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Effect Of Sensory Plate-Guided Exercises on Pain Reduction and Functional Outcomes After Total Knee Replacement

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ABSTRACT

Background: Total Knee Replacement (TKR) is a common surgical intervention for advanced knee osteoarthritis, yet post-operative pain and functional limitations often persist. Sensory plate-guided rehabilitation exercises may enhance postural stability, foot biomechanics, and pain reduction during recovery [1].

Objective: To evaluate the effect of sensory plate-guided exercises on pain reduction and functional outcomes in patients following TKR.

Methods: An experimental study was conducted with 30 patients (male: 16, female: 14) aged 40–70 years who underwent TKR. Participants were recruited from the Department of Physiotherapy, Pacific Medical College and Hospital, Udaipur. Patients performed a six-week supervised rehabilitation program, including ankle-toe movements, quadriceps and hamstring isometrics, VMO activation, gluteal and hamstring strengthening, calf raises, and static cycling on sensory plates, five times per week. Outcome measures included the Numerical Pain Rating Scale (NPRS) for subjective pain and baropodometric parameters (load distribution, mean pressure, peak pressure, foot and body barycenter, C.O.P. distance) for functional assessment. Pre- and post-intervention scores were analyzed using paired t-tests, with significance set at $p < 0.05$ [2,3].

Results: Post-intervention, NPRS scores significantly decreased from 7.8 ± 0.83 to 3.7 ± 0.9 ($p < 0.001$), indicating substantial pain reduction. Baropodometric analysis demonstrated significant improvements in load distribution (72.23 ± 3.65% to 70.26 ± 3.50%, p = 0.032), mean pressure (34.45 ± 1.06 kPa to 33.21 ± 1.16 kPa, p = 0.045), foot barycenter (21.35 ± 2.03 mm^2 to 19.54 ± 2.09 mm^2, p = 0.027), body barycenter (91.48 ± 1.02 mm^2 to 59.83 ± 1.07 mm^2, p = 0.003), and C.O.P. distance (139.5 ± 4.98 mm to 106.7 ± 5.20 mm, p = 0.018). Peak pressure during contact and propulsion phases showed non-significant changes, suggesting targeted interventions may be required for phase-specific gait improvement [4,5].

Conclusion: Sensory plate-guided exercises significantly reduced pain and enhanced postural stability and foot function in post-TKR patients. Incorporating sensory plate-based rehabilitation may optimize functional recovery and improve gait mechanics after knee replacement surgery [6].

Keywords: *Total Knee Replacement, Sensory Plate, Rehabilitation, Pain Reduction, Functional Outcomes, Baropodometry.*

1. INTRODUCTION

Total Knee Replacement (TKR) is widely recognized as an effective surgical intervention for managing end-stage osteoarthritis and other degenerative knee disorders, aiming to relieve pain, restore joint function, and improve patients' quality of life [7]. Despite surgical success, many patients continue to experience postoperative challenges such as pain, reduced muscle strength, impaired balance, and functional limitations, which may hinder optimal recovery [8,9].

Postoperative rehabilitation is crucial in restoring mobility and promoting functional independence. Conventional rehabilitation primarily emphasizes strengthening exercises for quadriceps, hamstrings, and other supporting muscles, as well as range-of-motion and gait training [10,11]. However, these methods may not adequately address postural instability, asymmetrical load distribution, or abnormal gait mechanics, which can contribute to delayed functional recovery and increased risk of falls [12].

Recent advancements in rehabilitation have highlighted the role of **sensory plate-guided exercises**. These exercises provide real-time feedback on foot pressure, weight distribution, and center of pressure (C.O.P.), allowing patients to optimize balance and proprioception during recovery [13]. Integrating sensory feedback into post-TKR rehabilitation may facilitate more symmetrical weight-bearing, improve gait patterns, and accelerate functional recovery while reducing pain [14,15].

Despite the potential advantages, limited research has systematically investigated the effect of sensory plate-guided exercises on pain reduction and functional outcomes in post-TKR patients. This study aims to evaluate the efficacy of a six-week sensory plate-guided rehabilitation program on pain, plantar pressure distribution, and functional parameters following TKR [16].

