Indian Journal of Orthopaedics
https://doi.org/10.1007/s43465-024-01218-z

ORIGINAL ARTICLE

Does Proprioception-Based Rehabilitation Enhance Functional Outcome in Total Knee Arthroplasty? A Prospective Randomised Study

Yuvarajan Palanisamy[1] · Arjun R. Prasad[2] · Karthik Seetharaman[2] · K. Ganesan[3] · M. Kavitha[3] · David V. Rajan[1]

Received: 20 February 2024 / Accepted: 24 June 2024
© Indian Orthopaedics Association 2024

Abstract

Introduction Rehabilitation after Total Knee Arthroplasty (TKA) often includes proprioceptive exercises to prevent falls, but studies on proprioceptive training have yielded conflicting findings. This study aims to explore impact of proprioceptive training on functional performance after TKA.

Methods Eighty patients who underwent unilateral TKA were randomly assigned to a proprioceptive exercise (PE) group or a routine exercises (RE) group. The PE group received proprioceptive exercises in addition to routine physiotherapy. Osteoarthritis Research Society Internal (OARSI) recommended tests and Oxford Knee Score (OKS) were used to assess performance and outcome at 3 and 6 months.

Results In the 30-s chair sits test, the PE group outperformed the RE group at 3 months (13.69 vs. 9.17) and 6 months (21.07 vs. 18.63) ($p < 0.001$ and $p = 0.030$). Stair climbing favoured PE group at 3 months (8.86 vs. 16.66, $p = 0.037$) and 6 months (0.556 vs. 1.133, $p = 0.001$). At 6 months in the 40-m fast-paced walk test, the PE group had a significantly shorter time (0.308 min vs. 0.557 min, $p < 0.001$). Timed up and go test at 6 months favoured PE group (0.204 min vs. 0.377 min). In the 6-min walk test, the PE group covered significantly greater distances than the RE group at 3 months (589.59 vs. 346.53 m, $p < 0.001$) and 6 months (649.60 vs. 448.32 m, $p < 0.001$). OKS at 3 months was 38 ± 2.0 for PE group and 38 ± 4 for RE group ($p = 1$). OKS at 6 months was 42 ± 4 for PE group and 40 ± 2 for RE group ($p = 0.94$).

Conclusion This study highlights the importance of proprioception-based rehabilitation in improving functional performance for TKA patients, surpassing traditional rehabilitation programmes.

Keywords Total knee replecement rehabilitation · Proprioceptive rehabilitaion after TKA · Physiotherapy in TKA

✉ Arjun R. Prasad
dr.arjun13@gmail.com

Yuvarajan Palanisamy
yuvamamc@gmail.com

Karthik Seetharaman
karthiksr93@gmail.com

K. Ganesan
kganesan77@gmail.com

M. Kavitha
kavikarthik8@gmail.com

David V. Rajan
davidvrajan@gmail.com

[1] Ortho-One Orthopaedic Speciality Centre, Coimbatore, Tamil Nadu 641005, India

[2] Ortho-One Orthopaedic Speciality Centre, Coimbatore, Tamil Nadu 641005, India

[3] Department of Physiotherapy, Ortho-One Orthopaedic Speciality Centre, Coimbatore, Tamil Nadu 641005, India

Introduction

Total knee arthroplasty is a procedure done for end-stage arthritis to alleviate pain and restore the function of the knee for daily activities. Advanced age, arthritis, and surgery result in the loss of proprioceptors [1–3]. After TKA, when the patient is made to walk, they tend to bend the trunk forward and look at the feet. When a patient engages in knee range-of-motion exercises, they often lack awareness regarding the extent to which their knee is bent. These observations suggest that the patients are not aware of their limb's position and are experiencing a loss of proprioception. Proprioception is the ability to sense the stimuli arising from the body regarding position, motion, and balance [4].

Research suggests that a considerable proportion of patients (between 7 and 33%) experience falls within the first year after the surgery [5]. Some patients have experienced an increase in fall risk due tso postural sway and increased

Published online: 05 August 2024

forward trunk bending [6]. Patients often express dissatisfaction due to inadequate rehabilitation. Rehabilitation after total knee arthroplasty generally focuses on muscle activation and static and dynamic strengthening exercises. Balance and proprioception may be included but are often overlooked. Furthermore, little is known about proprioceptor recovery and neuromuscular control [6]. Jogi et al. showed that proprioceptive training protocols resulted in significantly greater improvements in function [4]. However, there are conflicting opinions regarding proprioceptive training for individuals undergoing joint arthroplasty [3]. A recent meta-analysis also highlighted the need for studies in this regard [7].

This study examines the effects of proprioception-based rehabilitation on total knee arthroplasty patients, given the positive effects of proprioception and balance on basic functional activities. Our hypothesis was that proprioception-based rehabilitation improved performance and outcomes in patients undergoing TKA. This study used The Osteoarthritis Research Society International (OARSI) [8, 9] recommended performance-based tests and the Oxford Knee Score (OKS) for assessment.

Materials and Methods

This prospective randomised study was conducted from May 1, 2020 to May 1, 2021. The study was approved by the Institutional Clinical Ethics Committee. The inclusion criteria were as follows: (a) age 60 years or above; (b) patients undergoing primary total knee arthroplasty for grade IV osteoarthritis; and (c) patients who participated voluntarily and signed an informed consent form. The exclusion criteria were as follows: (a) patients with Parkinson's disease; (b) patients who had cognitive or mental disorders that prevent rehabilitation training; (c) patients undergoing revision TKA; (d) inflammatory joint diseases.

The enrolled patients were divided randomly into two groups a proprioceptive exercise (PE) group and a routine exercises (RE) group. For randomisation, a simple 'chit method' was used by preparing 160 chits of paper indicating either PE or RE group.

Surgeon and the two outcome assessors were unaware of the grouping and implementation during the study. Patients did not know whether they were in the PE or RE group.

