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Original Article

Physiotherapy Section

Effect of Pressure Biofeedback Training on Quadriceps Muscle Strength and Knee Range of Motion among Normal BMI Patients with Total Knee Replacement: A Quasi-experimental Study

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ABSTRACT

Introduction: Total Knee Replacement (TKR) is a common treatment for knee OA, but rehabilitation can be challenging due to postoperative quadriceps weakness and limited knee Range Of Motion (ROM). Pressure Biofeedback (PBF) training is presented as a viable method to potentially enhances ROM recovery and quadriceps activation.

Aim: This study aimed to determine the effectiveness of PBF training on quadriceps muscle strength and knee ROM in people with TKR.

Materials and Methods: A quasi-experimental study was conducted at KS Hegde Hospital, Mangaluru, between May 2024 and May 2025. The study included twenty patients with normal BMI who had undergone TKR. From Postoperative Day (POD) 1 to POD 7, participants received PBF training in addition to standard physiotherapy. Knee ROM was measured using a goniometer, while quadriceps strength was assessed with a PBF device. The effectiveness of PBF training on muscle strength and functional outcomes was evaluated using the paired t-test, with statistical significance set at $p<0.05$

Results: A total of 20 patients were enrolled in the study, comprising seven males and 13 females, with ages ranging from 45 to 74 years. Significant functional improvements were observed over the postoperative period. Knee flexion increased from 23.10° on POD 1 to 67.73° on POD 7, while knee extension improved from 6.03° to 2.20°. Quadriceps strength also rose markedly, from 55.25 mmHg to 94.88 mmHg. All changes were statistically significant ($p<0.001$)

Conclusion: The study demonstrates that PBF training significantly improves knee ROM and quadriceps strength during the early postoperative phase of TKR. Early incorporation of PBF training into routine TKR rehabilitation can accelerate recovery, optimise quadriceps strength, and improve knee mobility, offering patients a more effective pathway to regain function and independence.

Keywords: Aural feedback, Knee osteoarthritis, Muscle inhibition, Range of motion

INTRODUCTION

For individuals with advanced knee Osteoarthritis (OA), Total Knee Arthroplasty (TKA) is a widely performed surgical intervention aimed at alleviating pain and restoring function [1]. Despite advances in implant design and surgical techniques, postoperative functional recovery remains highly variable [2]. Several factors including preoperative muscle strength, rehabilitation strategies, and neuromuscular control play a critical role in determining outcomes following TKA [3]. Rehabilitation is therefore essential to optimise healing, enhance mobility, and improve overall quality of life after surgery [4].

A major challenge in post-TKA recovery is the loss of quadriceps strength, which significantly impacts mobility and functional performance [5]. Arthrogenic Muscle Inhibition (AMI), characterised by impaired voluntary muscle activation due to inflammatory and neurological changes, is frequently associated with quadriceps weakness [6]. Isometric quadriceps exercises have been shown to improve muscle strength and reduce pain in patients with knee OA [7]; however, conventional rehabilitation approaches may not fully resolve postoperative muscle dysfunction [8].

Biofeedback-based rehabilitation has emerged as a promising strategy to enhance quadriceps activation and improve functional outcomes after TKA [9]. Cornwall MW (2007) highlighted that biofeedback techniques facilitate neuromuscular re-education and voluntary muscle activation by providing patients with real-time visual or auditory feedback [10]. Evidence suggests that biofeedback training can reduce AMI, accelerate functional recovery, and increase quadriceps strength following TKA [11]. Specifically, PBF has been employed to promote early quadriceps activation during rehabilitation and mitigate AMI [12]. To further improve recovery, rehabilitation programs often incorporate proprioceptive and balance training alongside biofeedback [4]. These interventions aim to enhance movement control, reduce fall risk, and improve joint position awareness [13]. By addressing neuromuscular deficits and improving movement efficiency, they complement strength training and contribute to better functional outcomes.

Restoring knee ROM is another critical component of post-TKA rehabilitation, as it is closely linked to regaining independence [14]. Limited early ROM recovery has been associated with delayed rehabilitation progress and poorer long-term outcomes [15]. Early mobilisation programs have therefore been introduced, demonstrating benefits in pain reduction, self-reported function, and performance-based assessments after TKA [16].

