# Early Postoperative Rapid Rehabilitation Yields More Favorable Short-term Outcomes in Patients Undergoing Patellar Realignment Surgery for Recurrent Patellar Dislocation

## A Prospective Randomized Controlled Study

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**Background:** Use of a rapid rehabilitation protocol for postoperative recovery after recurrent patellar dislocation (RPD) has gradually gained attention; nonetheless, evidence of its safety and effectiveness is lacking.

**Purpose:** To compare the short-term postoperative outcomes of early rapid rehabilitation with those of conservative rehabilitation in patients with RPD.

**Study Design:** Randomized controlled trial; Level of evidence, 2.

**Methods:** A total of 50 patients with RPD who underwent tibial tubercle osteotomy combined with medial patellofemoral ligament reconstruction were enrolled between January 2018 and February 2019. Postoperatively, the patients were randomly assigned to either the early rapid group (rapid group; n = 25 patients) or the conservative group (control group; n = 25 patients) for rehabilitation training. The rapid group underwent faster progression in weightbearing and range of motion (ROM) training. Knee joint functional scores, ROM, bilateral thigh circumference differences, and imaging data were recorded preoperatively and at 6 weeks and 3, 6, 12, and 24 months postoperatively for comparison. Postoperative complications were recorded over the 24-month follow-up period.

**Results:** The baseline data did not significantly differ between the 2 groups. Postoperatively, compared with the control group, the rapid group had higher Tegner scores at 6 weeks and 3 months; higher Lysholm scores at 3 and 6 months; higher International Knee Documentation Committee scores at 6 weeks, 3 months, and 12 months; better ROM; and smaller bilateral thigh circumference differences at 24 months ($P < .05$ for all). However, no differences were observed in the Tegner, Lysholm, and International Knee Documentation Committee scores at 24 months postoperatively. At the 6-week and subsequent follow-up visits, the Caton and Insall indices were lower in the control group than in the rapid group ($P < .01$ for all). Moreover, compared with the control group, the rapid group had a lower incidence of patella baja at 24 months (0% vs 17%) and fewer complications during the whole follow-up period ($P < .01$).

**Conclusion:** Early rapid postoperative rehabilitation appears to be safe and effective for patients who undergo tibial tubercle osteotomy combined with medial patellofemoral ligament reconstruction to treat RPD. In the short term, this approach was shown to be more advantageous than conservative rehabilitation in improving functional scores, allowing an earlier return to daily activities, although the lack of difference at 24 months implies no long-term benefits. In addition, it potentially helped to prevent the occurrence of complications, including patella baja.

**Registration:** ChiCTR1800014648 (ClinicalTrials.gov identifier).

**Keywords:** medial patellofemoral ligament reconstruction; patellar height; rapid rehabilitation; recurrent patellar dislocation; tibial tubercle osteotomy

Patellar dislocation is a common knee joint disorder that affects 5.8 to 77.8 individuals per 100,000 people in the general population, with a higher incidence in women.[5] After initial dislocation, approximately 15% to 44% of

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patients may progress to recurrent patellar dislocation (RPD),[10] and in some instances, this incidence can[6] reach 71%. RPD can lead to patellar cartilage injury and, in severe cases, progress to patellofemoral joint arthritis, significantly affecting patients' daily lives and mobility and often necessitating surgical intervention.[8,42] For patients with RPD exhibiting patella alta and an increased tibial tuberosity–trochlear groove (TT-TG) distance, medial patellofemoral ligament (MPFL) reconstruction (MPFLR) alone may be insufficient to correct osseous structural abnormalities. In such cases, a combined procedure involving tibial tubercle osteotomy (TTO) may be preferable. TTO improves patellar tracking by altering the attachment point of the patellar ligament on the tibia, thereby addressing bone-related structural issues.[2,36]

Postoperative rehabilitation is equally crucial, traditionally involving weightbearing, knee joint range of motion (ROM), and muscle training.[19] There has been significant variability in postoperative rehabilitation strategies over the years, perhaps because of safety concerns.[17] Conservative rehabilitation often involves postoperative fixation in a 0° extended position, with relatively prolonged restrictions on weightbearing and functional exercises.[1,9,12,17,27,39] This approach may lead to adhesions in the surgical site and patellar ligament contracture, resulting in the development of patella baja and quadriceps atrophy as well as pain and restricted movement.[2,8,20] For some patients, the return to physical activity is delayed. However, aggressive rehabilitation can cause serious complications, such as graft laxity, fractures, and recurrent dislocation, ultimately compromising the effectiveness of the surgery.

Early rapid postoperative training, considering the reparative characteristics and biomechanical properties of biological tissues, can stimulate collagen rearrangement in damaged soft tissues and facilitate blood supply restoration, facilitating the early return to physical activity.[26,41] In recent years, Hilber et al[13] were the first to implement early functional rehabilitation strategies after patellar dislocation, including allowing earlier weightbearing and unrestricted ROM. However, a comprehensive literature review revealed a limited number of studies reporting the clinical outcomes related to rehabilitation programs.[17] Moreover, there is a notable absence of research comparing early rapid rehabilitation with conservative rehabilitation after TTO combined with MPFLR.