Surgical Procedure

All surgical procedures were performed under spinal and epidural anaesthesia by a fellowship trained senior arthroplasty surgeon. The procedure was performed in a standard manner with an anterior longitudinal midline incision for medial parapatellar exposure. Selective patellar resurfacing was done. For all patients, Smith and Nephew posterior stabilized (PS) (ANTHEM/GEN II) prosthesis was used. A tourniquet was used during the procedure.

Three Phased Rehabilitation Programs

The participants in both the group received a three phased program. The training program for both the groups were developed by combining the previously published rehabilitation program.

The first phase (Day 1 to 4 weeks) was common to both the groups and included exercises targeting muscle activation and active knee ROM. Patients were mobilized with walker support.

The second phase (4 weeks to 8 weeks) shifted from active training to strength training using resistance band with a short lever. Patients were mobilized unassisted. In the second phase, patients under PE group were trained in standing exercises to improve proprioception and RE group was trained with a similar set of exercises in supine position. PE group was trained in exercises like figure of 8 walk (Fig. 1), single leg standing with eyes open and eyes closed, chair-sits and step-up exercises. Both the groups were trained in stair climbing.

The third phase (after 8 weeks) exercises targeted on progressive strengthening as tolerated using resistance band with long lever arm in both the groups. The proprioception exercises in PE group included standing on foam pad with eyes open and eyes closed and tandem walking in addition

Fig. 1 Demonstration of figure of eight walk to improve balance and coordination in proprioception group of exercises

to the proprioception exercises in second phase (Fig. 2). The rehabilitation therapist explained and assessed the patient on a weekly basis through video conferencing to ensure the rehabilitation plan was followed accurately.

Outcomes Measures

OARSI Recommended Performance Tests

OARSI recommended tests were done at 3 months and 6 months. The five performance-based tests of physical function selected by the OARSI advisory group were the 30-s chair-stand test, 40 min fast-paced walk test, a stair-climb test, the timed up and go test and a 6-min walk test. The tests assessed patients' ability to perform the activities of daily living (ADL).

Oxford Knee Score (OKS)

OKS pain and functional disability assessments were done at 3 and 6 months in post-operative period. OKS is a 12-item self-reported pain and function questionnaire. As recommended each question was assessed on a Likert scale from 0 to 4, with a summary score of 0 being worst and 48 as excellent. OKS has two subscales: Pain Component Scale (PCS) and Function Component Scale (FCS) [10]. OKS PCS questions are 1, 4, 5, 6, 8, 9, and 10, and OKS FCS questions are 2, 3, 7, 11 and 12 [11].

Statistical Methods

Quantitative variables were expressed as mean and standard deviation. Qualitative variables were expressed as frequency and proportion. Comparison of quantitative data between two group were analysed by independent sample t test. A p-value < 0.05 was considered statistically significant. Data analysis was performed using SPSS ver 22.0.

Results

During the designated study period, a total of 80 patients afflicted with grade IV Osteoarthritis (OA) who underwent total knee arthroplasty at our institute were enrolled for the study following acquisition of informed consent. Both PE and RE groups had 40 patients each. Among the participants, in proprioception group, 27 (67.5%) patients were women and 13 (32.5%) patients were men and under routine group 29 (72.5%) patients were women and 11 (27.5) patients were men, with an age range of 55 to 77 years at the time of the surgical intervention.

OARSI Recommended Performance Tests

Thirty-Second Chair-Sits

The PE group had a mean of 13.69 ± 5.33 chair-sits in a duration of 30 s, while the RE group had a lower mean of 9.17 ± 2.55 chair sits ($p < 0.001$). After 6 months, PE group demonstrated a significant increase in the average number of chair-sits to 21.07 ± 6.58, whereas the RE group showed a smaller rise to 18.63 ± 2.64 ($p = 0.030$). (Table 1, Fig. 3).

Stair Climbing (22 steps):

At the 3-month time point, the mean time for PE group to ascend 22 steps was 8.86 ± 22.83 min and the mean duration for the routine group was 16.66 ± 1.28 min ($p = 0.037$). At the 6-month mark, the average duration of time for proprioception group reduced to 0.55 ± 0.271 min, while the average

Fig. 2 3 months post-operative TKA patient in proprioception group during exercises **a** recumbent cycling to improve coordination and automation, **b** standing on foam pad with one leg with eyes open and eyes closed to improve balance)

Table 1 OARSI recommended performance tests in proprioception and routine group

OARSI performance test	Proprioception exercise (PE) group		Routine exercise (RE) group		Man difference	*t*-value	*p*-value
	Mean number	SD	Mean number	SD			
30 s chair sits (3 months)	13.69	5.33	9.17	2.55	4.515	4.746	< 0.001
30 s chair sits (6 months)	21.07	6.58	18.63	2.68	2.444	− 2.211	0.030
Stair climbing 3 months (22 Steps)	8.86	22.83	16.66	1.28	7.892	2.126	0.037
Stair climbing 6 months (22 Steps)	0.556	0.271	1.133	0.527	0.030	− 0.282	0.779
40 m fast paced walk 3 months	0.61	0.35	0.62	0.43	0.012	0.141	0.889
40 m fast paced walk 6 months	0.308	0.123	0.557	0.236	0.25	5.701	< 0.001
Timed up and go at 3 months	0.44	0.26	0.45	0.27	0.015	− 0.263	0.793
Timed up and go at 6 months	0.204	0.077	0.377	0.201	0.17	− 5.031	0.001
6-min walk test at 3 months	589.59	212.80	346.53	206.05	243.057	5.179	< 0.001
6-min walk test at 6 months	649.60	212.74	448.32	185.72	201.279	4.487	< 0.001

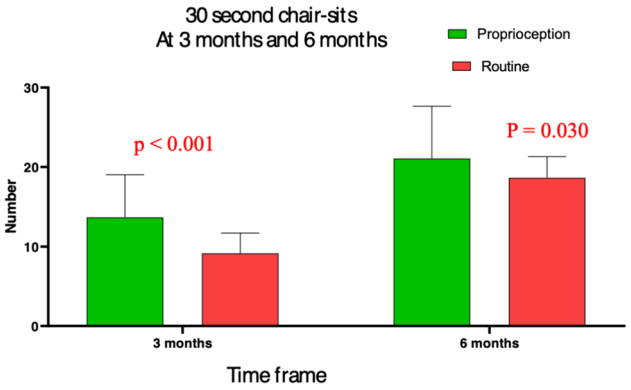


Fig. 3 Bar diagram showing the number of chair-sits done in 30 s by both the groups