The PBF is a simple, cost-effective tool that retrains muscle activity while providing visual feedback [9]. Visual input is particularly valuable for engaging patients, encouraging cooperation, and shaping motor behaviour. Continuous feedback supports voluntary muscle control and helps establish threshold goals [10]. PBF has been successfully applied in deep cervical flexor training to maintain neck endurance and mobility [13]. In the context of knee replacement, biofeedback interventions have shown improvements in gait symmetry, pain reduction, and activity levels [11].

Beyond TKA, PBF has demonstrated effectiveness in quadriceps activation during orthopaedic conditions such as femoral fractures, periarticular knee fractures, Anterior Cruciate Ligament (ACL) injuries, and tibial fractures. Studies indicate that combining biofeedback with active exercise after TKR enhances quadriceps torque and knee function [17]. Furthermore, a randomised clinical trial has provided insight into the efficacy of movement training after unilateral TKR along with mechanism for optimising the long term physical function and minimising negative sequele of compensatory movement patterns [18]. Nevertheless, the specific impact of PBF training on early quadriceps activation and knee ROM recovery after TKR has not yet been reported. This study aimed to determine the effectiveness of PBF training on quadriceps muscle strength and knee ROM in people with TKR.

MATERIALS AND METHODS

A quasi-experimental study was conducted at KS Hegde Hospital, Mangaluru, between May 2024 and May 2025. Ethical clearance was obtained (Ref. No: NIPT/IEC/Min//21/2023-2024), and written informed consent was secured from all participants.

Eligibility criteria:

- **Inclusion:** Patients admitted to the inpatient department who had undergone unilateral TKR on POD 1, aged 45-74 years, of either gender.
- **Exclusion:** Patients with neurological signs, psychiatric disorders, severe cognitive impairment, bilateral TKR, or a Body Mass Index (BMI) above 24.9 kg/m².

In line with rehabilitation standards, therapy was initiated only when patients were medically stable, able to manage pain effectively, free of complications, and able to follow commands. A pain-free ROM, surgeon clearance, and the presence of a single knee replacement with normal BMI were also required before participation.

Sample size: Based on a 5% level of significance, an expected mean difference of 205.4, and a pooled standard deviation of 282.47 (mild contraction experimental group) [12], the required sample size was calculated using G*Power version 3.1. The formula applied was:

$$n = \frac{(Z1\text{-}\alpha/2+Z1\text{-}\beta)^2\sigma^2}{(\mu1\ \text{-}\mu2)2}$$

Where:

- (n)=required sample size
- (Z_{1-\alpha/2})=1.96 (for $\alpha = 0.05$)
- (Z_{1-\beta})=0.842 (for 80% power)
- (\sigma)=pooled standard deviation
- ((\mu_1 - \mu_2))=expected mean difference

The calculated sample size was 15. Accounting for a 20% attrition rate, the final sample size was set at 20. The relatively small sample size reflects the limited pool of eligible participants, as most TKR patients were obese, and only those with a normal BMI who underwent unilateral TKR were included.

All patients received the standardised TKR rehabilitation protocol [Table/Fig-1,2] supplemented with PBF training from POD1 to POD7. Each training session lasted 30-40 minutes.

To avoid distortion of readings caused by the soft hospital bed, a wooden plank was placed beneath the patient's leg to minimise false positives. The PBF device was positioned at the knee, with a baseline inflation of 30 mmHg. To familiarise patients with the procedure, two practice trials were performed on the unoperated knee. For each trial, patients were instructed to press their knee firmly against the cuff and maintain the pressure for 10 seconds before returning to the starting position. The peak pressure achieved was recorded, and a one-minute rest period was provided before repeating the attempt [12].

POD1	Initiation of ankle-toe movements, quadriceps, hamstrings, and gluteus isometrics, hip abduction, short arc quadriceps, straight leg raises, and bed mobility/transfer training (1-2 sets × 10 repetitions). Gait training with an assistive device.
POD2	Exercise for active ROM, Active assisted ROM exercises, Heel slides, ankle-toe movement, Isometric quadriceps, Isometric hamstrings, Gluteus isometric, Straight leg raise, supine hip abduction (1-3 sets ×10 reps) Gait training with an assistive device.
POD3-7	Progression of ROM exercise, progression of strengthening exercise to patient tolerance (1-3 sets × 10 reps) Gradual increase in ambulation distance.

