, impaired physical function, and disability. Conventional rehabilitation primarily focuses on the knee and proximal lower-limb musculature. The foot, however, represents the distal segment of the kinetic chain, and intrinsic foot muscle function and foot core stability may influence lower-limb alignment and knee loading.
Objective: To evaluate the effect of combined intrinsic foot muscle strengthening and foot core stabilization training on knee joint loading and functional outcomes in individuals with knee osteoarthritis.
Methods: Sixty individuals with clinically and radiographically confirmed Grade II–III KOA were recruited using convenient sampling and randomly allocated to Group A (control group; n=30) or Group B (experimental group; n=30). Both groups received a conventional knee exercise protocol. The experimental group additionally received intrinsic foot muscle strengthening and foot core stabilization training. The study duration was six months. The reported outcomes were the Knee Abduction Test, Timed Up and Go (TUG) Test, and Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC). Pre- and post-intervention data were analyzed using paired-sample t-tests for within-group comparisons and independent-sample t-tests for between-group change-score comparisons.
Results: Both groups demonstrated statistically significant pre- to post-intervention improvement in all three reported outcomes ($p<0.0001$). Group B demonstrated greater improvement than Group A. Knee Abduction Test scores improved by 3.47 kg in Group A and 6.50 kg in Group B. TUG time decreased by 1.97 seconds in Group A and 5.83 seconds in Group B. WOMAC scores decreased by 8.27 points in Group A and 18.43 points in Group B. Between-group comparisons were statistically significant for the Knee Abduction Test ($t=-9.71$, $p<0.0001$), TUG ($t=16.98$, $p<0.0001$), and WOMAC ($t=16.33$, $p<0.0001$).
Conclusion: According to the reported study findings, both interventions improved functional outcomes, while the group receiving the additional intrinsic foot muscle strengthening and foot core stabilization program demonstrated significantly greater improvement. Foot-focused rehabilitation may therefore be considered as an adjunct to conventional physiotherapy in individuals with KOA.

Keywords: Knee osteoarthritis, intrinsic foot muscles, foot core stabilization, functional outcomes, WOMAC, Timed Up and Go, randomized controlled trial

Introduction

Knee osteoarthritis is one of the most prevalent chronic musculoskeletal disorders and is a major contributor to pain, physical disability, and reduced quality of life among middle-aged and older adults. The condition is characterized by progressive degeneration of articular cartilage, subchondral bone remodeling, osteophyte formation, synovial inflammation, and joint-space narrowing, resulting in pain, stiffness, reduced muscle strength, impaired mobility, and limitations in activities of daily living. Osteoarthritis is a major contributor to years lived with disability worldwide. [1, 2]

The prevalence of knee osteoarthritis has increased with population ageing, obesity, previous joint injury, sedentary behavior, and increased life expectancy. Exercise therapy, including strengthening and functional exercise, is an important component of conservative management and has been recommended as a first-line rehabilitation approach.[3]

The foot provides the base of support for standing, balance, posture, and gait. Intrinsic foot muscles contribute to maintenance of the medial longitudinal arch, foot stability, and control of foot motion during weight-bearing. Weakness or impaired activation of these muscles may influence arch stability, plantar pressure distribution, pronation-supination control, and lower-limb biomechanics.[5, 6, 7]

The foot core system conceptualizes foot function as the interaction of passive structures, active muscular components, and neural control mechanisms. Training directed at the foot core may improve intrinsic muscle activation, proprioception, neuromuscular coordination, and dynamic foot stability. Because the foot is the first segment to contact the ground during gait, changes in foot mechanics may influence tibial rotation and the loading environment of the knee.[7]

Exercises such as short-foot exercises, toe-spread-out exercises, toe yoga, towel curls, marble pickup, and resisted foot doming are used to activate and strengthen intrinsic foot musculature. Previous studies have reported beneficial effects of foot and ankle strengthening on pain and function in individuals with KOA.[8, 10, 13, 15] The present study therefore examined the effect of adding intrinsic foot muscle strengthening and foot core stabilization training to conventional knee-focused physiotherapy.

Objectives

Primary objectives:

- To compare the effect of combined intrinsic foot muscle strengthening and foot core stabilization training versus conventional knee exercise alone on knee joint loading surrogates and gait-related parameters in individuals with knee osteoarthritis.
- To compare the effect of the two interventions on knee pain as proposed in the study protocol.
- Secondary objectives:
- To compare self-reported function and stiffness using the WOMAC Index and KOOS as proposed in the study objectives.
- To compare selected foot-related parameters, including navicular drop, medial longitudinal arch height, and abductor hallucis cross-sectional thickness, where assessed.
- To compare dynamic postural control using the Star Excursion Balance Test, where assessed.
- To compare walking capacity using the Six-Minute Walk Test, where assessed.
- To determine whether improvements are retained at the proposed follow-up, where applicable.

Materials and Methods

Study design: Randomized controlled trial.

Study setting/source of data: SJS Hospital, Kopargaon, as reported in the source study document.

Study population: Individuals diagnosed with Grade II–III knee osteoarthritis.