Therefore, by integrating the findings in previous literature and clinical expertise, this study devised 2 rehabilitation protocols to compare patient outcomes and explore clinical efficacy and safety. It was hypothesized that both clinical and radiological results would significantly change postoperatively and that the early rapid protocol would offer additional benefits compared with the conservative protocol.

## METHODS

### Patients and Study Design

This prospective randomized controlled trial was approved by the ethics committee of West China Hospital, Sichuan University (approval No. 2017-401) and prospectively registered with the Chinese Clinical Trial Registry (registration No. ChiCTR1800014648).

The sample size was determined based on the calculation of differences in International Knee Documentation Committee (IKDC) subjective knee evaluation form scores during the follow-up, with grouping primarily dependent on weightbearing time and initiation of ROM exercises. According to previous studies,[4,33,37,40] with a power of 90% and an alpha of .05, the sample size for each group was set at 21 participants, indicating a mean difference of 18.9 points in IKDC scores between the intervention groups. Considering the dropout rate, the sample size was increased by 20%. Ultimately, the sample size for each group was determined as 25, totaling 50 participants. A total of 50 patients with RPD were recruited for the study between January 2018 and February 2019 (Figure 1). All participants provided informed consent, and they were informed of their group assignments only after the conclusion of the study.

Patients were enrolled if they met the following criteria: (1) diagnosed with RPD and required TTO; (2) aged $\leq$50 years; (3) had a closed epiphysis; (4) had a Caton-Deschamps index (Caton index) of $>$1.2 or an Insall-Salvati index (Insall index) of $>$1.2; and (5) had a TT-TG of $\geq$15 mm.[9] The exclusion criteria were as follows: (1) $>$50 years of age; (2) unclosed epiphysis; (3) unsuitability for early rapid rehabilitation (eg, fractures requiring reduction and fixation); (4) history of previous surgery on the target knee; (5) severe patellar maltracking; and (6) inability to tolerate anesthesia or surgery. Baseline data—including age, sex, operative side, height, weight, body mass index, ROM, and bilateral thigh circumference difference (BTCD; cm) at the upper 10 cm of the patella—were collected preoperatively. TT-TG was measured based on computed tomography scans.

Randomization was conducted using SPSS 23.0 (IBM), which generated 50 random numbers concealed in sealed envelopes. A third-party researcher independently stored these envelopes. Allocation was performed by sequentially

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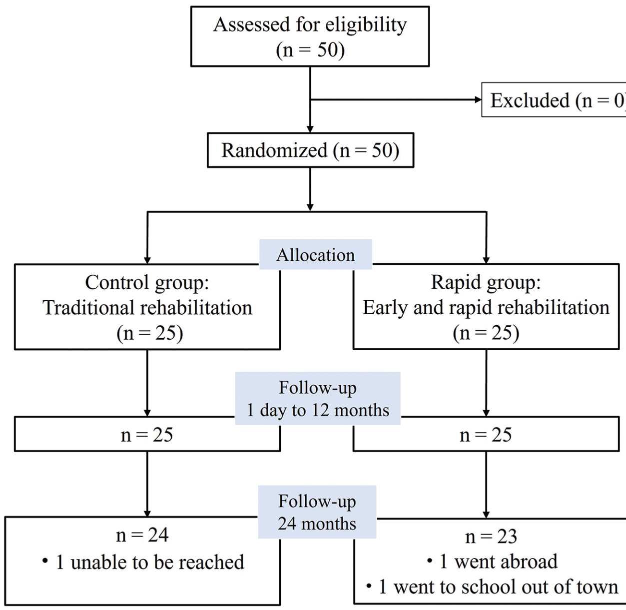


**Figure 1.** A flowchart depicting the patient enrollment process in the randomized controlled study. At the 24-month follow-up visit, 2 participants were lost to follow-up in the rapid group, and 1 was lost to follow-up in the control group.

opening the sealed envelopes, with even numbers assigned to the early rapid rehabilitation group (rapid group; n = 25) and odd numbers assigned to the conservative rehabilitation group (control group; n = 25). A third-party researcher recorded the allocation information. The surgeon (Q.L.) was informed of the allocation of information immediately after the surgical procedure to facilitate intervention. Independent of the primary operating surgeon, the surgeons (S.L. and J.Z.), who were blinded to grouping, conducted all radiological measurements and follow-up assessments.