[Table/Fig-1]: Standardised rehabilitation protocol for Total Knee Replacement (TKR) from Postoperative Day (POD) 1 to POD 7 [16].

[Table/Fig-2]: Patient undergoing Pressure Biofeedback (PBF) training.

Demographic details (age, gender and BMI [19]) were recorded using a structured data collection form. Muscle strength was assessed with a chattanooga stabiliser PBF device, and knee ROM was measured using a universal goniometer at baseline and post-intervention on the 7th day. For both PBF and knee ROM assessments, two trials were performed, and the average of the two readings was used for analysis.

STATISTICAL ANALYSIS

Data analysis was performed using SPSS software, version 29.0.10 (SPSS Inc., Chicago, IL). Descriptive statistics, including frequency, percentage, mean, and standard deviation, were employed to summarise the collected data. The effectiveness of PBF training on muscular strength and biofeedback measures was evaluated using the paired t-test. Relationships between BMI and PBF were examined using Pearson's correlation coefficient (r). A p-value less than 0.05 was considered statistically significant.

RESULTS

A total of 32 participants were screened, of whom 20 met the inclusion criteria. Among these, 7(35%) were males, and 13(65%) were females. Ten participants had left TKR, and ten had right TKR. Participants' ages ranged from 45 to 74 years (mean 59.95±7.66), while BMI ranged from 20.5 to 24.9 kg/m² (mean 22.7±2.2 [Table/Fig-3].

(n = 20)	Range	Mean	SD
Age (Years)	45 to 74	59.95	7.66
BMI (Kg/M²)	20.5 to 24.9	22.7	2.2

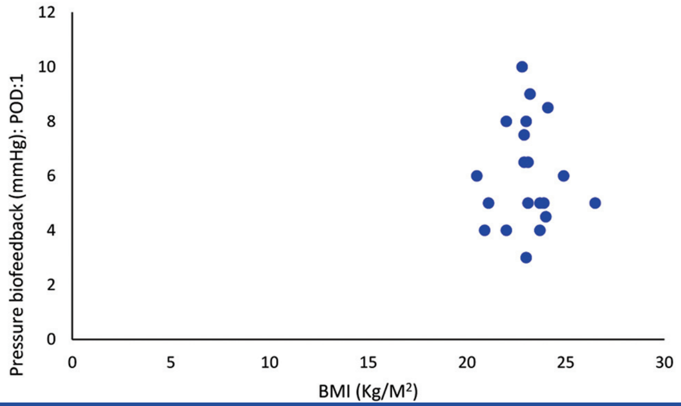
[Table/Fig-3]: Descriptive statistics for age and BMI.

Knee flexion improved significantly from a mean of 23.10° (SD 5.77) on POD 1 to 67.73° (SD 8.47) on day 7 ($p<0.001$). Knee extension decreased from 6.03° (SD 1.92) to 2.20° (SD 1.24) over the same period ($p<0.001$). PBF values also showed marked improvement, rising from 55.25 mmHg (SD 14.73) on day 1 to 94.88 mmHg (SD 15.88) on day 7 ($p<0.001$) [Table/Fig-4].

		Mean	SD	t	p-value
Knee flexion (Degrees)	POD:1	23.10	5.77	-25.27	< 0.001*
	POD:7	67.73	8.47		
Knee extension (Degrees)	POD:1	6.03	1.92	14.45	< 0.001*
	POD:7	2.20	1.24		
Pressure Biofeedback (PBF) (mmHg)	POD:1	55.25	14.73	-15.60	< 0.001*
	POD:7	94.88	15.88		

[Table/Fig-4]: Effectiveness of Pressure Biofeedback (PBF) training on muscle strength and knee Range Of Motion (ROM) pre and post intervention.
*(t = Paired t-test; * Significant-value <0.05).

The correlation analysis between BMI and PBF values on POD 1 [Table/Fig-5] revealed a statistically significant positive relationship (r=0.713, p<0.001). Although individual variability was present within the BMI range of 20–25 kg/m², overall higher BMI was correlated with higher PBF values.