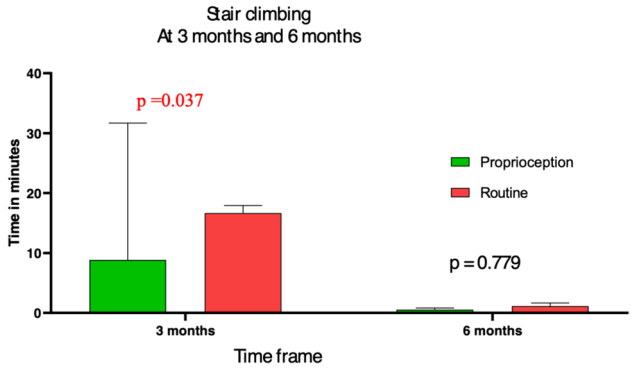


Fig. 4 Bar diagram showing the time taken to climb 22 steps by both the groups

duration of time for the routine group was 1.133 ± 0.527 min ($p = 0.779$) (Table 1, Fig. 4).

Forty Meter Fast Paced Walk

The proprioception group had a mean duration of 0.61 ± 0.35 for "40 m fast paced walk (min)" at 3 months, while the routine group had a mean of 0.62 min ± 0.43 ($p = 0.889$).

At 6 months, the proprioception group had a mean of 0.308 min ± 0.123, while the routine group took 0.557 min ± 0.236 ($p < 0.001$). (Table 1, Fig. 5).

Timed Up and Go Test

The test measures the time that a person takes to rise from a chair, walk three meters, turn around 180 degrees, walk back to the chair, and sit down while turning 180 degrees.

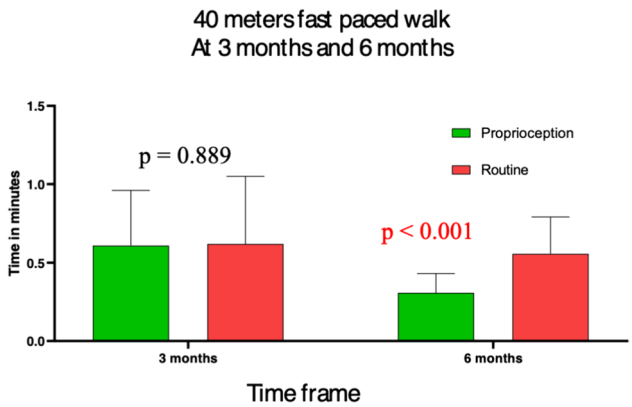


Fig. 5 Bar diagram showing the time taken for a 40 m fast paced walk by both the groups

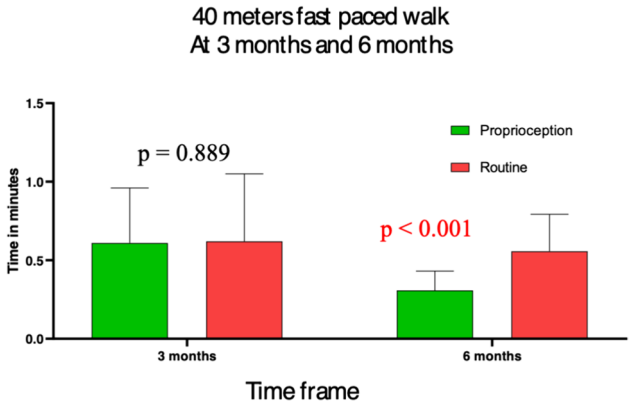


Fig. 6 Bar diagram showing the time taken for timed up and go by both the groups at 3 months and 6 months

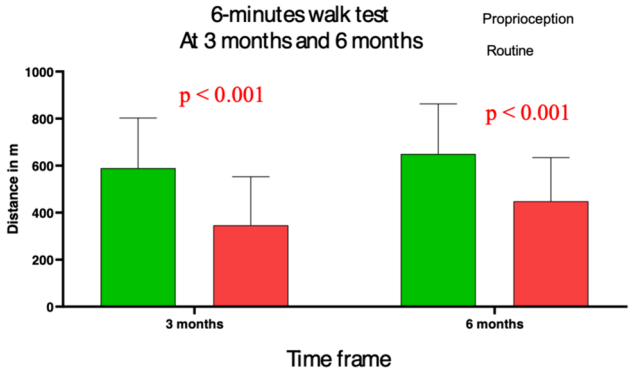


Fig. 7 Bar diagram showing the time taken for 6 min by both the groups at 3 months and 6 months

Table 2 Oxford knee score at 3 months and 6 months

OKS	Proprioception exercise group	Routine exercise group	*p*-value
3 months OKS	38 ± 2	38 ± 4	1.0
3 months OKS PCS	20 ± 4	22 ± 4	0.78
3 months OKS FCS	18 ± 4	16 ± 2	0.08
6 months OKS	42 ± 4	40 ± 2	0.94
6 months OKS PCS	24 ± 2	24 ± 2	0.74
6 months OKS FCS	18 ± 2	16 ± 2	0.09

At 3 months, the proprioception group had a mean duration of 0.44 ± 0.26 min, while the routine group had 0.45 ± 0.27 min ($p = 0.793$). At 6 months, the proprioception group had a mean duration of 0.204 ± 0.077 min, while the routine group had 0.377 ± 0.20 min ($p < 0.001$) (Table 2, Fig. 6).