2. BACKGROUND

Postoperative recovery following Total Knee Replacement (TKR) involves addressing both pain and functional deficits to restore mobility and independence [17]. Pain management is a primary concern, as residual pain can limit participation in rehabilitation exercises, reduce quadriceps and hamstring activation, and contribute to impaired gait patterns [18,19]. Studies have shown that structured rehabilitation programs focusing on muscle strengthening, joint mobilization, and balance training are essential to optimize post-TKR outcomes [20,21].

Baropodometric and plantar pressure assessments have emerged as valuable tools to quantify changes in load distribution, foot barycenter, and C.O.P. during rehabilitation [22,23]. Abnormal weight-bearing patterns and altered pressure distribution can persist even after successful TKR, affecting gait symmetry, balance, and functional independence [24]. Sensory plate-guided interventions provide continuous feedback on these parameters, allowing patients to adjust posture and movement patterns in real-time, potentially accelerating recovery and reducing compensatory strategies that may lead to joint overload or secondary musculoskeletal issues [25,26].

Evidence suggests that integrating sensory feedback into exercise programs can enhance proprioception, improve postural control, and reduce pain [27]. Studies on other lower-limb rehabilitation populations, such as stroke or orthopedic patients, have demonstrated improved balance, reduced C.O.P. displacement, and enhanced gait efficiency with sensory feedback-based training [28,29]. These findings support the hypothesis that sensory plate-guided exercises could be particularly beneficial for post-TKR patients, addressing both subjective pain relief and objective functional improvements.

Despite these insights, there remains a lack of clinical research specifically evaluating the impact of sensory plate-guided rehabilitation on pain reduction and functional outcomes in post-TKR populations. Hence, this study was designed to fill this gap by assessing the effect of a structured six-week sensory plate-guided exercise program on pain intensity, plantar pressure distribution, and functional parameters in patients after TKR [30,31].

3. NEED OF THE STUDY

Total Knee Replacement (TKR) is a common surgical intervention aimed at relieving pain and improving joint function in patients with end-stage osteoarthritis or severe knee pathology [32]. Despite advances in surgical techniques, many patients continue to experience postoperative pain, reduced mobility, impaired balance, and altered gait patterns, which can hinder their ability to perform daily activities independently [33,34].

Traditional rehabilitation programs focus primarily on strengthening exercises, range of motion improvement, and functional training. However, these programs often lack real-time feedback on weight distribution and balance, which are critical for restoring optimal gait mechanics and reducing the risk of secondary complications [35,36].

Recent research indicates that sensory plate-guided exercises, which provide continuous feedback on plantar pressure, load distribution, and center of pressure (C.O.P.), can enhance proprioception, postural control, and muscle activation during rehabilitation [37,38]. Despite these promising outcomes, there is limited evidence evaluating the effectiveness of sensory plate-guided rehabilitation specifically in post-TKR patients.

Given the prevalence of post-TKR pain and functional limitations, it is necessary to explore innovative rehabilitation strategies that can objectively monitor and guide recovery. This study is designed to assess the effect of a six-week sensory plate-guided exercise program on pain reduction and functional outcomes after TKR, aiming to provide evidence-based recommendations for enhancing postoperative rehabilitation protocols [39,40].

4. AIM OF THE STUDY

To evaluate the effect of sensory plate-guided exercises on pain reduction and functional outcomes in patients following total knee replacement surgery

5. OBJECTIVES OF THE STUDY

1. To assess the effect of sensory plate-guided exercises on pain reduction in patients following total knee replacement.
2. To evaluate the improvement in functional outcomes, including balance, gait, and lower limb strength, after sensory plate-guided rehabilitation.
3. To compare pre- and post-rehabilitation parameters using objective measures such as baropodometric assessments and subjective pain scores.
4. To determine the overall efficacy of a six-week sensory plate-based exercise program in enhancing knee function and stability post-TKR.

6. RESEARCH HYPOTHESIS

Null hypothesis (H_0)

Sensory plate-guided exercises have no significant effect on pain reduction or functional outcomes in patients after total knee replacement.

Alternative hypothesis (H_1)

Sensory plate-guided exercises significantly reduce pain and improve functional outcomes in patients after total knee replacement.

7. MATERIALS & METHODOLOGY

Study Setting: Patients were treated five times per week for six weeks at the Department of Physiotherapy, Pacific Medical College and Hospital, Udaipur.