[Table/Fig-5]: Scatter plot showing the correlation between BMI and Pressure Biofeedback (PBF) values on Postoperative Day (POD) 1.
(p-value= <0.001*, r value = 0.713)

DISCUSSION

TKR is a well-established surgical intervention for end-stage knee OA, effectively reducing pain and improving knee function. Despite these benefits, postoperative quadriceps weakness and restricted ROM remain major concerns. Quadriceps weakness following TKR is well documented; Stevens-Lapsley JE et al., (2010) reported a 60% reduction in quadriceps strength one month postsurgery, with deficits persisting for years [8]. In contrast, the present study demonstrated that PBF training significantly improved quadriceps strength within the first postoperative week (p<0.001).

Biofeedback techniques enhance motor control by providing real-time sensory input. Achens JT (2022) highlighted that early quadriceps activation using PBF can prevent AMI in lower limb orthopedic surgeries [12]. Consistent with this, our findings suggest that PBF reduces inhibition and facilitates voluntary activation, thereby accelerating recovery.

Early restoration of knee ROM is critical for functional independence. Mehta S et al., (2020) emphasised that the most substantial ROM gains occur within the first 12 weeks after surgery [14]. In our study, knee flexion improved significantly from 23.10° (POD 1) to 67.73° (POD 7), while knee extension improved from 6.03° to 2.20° (p<0.001). Although Kornuijt A et al., (2019) reported greater improvements by week 8 (80° to 110°) [15], our shorter timeframe indicates that PBF training accelerates early ROM recovery, potentially contributing to better long-term outcomes.

Various rehabilitation strategies have been explored for post-TKR recovery, including isometric exercise, Neuromuscular Electrical Stimulation (NMES), and proprioceptive training. Harkey MS et al., (2014) emphasised the importance of voluntary quadriceps activation, suggesting that neuromuscular facilitation enhances recovery [6]. Pfeufer D et al., (2019) found NMES effective for strength gains but less impactful on functional mobility [11]. In contrast, PBF provides immediate sensory feedback, actively engages patients, and may serve as a more interactive rehabilitation tool.

Traditional early rehabilitation often relies on passive or assisted ROM exercises. Harikesavan K et al., (2019) demonstrated that early mobilisation reduces pain and improves functional outcomes [16]. Incorporating PBF into early mobilisation programs may therefore offer superior quadriceps activation compared to conventional therapy. This aligns with our findings, as PBF's real-time feedback minimises incorrect muscle engagement common in self-monitored isometric exercise, supporting neuromuscular re-education and motor control.

Aftab S et al., (2025) reported that early physiotherapy-including conventional exercise, isotonic strengthening, patellar resurfacing, acupoint quadriceps massage, manual therapy, continuous passive movement, NMES, and supervised outpatient rehabilitation-significantly improves pain, ROM, and quality of life in post-TKR patients [20]. Our study adds to this evidence, demonstrating that PBF training accelerates recovery during the first postoperative week by improving quadriceps strength and knee ROM. Although physiological muscle strength typically requires weeks to recover, early quadriceps activation within the first week is crucial, and PBF appears to facilitate this process.

Limitation(s)

This study's quasi-experimental design without a control group limits attribution of improvements solely to PBF, as natural recovery and routine physiotherapy may have contributed. The absence of randomisation and assessor blinding introduces potential bias. The short follow-up period (POD 1-7) restricts conclusions about long-term outcomes. Quadriceps strength was assessed using the same PBF device employed for training, which may have introduced familiarity effects and reflects activation rather than true strength. Since all participants received standard physiotherapy, isolating the independent effect of PBF was not possible. Finally, the small sample size, restriction to normal-BMI unilateral TKR patients, and unmeasured factors such as pain levels and surgical variability limit generalisability.

CONCLUSION(S)

This study demonstrates that PBF training significantly improves quadriceps strength and knee ROM in the early postoperative phase following TKR. The findings support incorporating PBF as an adjunct to conventional rehabilitation. Future research with larger sample sizes and extended follow-up periods is necessary to validate the long-term benefits of PBF training in TKR rehabilitation.

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