Sampling method: Convenient sampling.

Sample size: 60 participants.

Group allocation: Group A (control group), n=30; Group B (experimental group), n=30.

Study duration: Six months.

Materials: Pen, paper, scale, WOMAC scale, Timed Up and Go assessment materials, Knee Abduction Test materials, and stopwatch.

Selection Criteria

Inclusion criteria:

- Age 45–70 years, either sex.
- Clinically and radiographically confirmed knee osteoarthritis, Kellgren-Lawrence Grade II or III.
- Knee pain on most days for at least the preceding three months, with NPRS ≥3/10 as specified in the protocol.
- Ability to walk independently for at least six minutes without an assistive device.
- Willingness to provide written informed consent and attend supervised sessions.

Exclusion criteria:

- Kellgren-Lawrence Grade I or IV, or previous knee, hip, or ankle joint replacement surgery.
- Intra-articular corticosteroid or viscosupplementation injection within the preceding three months.
- Structural foot deformity, severe pes planus/cavus, hallux valgus requiring surgery, peripheral neuropathy, or diabetic foot complications.
- Uncontrolled cardiovascular, neurological, or vestibular conditions affecting gait or balance.
- Concurrent participation in another structured lower-limb exercise or rehabilitation program.

Intervention Protocol

Both groups received a conventional knee exercise protocol consisting of quadriceps and hamstring isometric and isotonic strengthening, hip abductor and extensor strengthening, straight-leg-raise progressions, mini-squats, step-ups, stationary cycling, and stretching of the quadriceps, hamstrings, and gastrocnemius-soleus complex. The protocol was reported as three sets of 10–15 repetitions per exercise, progressed weekly according to tolerance.

In addition to the conventional protocol, the experimental group performed a progressive intrinsic foot muscle strengthening and foot core stabilization program. The reported program included short-foot exercise, toe-spread-out exercise, toe yoga, towel-curl or marble-pickup exercises, resisted foot doming in sitting and standing, single-leg balance on foam with foot doming, and gait retraining emphasizing active arch control. The program was based on principles described by McKeon *et al*. and Mulligan and Cook.[5 ,7]

Outcome Measures

The source protocol listed knee adduction moment (3D gait analysis) and the Timed Up and Go Test as primary measures, with WOMAC as a secondary measure. The reported final results presented the Knee Abduction Test, Timed Up and Go Test, and WOMAC Scale.

Knee Abduction Test: The participant was instructed regarding the procedure and asked to stand barefoot with feet approximately shoulder-width apart. A single-leg squat or step-down was performed according to the protocol while alignment of the hip, knee, and ankle was observed. The assessment considered medial movement of the knee relative to the foot, and three trials were performed.

Timed Up and Go Test: The participant started from a standard chair, stood on the command 'Go', walked three metres at a comfortable and safe pace, turned, returned to the chair, and sat down. Timing was started on 'Go' and stopped when the participant returned to sitting. Three trials were performed with adequate rest.

WOMAC Scale: The questionnaire consists of 24 items covering pain (5 items), stiffness (2 items), and physical function (17 items). The source document reported scoring according to the version used and calculation of total and domain scores.

Statistical Analysis

- Data analysis was carried out using Microsoft Excel 2016 with the Data Analysis ToolPak. The source document reported that pre- and post-intervention scores followed a normal distribution; therefore, parametric tests were used.
- Paired-sample t-tests were used for within-group comparisons of pre- and post-intervention scores in Group A.

- Paired-sample t-tests were used for within-group comparisons of pre- and post-intervention scores in Group B.
- Independent-sample t-tests were used for between-group comparisons of change scores.
- A p-value <0.05 was considered statistically significant.
- Effect sizes were reported as Cohen's d in the source study results.

Results

A total of 60 patients were enrolled and randomly allocated to Group A (n=30) and Group B (n=30). Both groups completed pre- and post-intervention assessments on the Knee Abduction Test, Timed Up and Go Test, and WOMAC Scale.

Within-Group Comparison

Outcome	Group A Pre	Group A Post	Group B Pre	Group B Post	p-value
Knee Abduction Test (kg)	11.00 ± 2.23	14.47 ± 2.60	11.53 ± 2.32	18.03 ± 2.77	<0.0001
TUG (sec)	17.83 ± 2.09	15.87 ± 2.42	17.50 ± 2.52	11.67 ± 2.76	<0.0001
WOMAC (0–96)	54.03 ± 7.26	45.77 ± 7.22	57.40 ± 7.96	38.97 ± 8.46	<0.0001

All three reported outcomes demonstrated statistically significant pre- to post-intervention changes within both groups.