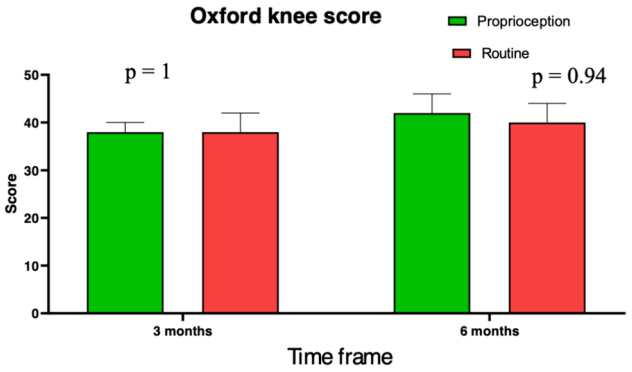


Fig. 8 Bar diagram showing OKS for both the groups at 3 months and 6 months

6 min Walk Test

At 3 months, the proprioception group covered an average distance of 589.59 m ± 212.80 in the 6 min walk test, while the routine group covered 346.53 ± 206.05 m ($p < 0.001$). At 6 months, the proprioception group covered 649.60 ± 212 m, while the routine group covered 448.32 m ± 185.72 ($p < 0.001$) (Table 1, Fig. 7).

Oxford Knee Score (OKS)

The mean OKS at 3 months for PE group was 38 ± 2.0 and for RE group was 38 ± 4. At 6 months, OKS for PE group was 42 ± 2 and for RE group was 40 ± 4 (Table 2, Fig. 8).

Discussion

The primary aim of our study was to investigate how proprioceptive exercise-based rehabilitation impacts individuals who have undergone total knee arthroplasty, using performance tests recommended by the Osteoarthritis Research Society International (OARSI) and the Oxford Knee Score (OKS). At 3 months assessment, participants in the proprioception exercise group outperformed participants in the routine exercise group in three out of five OARSI-endorsed performance assessments. Specifically, they showed improvement in the 30 s chair-stand, stair climbing, and 6-min walk tests, indicating better optimisation for daily activities. At 6 months, the group that underwent proprioception training had notable enhanced performance in almost all the performance assessments that were measured, except for the stair-climbing test. Despite the absence of a notable distinction in OKS, the OARSI-recommended performance tests highlighted the superiority of proprioception-based rehabilitation over the conventional rehabilitation program following total knee arthroplasty.

A comprehensive rehabilitation program should prioritize neuromuscular control essential for balance. Solely focusing on static and dynamic muscle strengthening does not adequately prepare the artificial joint for daily activities. Proprioception relies on mechanoreceptors, which detect mechanical stimuli including pressure, stretch, and vibration in muscles, tendons, ligaments, and joints. There are several types of joint mechanoreceptors [1, 12]. Type I receptors or free nerve endings, are widespread in capsule and surrounding ligaments and are sensitive to joint pressure and compression. Encapsulated Ruffini endings, the type II receptors, respond to joint position and slow, persistent stretching [1, 12]. Pacinian Corpuscles, the fast adapting type III receptors detect high-frequency vibrations and joint pressure changes. Ligaments and capsules have type IV receptors, Golgi tendon organs, that respond to joint tension and force [1, 12]. All these mechanoreceptors are better stimulated with closed chain exercises as they trigger increase in joint pressure in addition to the movement and joint tension triggered by open chain exercises.

A difference between native kinematics and knee kinematics post TKA is well established in literature. Numerous studies have demonstrated that patients with TKA walk different from controls with native knees. The abnormalities manifest as slower walking speed, shorter stride length, less time in stance phase, and the use of a more "stiff-legged" or a quadriceps avoidance gait [13, 14]. Various studies have shown that these abnormalities develop as an attempt to avoid quadriceps contraction during stance phase of gait cycle [15]. When evaluating patient's gait, anterior or paradoxical motion of the femur is seen in both posterior cruciate–retaining and posterior cruciate–substituting designs [16]. In our study, proprioception group subjects were trained in standing exercises to enhance proprioception, while the routine exercise group were engaged in supine exercises. During closed kinetic chain exercises, the terminal joint remains stationary, preventing free motion, whereas in open chain exercises, the terminal link can move freely through space. Closed kinetic chain exercises offer several advantages over open-chain exercises [17]. In open chain exercises, muscle groups may act in isolation, as exemplified by the predominance of the quadriceps during an open-chain lower extremity exercise like knee extension. Instead closed-chain exercises results in simultaneous activation of antagonistic muscle groups (e.g., the quadriceps and hamstrings during leg squats). In our study, we were able to demonstrate a statistically significant difference in performance tests done for assessment of either group. Based on our results, we assert that closed chain exercises can address this kinematic change in TKA more effectively.

At 6 months, in stair climbing test, the PE group outperformed the RE group but the difference in performance did not reach statistical significance.

In our study, we did not observe a statistical difference in Oxford Knee Scores between the two groups even after doing a subgroup analysis. Earlier studies which focused on balance and proprioception have yielded conflicting results when pain and quality of life was assessed. In the study by Lin et al., balance and proprioception exercises improved patient's pain and quality of life [18] but a similar effect on pain and quality of life was not demonstrated by Zhang et al. [7]. Up to 30% of patients undergoing TKA encounter moderate to severe pain one year post-surgery [19]. Various factors, such as peripheral and central sensitization, may contribute to postoperative pain [20]. Hove et al. demonstrated a strong correlation between the postoperative OKS and the OKS PCS with pain, suggesting that the OKS is more relevant to pain and provides less information regarding post-operative function [11]. He showed a correlation between OKS FCS and functional performance, but in our study though the functional score of PE group was better, the difference in the score in the two groups was not statistically significant.

This study is the first study to compare the effect of proprioception-based exercises with standard exercise regimen based on performance tests. The strengths of the study include a randomized prospective comparative design, providing a robust framework for assessing the impact of proprioception-based rehabilitation on patients undergoing total knee arthroplasty (TKA). The blinding of the surgeon and outcome assessors to the grouping and implementation during the study minimizes bias and strengthens the validity of the results. The study incorporated a thorough rehabilitation program, addressing different phases of postoperative recovery. The study utilized performance-based tests recommended by the Osteoarthritis Research Society International (OARSI) providing a comprehensive assessment of physical function.

Limitations of the study include lack of long-term follow-up which underestimate the long-term effects of proprioception-based rehabilitation, and its potential to prevent falls. Conducting the study at a single institution using a posterior stabilised design alone may introduce bias.