## Surgical Technique

The surgical procedures were all conducted by an experienced primary surgeon (Q.L.). Following the preoperative plan designed to correct the TT-TG distance (<15 mm) and Caton index (approximately 1), we used an oscillating saw for quadrangular wedge osteotomy, temporarily detaching the tibial tuberosity bone block connected to the patellar ligament. Subsequently, an equally sized bone block was excised below and medial to the original tibial tuberosity. As previously reported, the positions of the 2 bone blocks were interchanged to achieve medialization and distalization of the tibial tuberosity.[43] We slightly reduced the depth of the newly excavated bone bed to prevent posterior translation of the tibial tubercle. Two 4.5 mm–diameter bioabsorbable bicortical screws (BioFix) were subsequently used to secure the tibial tuberosity bone block. After removing the semitendinosus autograft, we performed anatomic double-bundle MPFLR.[25,27,45] The patellar tunnel was established at the midpoint and

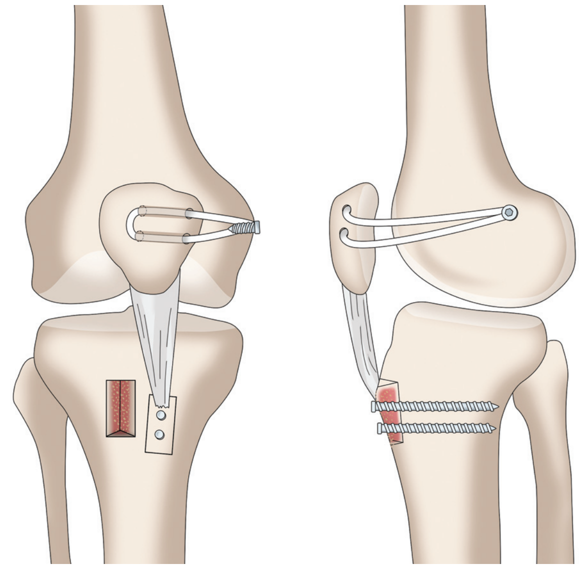

**Figure 2.** Diagrams of the tibial tubercle osteotomy and medial patellofemoral ligament reconstruction techniques.

upper midpoint of the medial edge of the patella, and the femoral tunnel was created at the anatomic termination point of the MPFL. The graft was inserted into a tunnel on the medial edge of the patella and exited through another tunnel, forming a U-shaped loop for implant-free patellar fixation. Subsequently, the graft strands were bundled together and passed through the femoral tunnel, where they were fixed with a 6-mm bioabsorbable interference screw (Smith & Nephew) at 30° of knee flexion. Figure 2 illustrates the TTO and MPFLR techniques. Selective release was performed as necessary for patients with high tension in the lateral retinaculum.

## Rehabilitation

Postoperative rehabilitation focused on weightbearing, ROM training, muscle strength, and proprioception exercises (Table 1). Both groups were subjected to weightbearing restrictions and gradually increased their load based on individual tolerance. The rapid group transitioned to full weightbearing after 3 weeks, and the control group transitioned after 6 weeks. Restricted ROM training from 0° to 120° was conducted with the protection of an adjustable hinged brace in both groups. In the rapid group, ROM was restored to 90° by 4 weeks and was 120° by 6 weeks. In contrast, the control group underwent initial immobilization in full extension for 3 weeks, reached 90° by 7 weeks, and attained 120° by 9 weeks. Early muscle strength and proprioception training commenced in accordance with the progress of weightbearing and ROM exercises. Postoperatively, ice was applied to the knees of all patients, and nonsteroidal anti-inflammatory drugs were administered orally or topically as needed, along with the utilization of lower limb pneumatic compression devices to prevent thrombosis formation. The rehabilitation timeline is

TABLE 1
Postoperative Rehabilitation Plans for the Rapid and Control Groups[a]

| | Weightbearing | ROM | Muscle Strength and Proprioception |
|---|---|---|---|
| Rapid | Weeks 1-3: partial weightbearing<br>After 3 weeks: full weightbearing | Weeks 0-2: 0°-45°<br>Weeks 2-4: 0°-90°<br>Weeks 4-6: 0°-120°<br>6 weeks to 6 months: restoration of normal ROM | 1 day to 2 weeks: quadriceps isometric training, ankle pump exercises, neuromuscular electrical stimulation<br>Weeks 2-4: periarticular muscle training around the knee<br>Weeks 4-6: "wall climbing" exercises,[b] air cycling training[c]<br>6 weeks to 3 months: half-squat training, balance feedback exercises, gait flexibility training |
| Control | Weeks 1-6: partial weightbearing<br>After 6 weeks: full weightbearing | Weeks 0-3: 0° in extension<br>Weeks 3-5: 0°-45°<br>Weeks 5-7: 0°-90°<br>Weeks 7-9: 0°-120°<br>9 weeks to 6 months: restoration of normal ROM | 1 day to 2 weeks: quadriceps isometric training, ankle pump exercises, neuromuscular electrical stimulation<br>Weeks 2-7: periarticular muscle training around the knee<br>Weeks 7-9: "wall climbing" exercises, air cycling training<br>9 weeks to 3 months: half-squat training, balance feedback exercises, gait flexibility training |

[a]ROM, range of motion.
[b]"Wall climbing" exercises: Patients positioned their buttocks opposite the head of the bed, lifted the affected limb, and crawled the sole of their foot on the wall to assist in knee flexion.
[c]Air cycling training: Patients elevated both legs at a 30° angle in a supine position with the lower back consistently against the ground. The legs were alternately flexed and extended slowly and with control, resembling a circular pedaling motion as on a bicycle.

available in Table 1 or Appendix 1 (available in the online version of this article).