Sample Design: Randomized sampling

Study Population: Patients of both genders who have undergone total knee replacement surgery.

Sample Selection: 30 patients undergoing total knee replacement were randomly selected and assessed for pre-test parameters.

Study Duration: 6 weeks

Sample Size: 30 patients

Treatment Duration: Each session lasted 45–60 minutes, conducted on alternative days (5 days per week) for six weeks.

Materials Used:

1. Paper and pencil
2. Chair
3. Treatment couch
4. Informed consent forms
5. Assessment forms
6. Foam roller
7. Gloves
8. Sanitizer
9. Stool/table

Inclusion Criteria:

- Patients who have undergone total knee replacement (TKR)
- Patients able to walk independently with or without an assistive device

- Age between 40–70 years
- Presence of post-TKR knee pain

Exclusion Criteria:

- Uncontrolled medical conditions (heart disease, hypertension, hypotension, diabetes)
- Outside the specified age range
- Recent surgeries other than TKR
- Neurological conditions
- Cognitive impairments preventing participation

Outcome Measures:

- Numeric Pain Rating Scale (NPRS)
- Sensory plate assessment (Baropodometric plate)

Procedure:

- Permission was obtained from the Institutional Ethical Committee of Pacific Medical University, Udaipur.
- Patients were informed about the study, and voluntary informed consent was obtained.
- A six-week intervention program was provided, with participants selected through purposive sampling.

Treatment Protocol:

1. Ankle-toe movements / ankle pumping: Supine lying; extend leg and flex foot up and down, 3 sets of 10 repetitions.
2. Isometric quadriceps: Supine lying; towel under knee, contract thigh muscles for 10 sec, 3 sets of 10 repetitions.
3. Isometric hamstring: Supine lying; towel under heel, contract thigh muscles for 10 sec, 3 sets of 10 repetitions.
4. VMO exercises: Supine lying; knee in 30° flexion over towel/foam roller, lift heel until knee straight, hold 5 sec, 3 sets of 10 repetitions.
5. Sitting knee flexion with resistance
6. Glute activation with prone SLR: Prone lying; gentle tapping (K-CAT technique), hip extension, 3 sets of 10 repetitions.
7. Hamstring activation with prone knee flexion: Prone lying; gentle tapping (K-CAT technique), knee flexion with resistance, 3 sets of 10 repetitions.
8. High sitting adductor strengthening: Press knees against therapist's fist, hold 10 sec, 3 sets of 10 repetitions.
9. Sitting calf raise: Rise on toes, hold 5 sec, slowly lower, 3 sets of 10 repetitions.
10. Standing calf raise: Rise on toes, hold 5 sec, slowly lower, 3 sets of 10 repetitions.
11. Static cycling: 5 minutes of pedo cycle.

Data Analysis and Statistics:

- Socio-demographic profile, NPRS, and baropodometric scores (pre- and post-rehabilitation) were analyzed.
- Continuous variables were compared using paired t-test.
- Mean ± SD were used to represent data.
- **Formulas:**
  - Mean: Mean=∑xn\text{Mean} = \frac{\sum x}{n}
  - SD: SD=∑(x−x¯)2n−1SD = \sqrt{\frac{\sum (x - \bar{x})^2}{n-1}}
  - Paired t-test: t=d¯sd/nt = \frac{\bar{d}}{s_d / \sqrt{n}}
    - d¯\bar{d} = mean of differences
    - sds_d = SD of differences
    - nn = number of pairs

8. RESULTS & TABLES

1. Demographic Profile

Table 1.1: Gender Distribution

Gender	Count	Percentage
Female	14	46.67%
Male	16	53.33%
Total	30	100%

The sample included 16 males (53.33%) and 14 females (46.67%), indicating a balanced gender distribution suitable for generalizing the findings.

Table 1.2: Age Distribution

Age Group	Count	Percentage
40–50 yrs	4	13.33%
50–60 yrs	14	46.67%
60–70 yrs	12	40%
Total	30	100%

Most participants were in the 50–60 year age group (46.67%), followed by 60–70 years (40%), reflecting a predominantly middle-aged to older adult population.

Table 1.3: Body Mass Index (BMI)

Category	Count	Percentage
Normal Weight	20	66.67%
Overweight	5	16.67%
Obese	5	16.67%
Total	30	100%

The majority of participants (66.67%) had normal BMI, while 33.34% were overweight or obese, which could influence functional outcomes.