In summary, the results of this study indicate that proprioception training should be an essential part of post-operative rehabilitation of TKA patients. Proprioception training have positive effects on patient's daily activities like getting up from sitting, fast paced walking and climbing stairs.

Conclusion

In conclusion, this study unequivocally establishes the efficacy of proprioception based rehabilitation as a superior approach in enhancing the functional performance for Total Knee Arthroplasty (TKA) patients when compared to

the traditional rehabilitation programs. The findings of this study emphasize the importance of incorporating proprioception-based exercises in post-operative rehabilitation of TKA patients.

Appendix 1: Supplementary data

Phase 1 exercises (up to 4 weeks, common to both the groups under study)
(Fig. 9, Fig. 10).

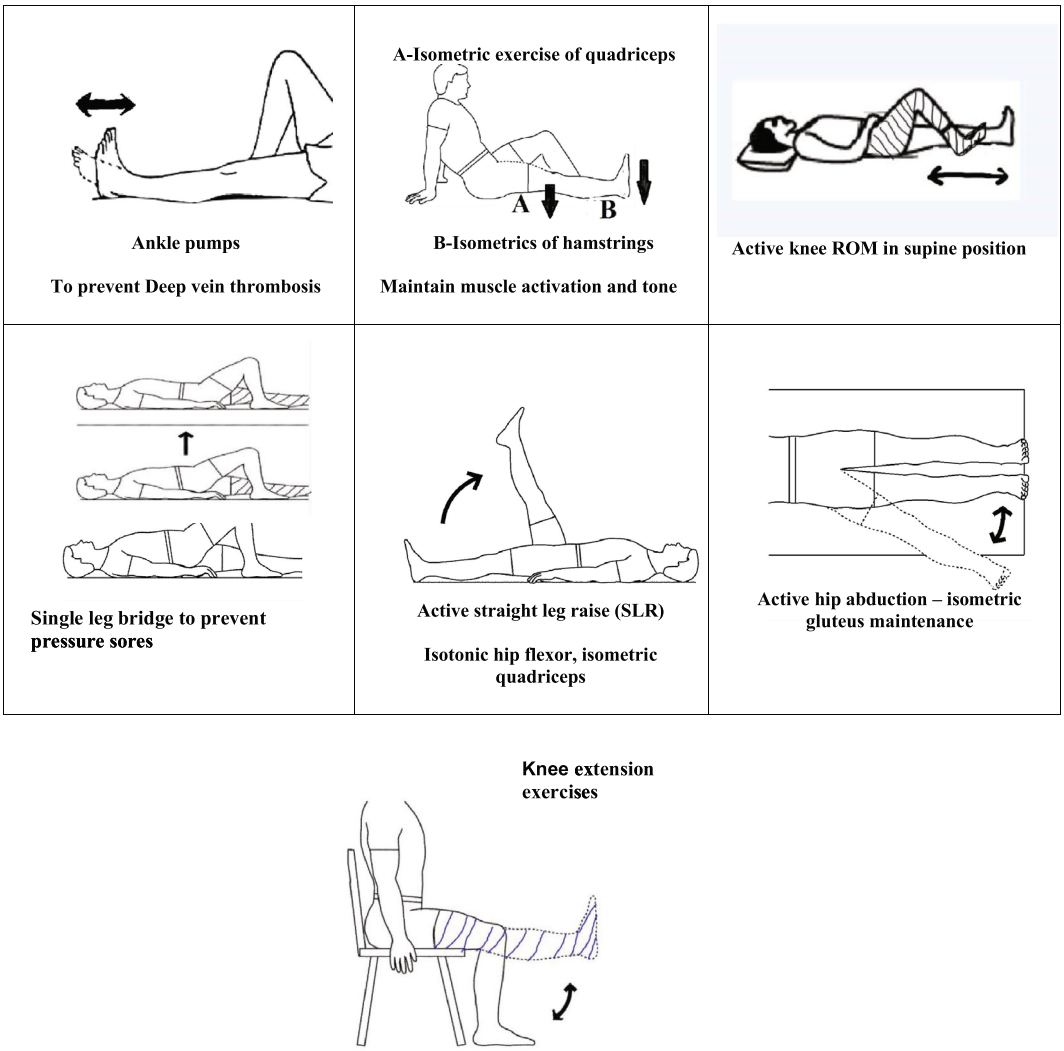


Fig. 9 Phase 1 exercises up to suture removal (up to 2 weeks)