## Clinical Evaluation

Knee joint function was measured using patient-reported outcomes,[9] including the Tegner activity scale, the Lysholm score, and the IKDC score, preoperatively and at 6 weeks and 3, 6, 12, and 24 months after surgery. Simultaneously, ROM of the affected limb and BTCD were documented. Over the 24-month follow-up period, occurrences of postoperative complications were recorded as safety assessment indicators.

## Radiographic Measurements

Lateral knee radiographs with the knee flexed to 30° were taken preoperatively; on the first postoperative day; at 6 weeks postoperatively; and at 3, 6, 12, and 24 months postoperatively. The Caton and Insall indices were measured to quantify the patellar position.[44] In the postoperative assessment of the Insall index, the preoperative insertion point was the distal endpoint of the measured patellar tendon.[34]

## Statistical Analysis

Statistical analysis was conducted using SPSS software Version 25 (IBM) and GraphPad Prism Version 8.0.2 (GraphPad Software Inc). Continuous variables are presented as the mean ± SD. Independent-samples *t* test was employed to compare continuous variables within or between groups. The Pearson chi-square test or the Fisher exact test was used to compare categorical variables between groups, and the Cramer V was used as an effect size. For the Cramer V, a value <0.3 was considered a weak association, between 0.3 and 0.5 was considered a moderate association, and >0.5 was considered a strong association. A 2-tailed $P < .05$ was considered to indicate statistical significance.

TABLE 2
Patient Characteristics[a]

| | Rapid (n = 25) | Control (n = 25) | *P* |
|---|---|---|---|
| Age, y | 20.7 ± 3.6 | 21.6 ± 7.3 | .58 |
| Sex, female/male | 18/7 | 17/8 | .758 |
| Operated side, left/right | 12/13 | 13/12 | .777 |
| Height, cm | 164.6 ± 8 | 166.5 ± 6.9 | .369 |
| Weight, kg | 59.8 ± 10.6 | 58 ± 9.1 | .531 |
| BMI | 21.9 ± 2.3 | 20.8 ± 1.9 | .072 |
| TT-TG value, mm | 19.81 ± 2.57 | 21.06 ± 2.11 | .066 |

[a]Data are presented as mean ± SD or n. BMI, body mass index; TT-TG, tibial tuberosity–trochlear groove.

# RESULTS

## Patients

The 50 enrolled patients were randomly allocated to 2 groups, with 25 in each group. At 24 months postoperatively, 2 participants from the rapid group (1 went abroad and 1 relocated for education) and 1 from the control group (unreachable) were unavailable for follow-up. Table 2 shows the characteristics of the patients.

## Clinical Evaluation Outcome

Preoperatively, the groups had no significant differences in functional scores (Table 3). Postoperatively, at 24 months, all 3 scores for both groups improved compared with the preoperative values ($P < .01$). The temporal changes in functional scores over time are depicted in Figure 3 A-C. At 6 weeks after surgery, all the scores reached their lowest points; they gradually increased thereafter and peaked at 24 months after surgery. Notably, the rapid group exhibited higher scores than did the control group at several time points after surgery ($P < .05$); specifically, Tegner scores at 6 weeks and 3 months, Lysholm scores at 3 and 6 months, and IKDC scores at 6 weeks, 3 months, and 12 months.

Regarding ROM (Table 3 and Figure 3D), the rapid group demonstrated significantly greater values at all time points ($P < .05$) except preoperatively. However, at the final follow-up, the difference in ROM was only 2°. Moreover, for the BTCD, no significant differences were found between the 2 groups at any time point except at 24 months after surgery, where the rapid group had lower values ($P = .043$) (Table 3 and Figure 3E).

### Radiographic Outcome

The Caton and Insall indices for the 2 groups are presented in Table 4, and the corresponding line graphs depicting their changes over time are illustrated in Figure 3 F and G. No significant differences were found between the groups in either the Caton or the Insall indices preoperatively or on the first day postoperatively. However, statistically significant differences ($P < .01$) were observed for both indices when comparing the values of the 2 groups at 1 day and 24 months postoperatively with their respective preoperative values. Due to the surgery, both indices showed a significant decrease from the preoperative day to the first postoperative day. In addition, compared with those in the rapid group, both indices in the control group exhibited more pronounced decreases from 1 day to 6 weeks postoperatively, with differences emerging at the 6-week mark and persisting in the subsequent follow-up periods.