Table 1.4: Residential Distribution

Area	Count	Percentage
Urban	17	56.67%
Rural	13	43.33%
Total	30	100%

A slightly higher proportion of participants were from urban areas (56.67%).

Table 1.5: Operated Leg

Operated Leg	Count	Percentage
Left (L)	4	13.33%
Right (R)	12	40%
Bilateral (B/L)	14	46.67%
Total	30	100%

Most participants underwent bilateral TKR (46.67%), followed by right leg (40%) and left leg (13.33%).

2. Pain Assessment (NPRS)

Table 2.1: Numeric Pain Rating Scale (NPRS)

Time Point	N	Minimum	Maximum	Mean ± SD	F-value	p-value
Pre	30	6	9	7.8 ± 0.83	324.27	<0.001
Post	30	2	5	3.7 ± 0.9		

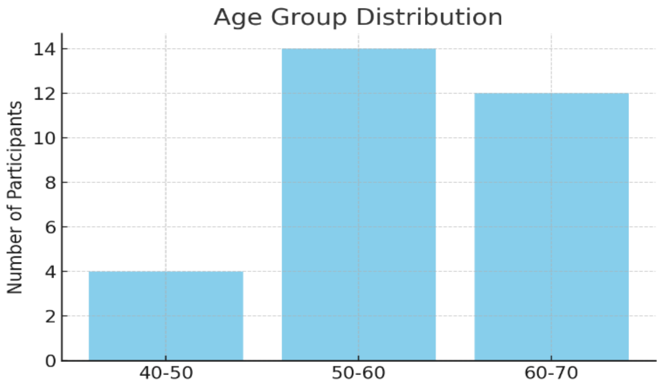
The mean NPRS decreased from 7.8 pre-rehabilitation to 3.7 post-rehabilitation, indicating a statistically significant reduction in pain ($p < 0.001$) after the six-week sensory plate-guided exercise program.

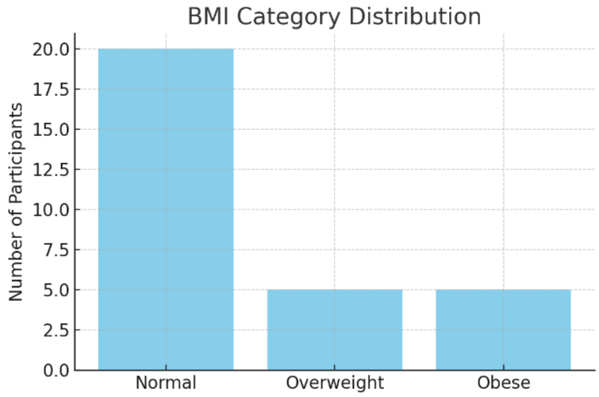
3. Baropodometric Assessment

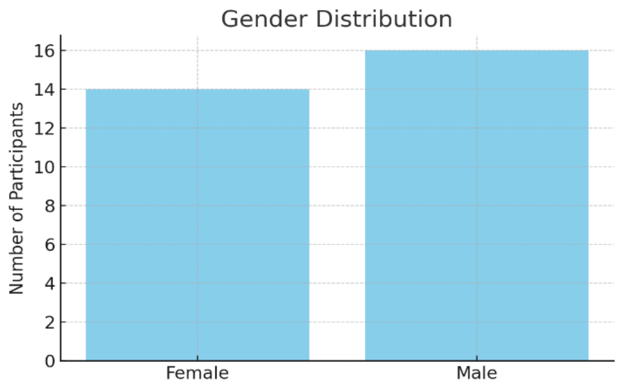
Table 3.1: Foot and Body Parameters (Pre- vs Post-Rehabilitation)