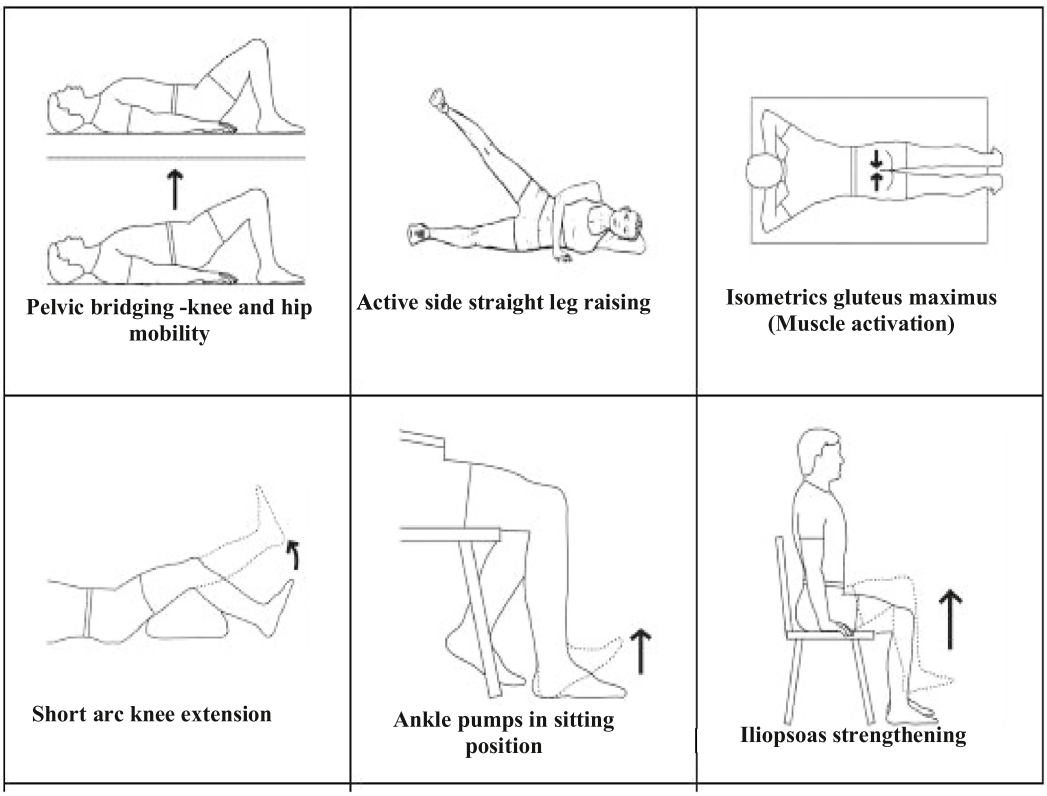


Fig. 10 Phase 1 exercises after suture removal (2 weeks to 4 weeks)

Phase 2 exercises- Proprioception vs Routine

(Fig. 11, Fig. 12).

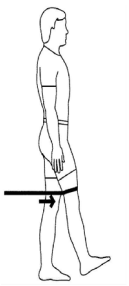
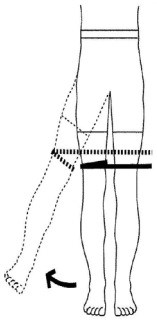
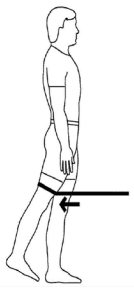
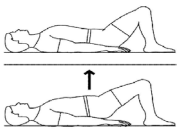
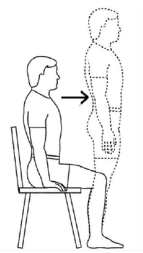
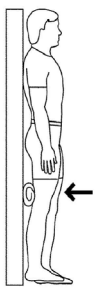
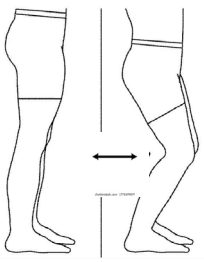
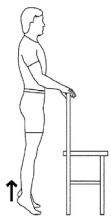
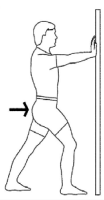
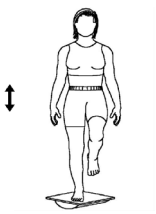
Hip flexor strengthening  **Using resistance band above knee, standing with support to improve proprioception**	**Hip abductor strengthening**  **Using resistance band in short lever (above knee) Standing with support to improve proprioception**	**Hip extensor strengthening**  **Using resistance band for strength in short lever at above knee** **Standing with support to improve proprioception**
Knee extensor strengthening  **Using resistance band for quadriceps strengthening in sitting position**	**Bridging with isometric hip adductor**  **Holding the ball in between knees, lift the hip up and down, improves hip and knee joint position sense**	**Bridging with isometric hip abductor**  **With resistance band at knee, abduct against resistance, lift hip up and down**
Sit to stand  **Sit to stand exercise improves joint Proprioception.**	**Isometrics of quadriceps**  **Quadriceps isometric exercises in standing to improve proprioception.**	**Terminal knee extension**  **With resistance band, pull back and hold for 20 counts, to maintain knee position, prevent extension lag and fixed flexion deformity.**
Calf rise  **Improves heel off in gait**	**Calf stretch**  **Calf stretching for 20 seconds**	**Single leg balance with and without support**  **Try to stand for 10 seconds**

Fig. 11 Phase 2 Proprioception exercises (4 weeks to 8 weeks)

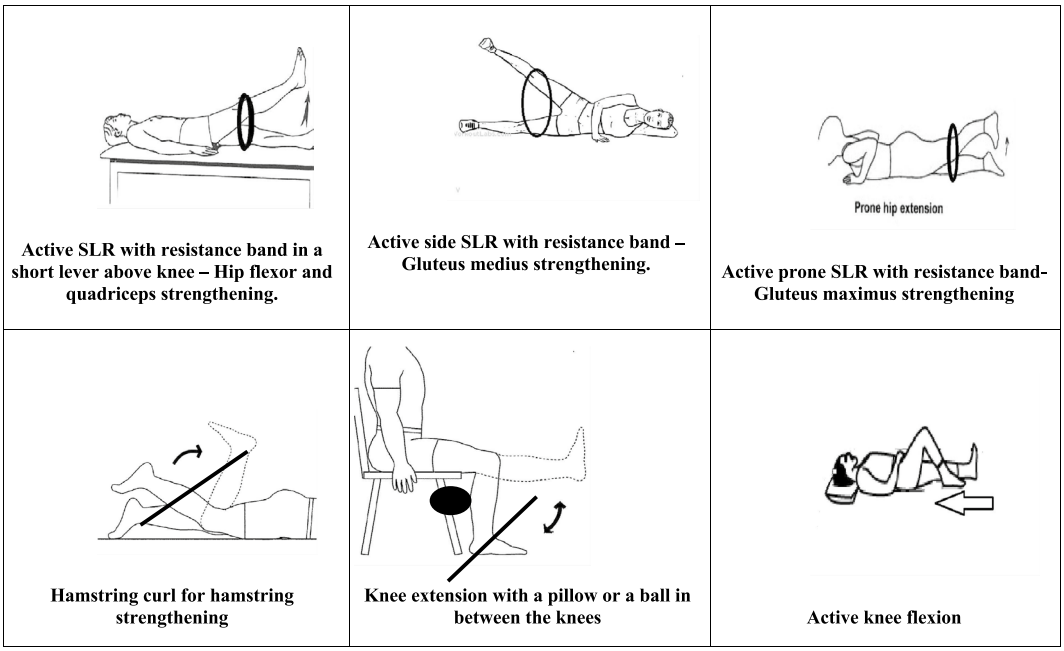


Fig. 12 Phase 2 Routine exercises (4 weeks to 8 weeks)

Phase 3 exercises- Proprioception vs Routine

(Fig. 13, Fig. 14).