### Complications

In the early postoperative period, the rapid group had 1 case of lower limb deep vein thrombosis and 3 cases of incisional fat liquefaction, and the control group had 3 and 4 cases, respectively. The incision issues healed well after management. At the last follow-up visit, 1 patient in the rapid group reported anterior knee pain but showed no signs of patella baja, whereas in the control group, 3 patients reported anterior knee pain, and 4 patients (17%) developed patella baja (Caton and Insall indices were[30,32] <0.8). Throughout the entire follow-up period, 1 patient in the control group underwent arthroscopic release for knee joint stiffness. No patients in either group experienced patellar redislocation, nonunion of the bone blocks, or avulsion fractures. The difference in the overall complication rate between the 2 groups was statistically significant ($P < .01$; Cramer V = 0.412). The incidence of patella baja was 0% in the rapid group compared with 17% in the control group ($P = .109$; Cramer V = 0.299). See Appendix 2 (available online) for details.

## DISCUSSION

This study is one of the few to date that presents a relatively clear rehabilitation schedule and prospectively and randomly compares the outcomes of 2 rehabilitation protocols for patients who underwent TTO combined with MPFLR to treat RPD. The surgery improved the patient's prognosis. Perhaps most importantly, the introduction of multiple assessment indicators suggests that early rapid rehabilitation is not only safe and effective but also potentially superior to conservative rehabilitation, especially in terms of early postoperative improvements in functional scores, prevention of complications, and restoration of knee joint ROM.

According to the outcomes of the present trial, postoperative knee joint function improved in both groups. These enhancements encompassed the levels of return to activity as indicated by the Tegner scale, the daily living capability emphasized by the Lysholm score, and the comprehensive reflection of knee joint symptoms and functional status indicated by the IKDC score.[8] The combination of several scores could more comprehensively reflect knee joint function and disability.[8] During the 24-month follow-up period, the rapid group had higher scores at several time points compared with the control group, which indicated that an early rapid rehabilitation protocol might be more advantageous for short-term functional improvements, potentially allowing an earlier return to daily activities and work. A few studies focusing on MPFLR have reported patient outcomes after rapid rehabilitation, with overall functional scores ranging from good to excellent.[21] Magnussen et al[24] compared the outcomes of patients who underwent a restrictive protocol or an accelerated protocol. They noted that accelerated rehabilitation does not increase the risk of recurrent instability and is unrelated to a worse Knee injury and Osteoarthritis Outcome Score. In the study by Krych et al,[19] patients underwent unrestricted ROM exercises immediately after surgery, regardless of whether TTO was performed. At the follow-up visit at a mean of 47 months postoperatively, the mean Kujala score for 39 patients was 91.1, and the median Tegner score was 6 (range, 4-9). Our results are comparable with those previously reported in the literature.

Clinical studies[13,18,24] have indicated that postoperative practices, including early weightbearing and unrestricted ROM, do not cause significant harm. However, some researchers[38,39] have suggested that to prevent potential issues—such as graft laxity, bone block separation, or nonunion—it is advisable to appropriately restrict knee joint weightbearing and ROM in the early postoperative period. The lack of standardized guidelines resulted in significant variations in the postoperative activity range and the timing of weightbearing restrictions.[8,17,21] According to a meta-analysis[17] incorporating 16 studies on the use of the MPFLR combined with TTO, 7 studies reported the

TABLE 3
Clinical Assessment Results of the 2 Groups[a]