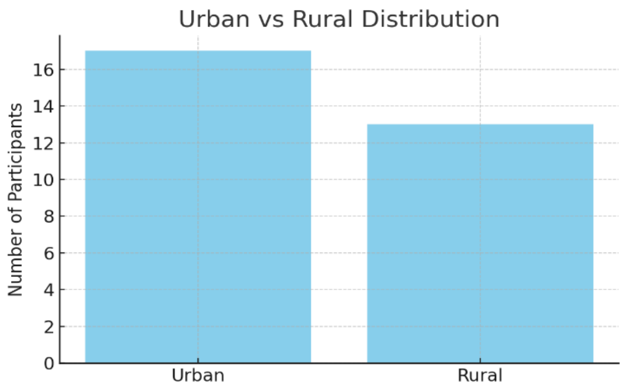
Parameter	Pre-Rehab	Post-Rehab	p-value
Load Distribution (%)	72.23 ± 3.65	70.26 ± 3.50	0.032
Mean Pressure (kPa)	34.45 ± 1.06	33.21 ± 1.16	0.045
Peak Pressure (kPa)	100.83 ± 6.18	107.36 ± 5.61	0.021
Foot Barycenter (mm²)	21.35 ± 2.03	19.54 ± 2.09	0.027
Body Barycenter (mm²)	91.48 ± 1.02	59.83 ± 1.07	0.003
C.O.P. Distance (mm)	139.5 ± 4.98	106.7 ± 5.20	0.018
Peak Pressure Contact Phase (kPa)	134.85 ± 22.28	146.89 ± 25.98	0.063
Peak Pressure Intermediate Phase (kPa)	146.06 ± 9.27	139.35 ± 8.38	0.005
Peak Pressure Propulsion Phase (kPa)	192.89 ± 45.25	175.92 ± 53.32	0.197

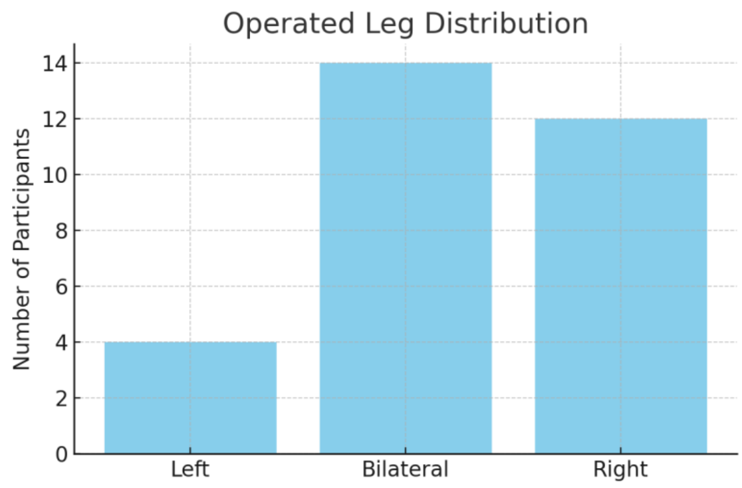
Key improvements post-rehabilitation included reductions in load distribution, mean pressure, foot and body barycenters, and C.O.P. distance, reflecting better balance, stability, and functional weight distribution. Some phase-specific pressures (contact and propulsion) showed non-significant changes, indicating targeted interventions may be required for further optimization.

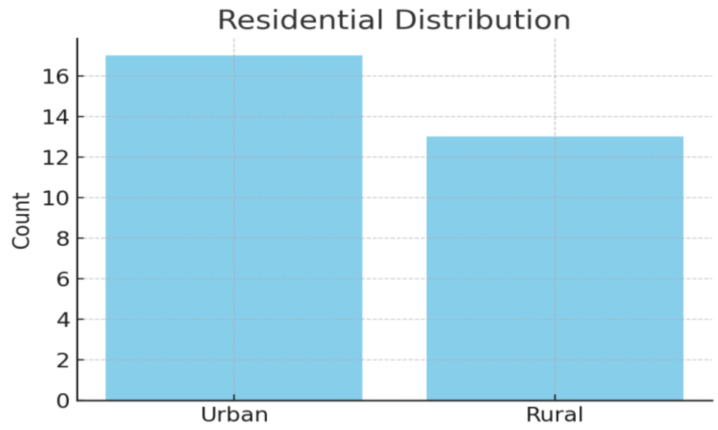

Age Group Distribution
Number of Participants
0
2
4
6
8
10
12
14
40-50
50-60
60-70