Outcome	Group	Mean change	% change	t-value	Cohen's d	p-value
Knee Abduction Test	A	+3.47	31.52%	14.84	2.71	<0.0001
Knee Abduction Test	B	+6.50	56.36%	31.31	5.72	<0.0001
TUG	A	-1.97	-11.03%	-13.32	-2.43	<0.0001
TUG	B	-5.83	-33.33%	-33.64	-6.14	<0.0001
WOMAC	A	-8.27	-15.30%	-21.56	-3.94	<0.0001
WOMAC	B	-18.43	-32.11%	-37.58	-6.86	<0.0001

Between-Group Comparison

Outcome	Group A change	Group B change	t-value	p-value
Knee Abduction Test	+3.47	+6.50	-9.71	<0.0001
Timed Up and Go	-1.97	-5.83	16.98	<0.0001
WOMAC	-8.27	-18.43	16.33	<0.0001

Between-group comparisons demonstrated statistically significant differences in the magnitude of improvement for all three reported outcomes. Group B demonstrated a greater mean improvement than Group A on the Knee Abduction Test, TUG, and WOMAC Scale.

Discussion

The present randomized controlled trial examined whether adding intrinsic foot muscle strengthening and foot core stabilization training to conventional knee-focused rehabilitation would improve outcomes in individuals with Grade II–III knee osteoarthritis. The reported findings demonstrated statistically significant improvement within both groups across the Knee Abduction Test, Timed Up and Go Test, and WOMAC Scale. Importantly, the magnitude of improvement was significantly greater in Group B, which the source methodology identified as the experimental group receiving the additional foot-focused program.

The greater improvement in the Knee Abduction Test may be interpreted in relation to improved foot stability and neuromuscular control. The foot core model proposes that intrinsic foot muscles contribute to dynamic arch control and the regulation of foot deformation during weight-bearing activities.[7] Improved intrinsic muscle activation may therefore influence the quality of distal support and lower-limb alignment during functional tasks.

Both groups demonstrated reduced TUG times, indicating improvement in functional mobility. The larger reduction reported in Group B may reflect the combined influence of conventional lower-limb strengthening and additional foot-focused neuromuscular training. Exercises such as short-foot training, toe-spread-out, foot doming, and balance activities may improve the capacity of the foot to provide a stable base during transitional and ambulatory activities. [5, 6, 11, 16]

WOMAC scores improved significantly in both groups, indicating reductions in osteoarthritis-related symptoms and disability. Group B demonstrated a larger mean reduction. Previous randomized trials of foot-ankle strengthening have similarly reported improvements in pain and function in individuals with KOA.[8, 10, 13] The present findings are therefore consistent with the rationale that rehabilitation directed toward the foot and ankle may complement conventional knee-focused management.

The results should be interpreted within the terminology and measurements reported in the source study. The title and protocol emphasize knee joint loading and, at the planning stage, include knee adduction moment as an outcome. However, the final results presented in the source document report the Knee Abduction Test, TUG, and WOMAC. Consequently, conclusions regarding direct changes in instrumented knee joint loading should be made cautiously unless such data are separately available.

Overall, the findings support a kinetic-chain approach to KOA rehabilitation. Conventional strengthening remains important, while the addition of intrinsic foot muscle strengthening and foot core stabilization may provide additional functional benefit. Because these exercises are relatively low-cost and can be progressed from seated to standing and functional activities, they may be clinically feasible as an adjunct to routine physiotherapy.

Conclusion

Based on the reported findings, both conventional physiotherapy and the program incorporating intrinsic foot muscle strengthening and foot core stabilization produced statistically significant improvements in the Knee Abduction Test, Timed Up and Go Test, and WOMAC Scale. However, Group B demonstrated significantly greater improvement across all three reported outcomes. The findings support the use of intrinsic foot muscle strengthening and foot core stabilization as an adjunct to conventional physiotherapy for improving selected functional outcomes in individuals with Grade II–III knee osteoarthritis.

Clinical Implications

- Foot-focused rehabilitation may be incorporated as an adjunct to conventional knee osteoarthritis exercise programs.
- Intrinsic foot muscle exercises are relatively low-cost and can be progressed from non-weight-bearing to functional weight-bearing activities.
- Improving foot stability and neuromuscular control may complement conventional strengthening of the knee and hip musculature.
- A kinetic-chain rehabilitation approach may provide broader functional benefits than a knee-only approach in selected individuals.

Limitations

- Blinding of participants and treating therapists is difficult in exercise-based interventions.
- The source document identifies potential limitations in access to full 3D gait analysis and possible reliance on surrogate measures of knee loading.
- The intervention and follow-up periods may not establish long-term maintenance of benefit or structural disease modification.
- Home exercise adherence may be influenced by self-report bias where home programs are used.
- The study population was restricted to individuals with Grade II–III KOA, which may limit generalizability to more advanced disease.
- A single-centre design may limit external validity.
- The source document contains differences between the planned outcome measures and the outcomes reported in the final results; this should be addressed before journal submission.

Recommendations For Future Research

- Conduct multicentre trials with larger and more diverse samples.
- Use longer follow-up periods to determine the durability of treatment effects.
- Use direct 3D gait analysis where available to quantify changes in knee joint loading.
- Examine dose-response relationships for foot core and intrinsic foot muscle training.
- Investigate whether baseline foot posture, alignment, or KOA severity predicts response to foot-focused rehabilitation.
- Conduct cost-effectiveness analyses of combined foot-knee rehabilitation programs.

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