| | Assessment Time | Rapid (n = 25) | Control (n = 25) | *P* |
|---|---|---|---|---|
| Tegner score | Preoperative | 2.5 ± 1.6 (1.9-3.2) | 2.1 ± 1.2 (1.6-2.6) | .309 |
| | 6 weeks | 1.4 ± 0.5 (1.2-1.6) | 1 ± 0.4 (0.90-1.19) | **<.01** |
| | 3 months | 2.2 ± 0.7 (2-2.5) | 1.7 ± 0.7 (1.4-2) | **<.01** |
| | 6 months | 3.1 ± 0.8 (2.8-3.4) | 2.8 ± 0.6 (2.6-3.1) | .150 |
| | 12 months | 4 ± 0.8 (3.6-4.3) | 3.6 ± 0.6 (3.4-3.9) | .121 |
| | 24 months | 5.3 ± 1.2 (4.7-5.8) | 4.8 ± 1.2 (4.2-5.3) | .152 |
| Lysholm score | Preoperative | 74 ± 17.3 (66.8-81.1) | 73.6 ± 13.1 (68.2-79) | .934 |
| | 6 weeks | 57.2 ± 6.8 (54.4-60) | 53.9 ± 8.9 (50.2-57.5) | .139 |
| | 3 months | 69.4 ± 13.2 (64-74.8) | 62.3 ± 11 (57.8-66.8) | **.043** |
| | 6 months | 79 ± 12.3 (74-84.1) | 70.2 ± 9.6 (66.2-74.1) | **<.01** |
| | 12 months | 84.6 ± 11.6 (79.8-89.4) | 79.2 ± 7.3 (76.1-82.2) | .054 |
| | 24 months | 89 ± 8.4 (85.3-92.6) | 85.5 ± 8.1 (82-88.9) | .153 |
| IKDC score | Preoperative | 65.6 ± 13.3 (60.1-71.1) | 67.3 ± 12.3 (62.2-72.3) | .648 |
| | 6 weeks | 57.7 ± 5 (55.7-59.8) | 52.7 ± 9.2 (48.9-56.5) | **.020** |
| | 3 months | 64.1 ± 6.6 (61.4-66.8) | 59.2 ± 9.3 (55.3-63) | **.035** |
| | 6 months | 74.3 ± 7.9 (71.1-77.6) | 68.9 ± 11.1 (64.3-73.5) | .054 |
| | 12 months | 84.2 ± 7.4 (81.2-87.3) | 78 ± 9.2 (74.2-81.8) | **.011** |
| | 24 months | 84.4 ± 6.6 (81.6-87.3) | 81.2 ± 7.1 (78.2-84.2) | .113 |
| ROM, deg | Preoperative | 131.2 ± 11.7 (126.4-136) | 131.4 ± 9.7 (127.4-135.4) | .848 |
| | 6 weeks | 117.8 ± 6.5 (115.1-120.5) | 66.2 ± 16.5 (59.4-73) | **<.01** |
| | 3 months | 128.6 ± 5.7 (126.3-130.9) | 115.8 ± 13.3 (110.3-121.3) | **<.01** |
| | 6 months | 133.8 ± 3.8 (131.2-134.4) | 126.2 ± 6.7 (123.5-129) | **<.01** |
| | 12 months | 133 ± 3.5 (131.5-134.5) | 130.2 ± 5.3 (128-132.4) | **.033** |
| | 24 months | 137.4 ± 3.7 (135.8-139) | 135.2 ± 3.1 (133.9-136.5) | **.033** |
| BTCD, cm | Preoperative | 1.3 ± 1.1 (0.9-1.7) | 1.1 ± 0.8 (0.8-1.4) | .494 |
| | 6 weeks | 1.5 ± 1.1 (1.1-2) | 1.9 ± 0.9 (1.6-2.3) | .209 |
| | 3 months | 1.2 ± 0.9 (0.8-1.6) | 1.5 ± 0.7 (1.2-1.8) | .183 |
| | 6 months | 0.8 ± 0.7 (0.5-1.1) | 1.1 ± 0.5 (0.9-1.3) | .126 |
| | 12 months | 0.6 ± 0.5 (0.4-0.8) | 0.8 ± 0.4 (0.7-1) | .138 |
| | 24 months | 0.3 ± 0.2 (0.2-0.4) | 0.5 ± 0.4 (0.3-0.6) | **.043** |

[a]Data are presented as mean ± SD (95% CI). Bold *P* values indicate statistically significant differences between the 2 groups. At 24 months postoperatively, 23 patients were in the rapid group, and 24 were in the control group. BTCD, bilateral thigh circumference difference; IKDC, International Knee Documentation Committee subjective knee evaluation form; ROM, range of motion.