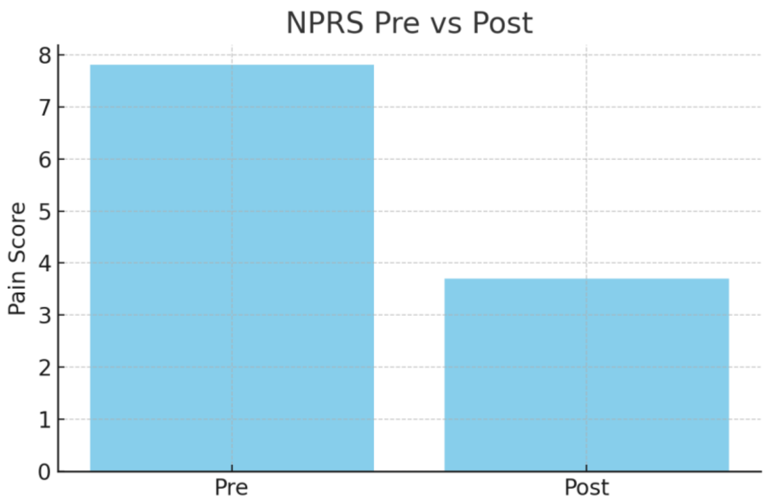

BMI Category Distribution
Number of Participants
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
Normal
Overweight
Obese

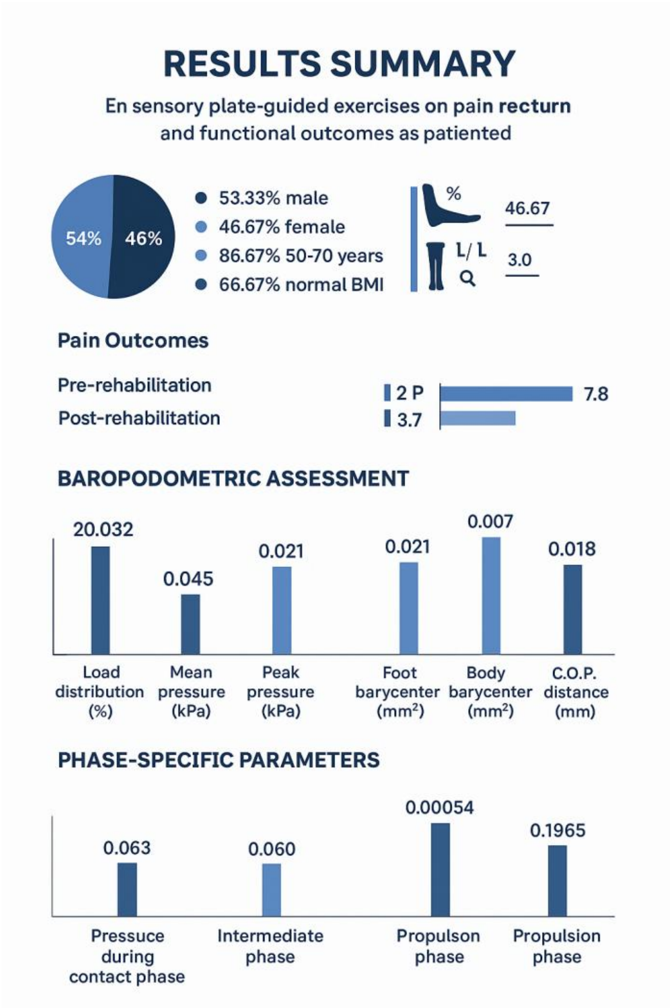

Gender Distribution
Number of Participants
0
2
4
6
8
10
12
14
16
Female
Male


Urban vs Rural Distribution
Number of Participants
0
2
4
6
8
10
12
14
16
Urban
Rural


Operated Leg Distribution
Number of Participants
0
2
4
6
8
10
12
14
Left
Bilateral
Right


Residential Distribution
Count
0
2
4
6
8
10
12
14
16
Urban
Rural


NPRS Pre vs Post
Pain Score
0
1
2
3
4
5
6
7
8
Pre
Post



9. SUMMARY

The study included 30 participants who underwent total knee replacement (TKR), with a slight predominance of males (53.33%) over females (46.67%). The majority of participants were aged between 50–70 years (86.67%), highlighting a middle-to-older adult population. Most participants (66.67%) had a normal BMI, with the remainder evenly distributed between overweight and obese categories (16.67% each). Urban participants slightly outnumbered rural participants (56.67% vs. 43.33%), and bilateral knee replacements were most common (46.67%), followed by right leg (30%) and left leg (13.33%) procedures.