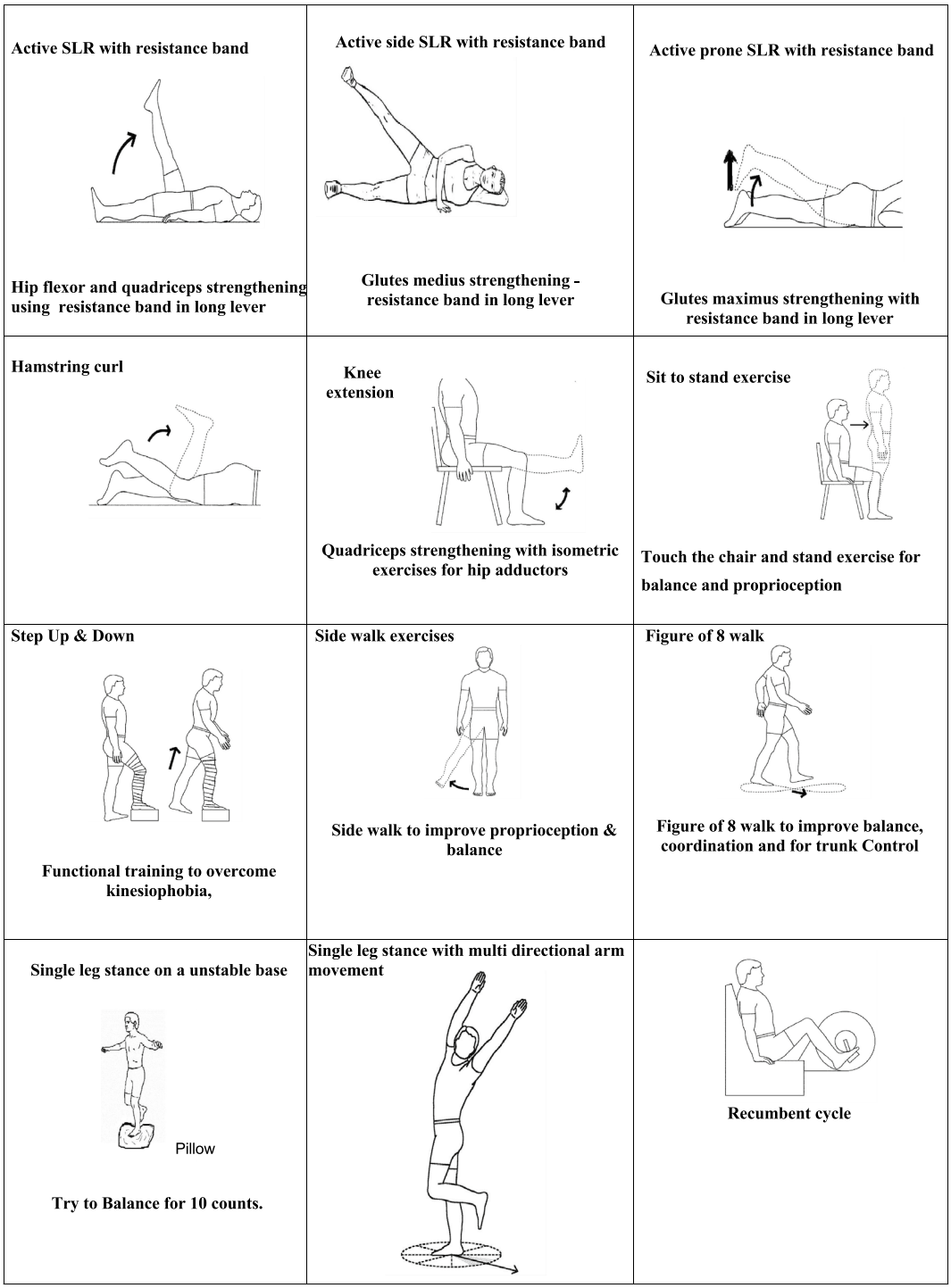


Fig. 13 Phase 3 proprioception exercises (After 8 weeks)

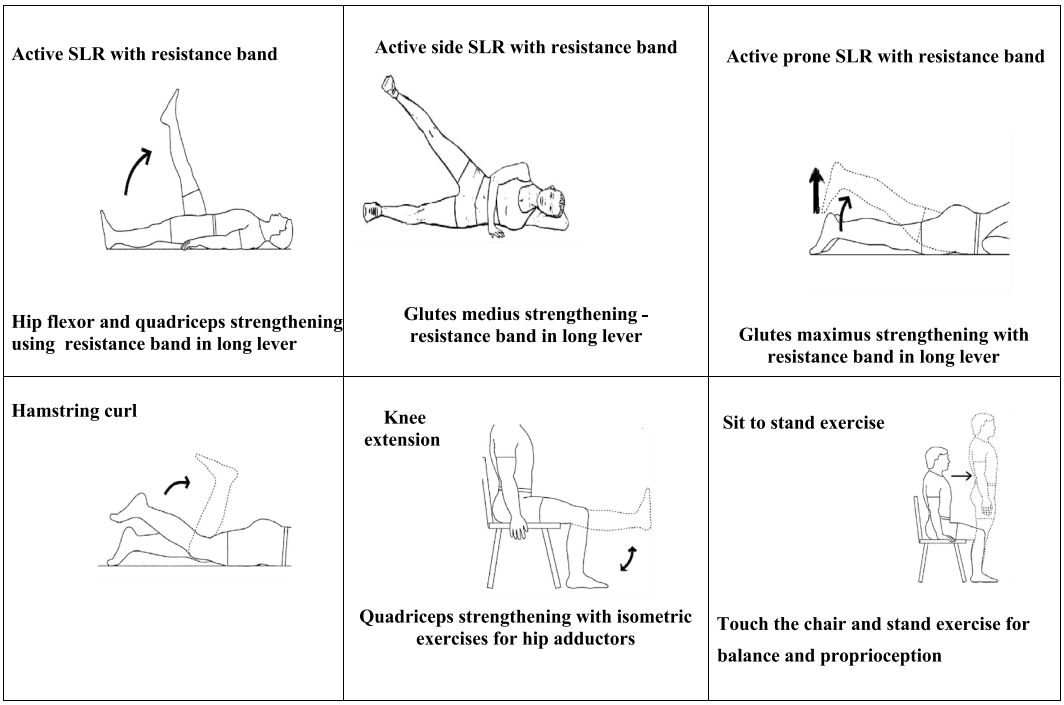


Fig. 14 Phase 3 routine exercises (After 8 weeks)

Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

Ethical approval This article does not contain any studies with human or animal subjects performed by the any of the authors.