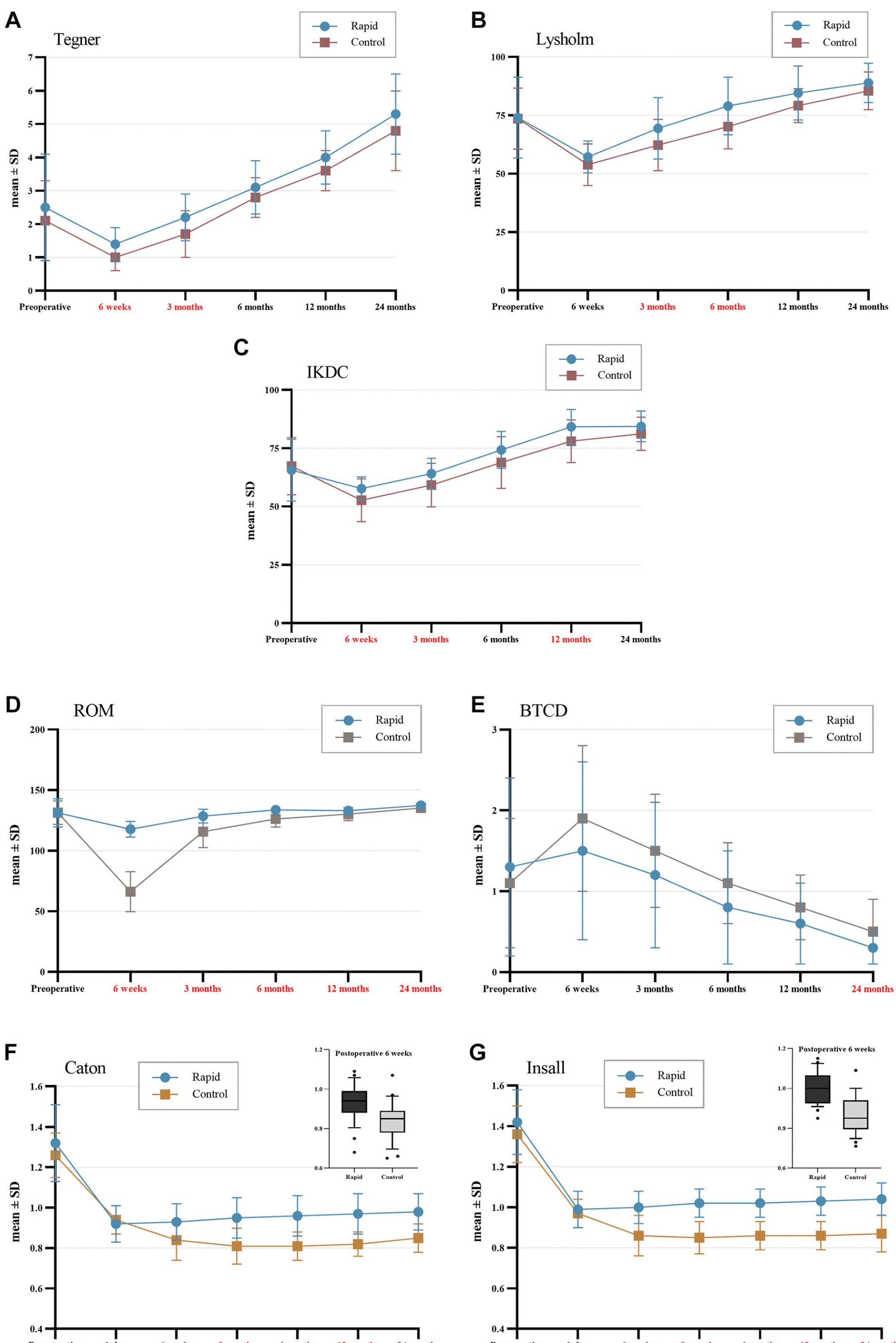


**Figure 3.** Line graphs depicting changes in functional scores, ROM (in degrees), BTCD (cm), and patellar height indices over time. The red font indicates statistically significant differences between the 2 groups at the specified follow-up time points. (A-C) represent the Tegner score, Lysholm score, and IKDC score, respectively, with the scores gradually increasing over time; (D) shows ROM gradually increasing over time; (E) shows BTCD gradually decreasing over time; and (F-G) represent the Caton and Insall indices, with box and whisker plots for the indices at 6 weeks after surgery shown in the upper right corners. BTCD, bilateral thigh circumference difference; IKDC, International Knee Documentation Committee subjective knee evaluation form; ROM, range of motion.

TABLE 4
Caton-Deschamps Index and Insall-Salvati Index Results of the 2 Groups[a]

| | Assessment Time | Rapid (n = 25) | Control (n = 25) | *P* |
|---|---|---|---|---|
| Caton-Deschamps | Preoperative | 1.32 ± 0.19 (1.25-1.40) | 1.26 ± 0.11 (1.22-1.31) | .163 |
| | 1 day | 0.92 ± 0.09 (0.88-0.96) | 0.94 ± 0.07 (0.91-0.97) | .381 |
| | 6 weeks | 0.93 ± 0.09 (0.97-1.04) | 0.84 ± 0.10 (0.82-0.90) | **<.01** |
| | 3 months | 0.95 ± 0.10 (0.91-0.99) | 0.81 ± 0.09 (0.77-0.85) | **<.01** |
| | 6 months | 0.96 ± 0.10 (0.92-1.01) | 0.81 ± 0.07 (0.78-0.84) | **<.01** |
| | 12 months | 0.97 ± 0.10 (0.93-1.01) | 0.82 ± 0.06 (0.80-0.85) | **<.01** |
| | 24 months | 0.98 ± 0.09 (0.94-1.02) | 0.85 ± 0.07 (0.82-0.88) | **<.01** |
| Insall-Salvati | Preoperative | 1.42 ± 0.16 (1.35-1.49) | 1.36 ± 0.14 (1.30-1.42) | .161 |
| | 1 day | 0.99 ± 0.09 (0.95-1.03) | 0.97 ± 0.07 (0.94-0.99) | .338 |
| | 6 weeks | 1 ± 0.08 (1.19-1.61) | 0.86 ± 0.10 (0.90-1.19) | **<.01** |
| | 3 months | 1.02 ± 0.07 (0.99-1.04) | 0.85 ± 0.08 (0.82-0.88) | **<.01** |
| | 6 months | 1.02 ± 0.07 (0.99-1.05) | 0.86 ± 0.07 (0.83-0.89) | **<.01** |
| | 12 months | 1.03 ± 0.07 (1-1.06) | 0.86 ± 0.07 (0.83-0.89) | **<.01** |
| | 24 months | 1.04 ± 0.08 (1-1.07) | 0.87 ± 0.09 (0.88-0.90) | **<.01** |

[a]Data are presented as mean ± SD (95% CI). Bold *P* values indicate statistically significant differences between the 2 groups. At the 24-month postoperative follow-up visit, 23 patients were in the rapid group, and 24 were in the control group.