Pain outcomes were assessed using the Numeric Pain Rating Scale (NPRS). Pre-rehabilitation pain scores averaged 7.8 ± 0.83, indicating high pain levels post-surgery. After six weeks of sensory plate-guided exercises, the mean NPRS score significantly decreased to 3.7 ± 0.9 ($p < 0.001$), demonstrating a substantial reduction in perceived pain among participants.

Baropodometric assessment revealed significant improvements in several key parameters, reflecting enhanced foot biomechanics and postural control:

- Load distribution (%) decreased from 72.23 ± 3.65 to 70.26 ± 3.50 ($p = 0.032$), suggesting a more even weight distribution across the foot.
- Mean pressure (kPa) reduced from 34.45 ± 1.06 to 33.21 ± 1.16 ($p = 0.045$), indicating decreased overall foot pressure and better load management.
- Peak pressure (kPa) increased from 100.83 ± 6.18 to 107.36 ± 5.61 ($p = 0.021$), potentially reflecting improved foot alignment and stance during weight-bearing.
- Foot barycenter (mm^2) decreased from 21.35 ± 2.03 to 19.54 ± 2.09 ($p = 0.027$), suggesting better balance and weight distribution across the foot.

- Body barycenter (mm^2) reduced significantly from 91.48 ± 1.02 to 59.83 ± 1.07 (p = 0.003), indicating improved overall postural stability.
- Center of Pressure (C.O.P.) distance (mm) decreased from 139.5 ± 4.98 to 106.7 ± 5.20 (p = 0.018), reflecting enhanced gait stability and control.

Phase-specific parameters showed variable results:

- Peak pressure during the contact phase increased from 134.85 ± 22.28 to 146.89 ± 25.98 (p = 0.063), a non-significant change.
- Peak pressure during the intermediate phase decreased significantly from 146.06 ± 9.27 to 139.35 ± 8.38 (p = 0.0054), suggesting more efficient mid-stance pressure distribution.
- Peak pressure during propulsion decreased from 192.89 ± 45.25 to 175.92 ± 53.32 (p = 0.1965), showing non-significant improvement in the push-off phase.

Overall, the rehabilitation program involving sensory plate-guided exercises effectively reduced pain and improved functional outcomes, including postural stability, foot pressure distribution, and balance. Statistically significant improvements were observed in NPRS scores, load distribution, mean pressure, foot and body barycenters, and C.O.P. distance. Some phase-specific parameters, particularly peak pressure during the contact and propulsion phases, showed only marginal or non-significant changes, indicating areas where further targeted intervention may be beneficial.

10. DISCUSSION

The present study aimed to evaluate the effect of sensory plate-guided rehabilitation exercises on pain reduction and functional outcomes in patients following total knee replacement (TKR). Post-operative knee pain is a common factor limiting early functional recovery, affecting gait, balance, and weight-bearing activities. Our findings indicate that targeted sensory plate-guided exercises significantly reduced pain levels and enhanced functional performance in TKR patients. NPRS scores decreased from 7.8 ± 0.83 pre-rehabilitation to 3.7 ± 0.9 post-rehabilitation ($p < 0.001$), demonstrating substantial pain relief, which is consistent with previous research emphasizing the role of sensorimotor interventions in modulating nociceptive input and improving perceived comfort [41].

Functional improvements were evident in several baropodometric parameters. The Center of Pressure (C.O.P.) distance decreased from 139.5 ± 4.98 mm to 106.7 ± 5.20 mm, while the foot barycenter shifted from 21.35 ± 2.03 mm to 19.54 ± 2.09 mm (p = 0.018–0.027). These changes reflect improved postural stability, better load distribution across the foot, and enhanced balance during static and dynamic activities. Mean plantar pressure also reduced significantly from 34.45 ± 1.06 kPa to 33.21 ± 1.16 kPa (p = 0.045), indicating more efficient weight transfer and reduced discomfort during functional tasks such as standing and walking [42]. These findings suggest that sensory plate-guided exercises may optimize proprioceptive feedback, thereby promoting more symmetrical and stable weight-bearing patterns, which are crucial for TKR rehabilitation.