References

1. Salamanna, F., Caravelli, S., Marchese, L., Carniato, M., Vocale, E., Gardini, G., et al. (2023). Proprioception and mechanoreceptors in osteoarthritis: a systematic literature review. *Journal of Clinical Medicine, 12*(20), 6623.
2. Ferlinc, A., Fabiani, E., Velnar, T., & Gradisnik, L. (2019). The importance and role of proprioception in the elderly: a short review. *Material Socio-Medica, 31*(3), 219–221.
3. di Laura Frattura, G., Zaffagnini, S., Filardo, G., Romandini, I., Fusco, A., & Candrian, C. (2019). Total knee arthroplasty in patients with knee osteoarthritis: effects on proprioception a systematic review and best evidence synthesis. *Journal of Arthroplasty, 34*(11), 2815–2822.
4. Stillman, B. C. (2002). Making sense of proprioception: the meaning of proprioception, kinaesthesia and related terms. *Physiotherapy, 88*(11), 667–676.
5. Chan, A. C. M., Jehu, D. A., & Pang, M. Y. C. (2018). Falls after total knee arthroplasty: frequency, circumstances, and associated factors—a prospective cohort study. *Physical Therapy, 98*(9), 767–778.
6. Moutzouri, M., Gleeson, N., Billis, E., Tsepis, E., Panoutsopoulou, I., & Gliatis, J. (2017). The effect of total knee arthroplasty on patients' balance and incidence of falls: a systematic review. *Knee Surgery, Sports Traumatology, Arthroscopy, 25*(11), 3439–3451.
7. Chao, Z. W., & Xiao, D. (2020). Efficacy of proprioceptive training on the recovery of total joint arthroplasty patients: a meta-analysis. *Journal of Orthopaedic Surgery and Research, 3*(15), 505.
8. Dobson, F., Hinman, R. S., Roos, E. M., Abbott, J. H., Stratford, P., Davis, A. M., et al. (2013). OARSI recommended performance-based tests to assess physical function in people diagnosed with hip or knee osteoarthritis. *Osteoarthritis Cartilage, 21*(8), 1042–1052.
9. Physical Performance Measures | Osteoarthritis Research Society International (OARSI) [Internet]. [Cited 2023 Dec 8]. Available from: https://oarsi.org/research-oarsi-success/physical-performance-measures
10. Harris, K., Dawson, J., Doll, H., Field, R. E., Murray, D. W., Fitzpatrick, R., et al. (2013). Can pain and function be distinguished in the Oxford Knee Score in a meaningful way? An exploratory and confirmatory factor analysis. *Quality of Life Research a International Journal of Quality of Life Aspects Treatment, Care Rehabilitation, 22*(9), 2561–2568.
11. van Hove, R. P., Brohet, R. M., van Royen, B. J., & Nolte, P. A. (2016). High correlation of the Oxford knee score with postoperative pain, but not with performance-based functioning. *Knee Surgery, Sports Traumatology, Arthroscopy Official Journal of the ESSKA, 24*(10), 3369–3375.
12 Freeman, M. A., & Wyke, B. (1967). The innervation of the knee joint. An anatomical and histological study in the cat. *Journal of Anatomy, 101*(Pt 3), 505–532.
13. Benedetti, M. G., Catani, F., Bilotta, T. W., Marcacci, M., Mariani, E., & Giannini, S. (2003). Muscle activation pattern and

gait biomechanics after total knee replacement. *Clinical Biomechanics Bristol Avon, 1*(18), 871–876.
14. Milner, C. (2009). Is gait normal after total knee arthroplasty? systematic review of the literature. *Journal of Orthopaedic Science Official Journal of Japan Orthopaedic Association, 1*(14), 114–120.
15. Kline, P. W., Jacobs, C. A., Duncan, S. T., & Noehren, B. (2019). Rate of torque development is the primary contributor to quadriceps avoidance gait following total knee arthroplasty. *Gait & Posture, 1*(68), 397–402.
16. Movassaghi, K., Patel, A., Ghulam-Jelani, Z., & Levine, B. R. (2023). Modern total knee arthroplasty bearing designs and the role of the posterior cruciate ligament. *Arthroplasty Today, 1*(21), 101130.
17. Kwon, Y. J., Park, S. J., Jefferson, J., & Kim, K. (2013). The effect of open and closed kinetic chain exercises on dynamic balance ability of normal healthy adults. *Journal of Physical Therapy Science, 25*(6), 671–674.
18. Lin, H., Xu, A., Wu, H., Xu, H., Lu, Y., & Yang, H. (2022). Effect of proprioception and balance training combined with continuous nursing on BBS score and HSS score of patients undergoing total knee arthroplasty. *Computational and Mathematical Methods in Medicine, 1*(2022), e7074525.
19. Li, J., Ma, Y., & Xiao, L. (2019). Postoperative pain management in total knee arthroplasty. *Orthopaedic Surgery, 11*(5), 755–761.
20. Aoyagi, K., Law, L. F., Carlesso, L., Nevitt, M., Lewis, C. E., Wang, N., et al. (2023). Post-surgical contributors to persistent knee pain following knee replacement: the multicenter osteoarthritis study (MOST). *Osteoarthritis and Cartilage Open, 5*(1), 100335.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.