implementation of weightbearing restrictions for 3 to 6 weeks. Regarding ROM limitation (≤90°), restrictions were enforced for 3 to 6 weeks in 6 studies. In most studies, the knee was immobilized for the first 1 to 2 weeks after surgery. Allen et al[2] outlined a protocol involving active flexion and passive extension within the initial 2 weeks, with weightbearing time restrictions lasting for 6 weeks. Franciozi et al[9] reported the gradual increase in ROM based on patient tolerance and the early initiation of quadriceps strengthening exercises; however, full weightbearing was postponed until after 8 weeks. Because of the combination of TTO, to ensure safety even in the rapid group, we implemented appropriate rehabilitation restrictions. The groups had weightbearing restrictions for durations of 3 weeks (rapid group) and 6 weeks (control group). Regarding the limitation of ROM, while descriptions of the degree range were vague in most studies, we established a clearer schedule, which included starting from 0° and gradually increasing until ROM was restored to normal, as outlined in Table 1. Although there is little consensus on a strict definition of "early," it is well established that early weightbearing and joint motion help maintain a nutritional balance in joint cartilage, ligaments, and tendons.[15,23] Restricting joint activity, on the other hand, can lead to the development of adhesions between fibers and limitations in tissue mobility.[11,43] The findings of this study support the viewpoint above. After all, with a more condensed time frame, the rapid group exhibited greater ROM postoperatively. Furthermore, although a difference in the BTCD was observed only at the final follow-up, this does not rule out the possibility of a lesser degree of muscle atrophy with early rapid rehabilitation.

The Caton index and Insall index were used to assess changes in patellar height. Postoperatively, correction of the elevated patella was achieved; however, a conservative rehabilitation strategy was associated with an increased risk of lower index values. Within 1 day to 6 weeks after surgery, the control group exhibited a decrease in patellar height, which decreased below that of the rapid group by the sixth week. This difference persisted until the last follow-up visit; 4 patients (17%) in the control group showed patella baja at the final follow-up visit. This finding indicates that the period within the first 6 weeks after surgery is a critical phase for rehabilitation, and missing this window may increase the risk of a lower patellar position. Notably, patella baja can result in anterior knee pain.[3] In the study by Lee et al,[20] 9.7% of patients exhibited patella baja during the 2-year follow-up period. After surgery, immobilization, inflammation, and quadriceps weakness may result in infrapatellar scarring and adhesions, ultimately leading to patella baja.[3,7,31] A lack of both active and passive knee joint extension produces a sharp decrease in patellar mobility.[28] In our study, no cases of patella baja were observed among any patients on the first day after surgery. Therefore, the occurrence of patella baja in the control group at 24 months after surgery cannot be attributed to surgical technique but rather to inadequate rehabilitation exercises. In tissue repair, both human and animal experiments have substantiated that early postoperative exercise provides appropriate stress stimuli, preventing contraction and functional changes in soft tissue structures.[14,26] In summary, we speculate that engaging in early exercise potentially plays a role in preventing the abnormal height of the patella, especially regarding ROM training. However, larger studies are needed to confirm this assumption because of the lack of significant differences.

Reported complications after TTO combined with MPFLR include fractures, delayed wound healing, deep vein thrombosis, knee joint stiffness, and patellofemoral arthritis secondary to patella baja.[16,20,22,29] Among these, proximal tibial fractures and severe complications are common.[29] Stetson et al[35] reported that 11% of patients experienced proximal tibial fractures postoperatively, possibly due to a lack of gradual progression in full weightbearing within the initial 6 weeks. Luhmann et al[22] reported a 5.9% incidence, suggesting that this difference was primarily associated with the surgical technique. A rapid rehabilitation protocol based on the principles of tissue healing was utilized in this study. Postoperatively, ice was applied to the knees of all patients, and the pain was managed during rehabilitation, resulting in good patient compliance; no patient experienced fractures. Compared with the control group, the rapid group demonstrated lower rates of total complications, further emphasizing its safety.

The present investigation does have some limitations. This represents a pilot study with a relatively small sample size, which might have been insufficient to detect the true incidence of wound healing problems, fractures, and so forth, in the rapid group or the significance of patella baja in the control group. In addition, we did not consider the time to return to sports, nor could we be content with the current follow-up period, as the benefits of early rapid rehabilitation diminish over time. Statistical significance may not necessarily translate to clinical importance; thus, the minimal clinically important difference concept was proposed. Interestingly, similar to the findings of the study conducted by Franciozi et al,[9] the difference in functional scores between groups did not reach the minimal clinically important difference. Furthermore, our study did not show whether the short-term benefits gained by the rapid group resulted from the faster progression of weightbearing, ROM, or both. Finally, it is crucial to note that comparisons of postoperative recovery should be based on the foundation of similar successful surgical procedures, where any uncontrollable factors such as patient, surgeon, or rehabilitation planning may influence the outcome. Despite these limitations, the results of this study still offer a reference for establishing future guidelines for standardizing rapid rehabilitation protocols.

## CONCLUSION

According to the findings of this randomized controlled trial, early rapid rehabilitation may be safe and effective for patients who undergo TTO combined with MPFLR for the treatment of RPD. It demonstrated advantages in improving postoperative functional scores in the short term and in preventing complications. In addition, rehabilitation within the first 6 weeks after surgery may need to be highly emphasized.

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