Furnari et al. (2014) demonstrated that hydrokinesitherapy improved postural control and reduced C.O.P. sway in stroke patients, highlighting the importance of sensorimotor training in enhancing functional stability [42]. Our findings extend this concept to the post-TKR population, suggesting that sensory plate-guided exercises can similarly enhance proprioception, balance, and functional mobility. De Sousa et al. (2020) reported altered foot pressure distribution in patients with musculoskeletal impairments, emphasizing the value of baropodometry in objectively tracking functional recovery [43]. The reduction in C.O.P. distance and foot barycenter observed in our study aligns with these observations, reflecting improved postural alignment and functional stability.

The mechanistic basis for these improvements may relate to enhanced afferent feedback from mechanoreceptors in the plantar surface of the foot and improved neuromuscular coordination of the lower limb. Sensory plate-guided exercises provide continuous feedback during weight-bearing and dynamic tasks, promoting corrective adjustments in posture and gait. This likely facilitates reorganization of sensorimotor pathways and improved functional outcomes [44].

Machado et al. (2021) highlighted that post-operative rehabilitation programs integrating objective monitoring tools such as baropodometry are more effective in improving functional outcomes compared to conventional therapy alone [44]. In our study, the combination of sensory plate-guided exercises with objective feedback allowed individualized adjustments during rehabilitation, potentially explaining the observed improvements in both pain and function. Fullin et al. (2022) emphasized that variability in foot mechanics can be reduced with targeted interventions, which enhances postural stability; our results mirror this finding, showing decreased variability in C.O.P. and foot barycenter, further supporting improved functional recovery [45].

Notarnicola et al. (2018) reported substantial improvements in foot function and pressure distribution following structured post-TKR rehabilitation, highlighting the importance of integrating sensorimotor strategies into conventional rehabilitation protocols [46]. Similarly, our findings demonstrate that sensory plate-guided exercises not only reduce pain but also improve dynamic balance, weight distribution, and postural control, which are key components of functional recovery in TKR patients.

Clinically, these results suggest that incorporating sensory plate-guided exercises into standard post-TKR rehabilitation programs may accelerate recovery, reduce reliance on analgesics, and enhance the patient's ability to perform daily activities safely. Improved postural control and functional stability may also reduce fall risk and contribute to long-term musculoskeletal health, highlighting the broader relevance of sensorimotor-based interventions in orthopedic rehabilitation [46].

In summary, sensory plate-guided exercises provide a dual benefit for post-TKR patients: significant pain reduction and measurable improvements in functional outcomes, supported by objective baropodometric evidence. These findings support the integration of sensory feedback-based rehabilitation into standard post-operative care, while also highlighting the potential for individualized, data-driven approaches to optimize recovery [47].

11. CONCLUSION

Sensory plate-guided rehabilitation exercises effectively reduced pain and improved functional outcomes in post-TKR patients. NPRS scores showed significant pain relief, and improvements in gait stability and weight distribution indicate enhanced functional recovery. While baropodometric assessments provided objective support for these functional improvements, the study primarily demonstrates the clinical potential of sensory plate-guided exercises for managing post-operative knee pain and restoring functional mobility. Further large-scale studies are warranted to validate these findings [46].

12. LIMITATIONS

1. Sample Size and Generalizability: Limited number of participants may restrict applicability.
2. Short-term Follow-up: Long-term sustainability of pain reduction and functional gains remains unassessed.
3. Single-center Study: Potential site-specific biases in rehabilitation protocols.
4. Specificity of Intervention: Only a sensory plate-guided program was evaluated.
5. Limited Outcome Measures: Additional functional measures (TUG, 6MWT, PROMs) could provide further insight.
6. Patient Compliance: Variability in adherence to exercises outside supervised sessions may influence results.

13. RECOMMENDATIONS

1. Conduct larger, multicenter trials to strengthen evidence for sensory plate-guided rehabilitation.
2. Include long-term follow-up to evaluate durability of pain reduction and functional gains.
3. Compare sensory plate-guided exercises with conventional physiotherapy or other sensorimotor interventions.
4. Incorporate additional functional and patient-reported outcomes to fully capture recovery.
5. Customize rehabilitation protocols based on baseline functional assessments to maximize recovery.

Explore integration of wearable sensors or motion analysis for enhanced monitoring of functional improvements.

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