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Review

Patellar Maltracking in Total Knee Arthroplasty: Mechanisms, Prevention and Treatment

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Abstract

Patellar maltracking is among the most common causes of anterior knee pain after total knee arthroplasty (TKA), underscoring the need for accurate prevention and treatment. Therefore, the purpose of this narrative review is to provide a comprehensive overview of current evidence on post-TKA tracking, focusing on component alignment, preoperative patient assessment, and revision treatment options. A PubMed database search was performed, leveraging the literature from the last 20 years, and the results were qualitatively synthesized. According to current studies, several precautions should be taken to prevent patellofemoral stress and, consequently, patellar maltracking, such as avoiding internal rotation, valgus alignment, and excessive flexion of the femoral component and internal rotation of the tibial component. Regarding alignment strategies, kinematic alignment appears to offer potential benefits over mechanical alignment in certain functional outcomes and patient satisfaction scores. However, these differences should be interpreted cautiously as they may not always exceed the minimal clinically important difference. Furthermore, recent evidence indicates that quadriceps biomechanics influence TKA outcomes, potentially suggesting that conventional surgical approaches may need to be individualized, though these preliminary findings require prospective validation. Currently, robotic-assisted surgery represents a developmental direction for patient-tailored interventions and offers great promise for better prosthesis customization to the individual patient. Integration of imaging data with dynamic soft-tissue assessment enables more predictable reconstruction of joint kinematics. Regarding surgical treatment, the selection of specific methods requires a prior clinical and radiographic assessment. Indications range from patellar maltracking direction and component malrotation to patient preferences and rehabilitation potential. Ultimately, the future of TKA relies on personalized interventions to prevent complications and improve patient outcomes. This evolution is driven by the shift from mechanical alignment to kinematic alignment, alongside quadriceps tendon assessment and intraoperative robotic-assisted measurement, all aimed at optimizing the accuracy of implant positioning.

Keywords: knee; arthroplasty; replacement; patellofemoral joint; surgery; computer-assisted alignment; prosthesis fitting; biomechanical phenomena; joint instability

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1. Introduction

Over the years, total knee arthroplasty (TKA) has become a standard medical procedure for treating advanced osteoarthritis or rheumatoid arthritis of the knee joint. However, dissatisfaction rates following this surgery range from around 20%, and anterior knee pain affects 8% of all patients after TKA [1]. One of the most common causes of this pain is patellar maltracking, with an incidence of 1% to 20% [2]. This prevalence can be attributed to differences in diagnostic methods and their measurement thresholds, implant designs [2,3], duration of follow-up in studies and finally lack of a generally agreed definition of patellar maltracking [4]. In contrast, in the general population without knee arthroplasty, the annual incidence of patellar maltracking is only approximately 0.05% [5].

The risk of revision surgery is estimated at around 5% within 10 years postoperatively. The number of TKA revision procedures is expanding, with the most frequent causes being: infection (36.3%), aseptic loosening (21.6%), and periprosthetic fracture (13.7%) [6]. Notably, extensor mechanism insufficiency, which includes complications related to the patella, accounts for 3.7% of all revisions but is significantly more prevalent in early cases, representing 9.2% of revisions performed within the first 2 years. Early revisions are mostly performed because of prosthetic infection, and late revisions were the most common in periprosthetic fractures. As for the re-revisions, infections were the most common reasons (44.2%) [6].

Patellar maltracking is referred to as the state in which, during knee movement, the patella center is displaced to a pathological position [7]. Most frequently, it is attributed to improper implant positioning and aligned limbs [2,4,8]. On the other hand, preoperative patient-related factors, such as weakness of the quadriceps muscle, patellofemoral dysplasia or preoperative valgus alignment [2,9] are also relevant. To confirm patellar maltracking, A-P, lateral, and merchant radiographic projections should be performed, in addition to assessing clinical symptoms. Eventually, to evaluate component positioning and rotational malalignment of TKA, CT scan is performed [9].

Patellar maltracking after TKA may lead to anterior knee pain (particularly during movements such as stair climbing or standing up from a seated position), excessive wear on the implant components (increasing the risk of loosening), as well as patellar fractures and instability [10,11]. The TKA procedure can increase pressure behind the patella by reducing the contact surface area compared to a natural, healthy knee. Malrotation of the implants, primarily the femoral component, also contributes to anterior knee pain by altering contact in the patellofemoral joint, elevating pressure between them [12,13].

Therefore, the purpose of this narrative review is to provide a comprehensive overview of current evidence on post-TKA patellar tracking. The topic is addressed across three domains: prosthetic component alignment, risk-reducing surgical techniques based on preoperative patient assessment, and revision surgical treatment options. Within this framework, outcomes of TKA with native patellar preservation are examined, addressing the biomechanical interplay between the patella and prosthetic components.

2. Methods

For the purpose of this narrative review PubMed database search was performed. The primary search in November and December of 2024 included the following terms: “patellar tracking” OR “patellar maltracking” OR “patella complications” AND “total knee arthroplasty”. A 20-year inclusion criterion was applied to the literature search to capture the full evolution of the research landscape. In the course of completing our paper (through February of 2026), we decided to broaden the range of reviewed articles by including clinical studies of first, second, and third level of evidence (meta-analyses, systematic reviews, randomized controlled trials, prospective and retrospective cohort

studies, narrative reviews) due to low coverage of the objects of our research in the literature. To better understand and elucidate the mechanical forces within biomechanical sections of our publication, we also leveraged pre-clinical models and radiological studies. It allowed us to investigate our subjects widely, also from a perspective that has not yet been proven clinically. We excluded studies with only an abstract available, non-English articles and gray literature to maintain the consistency and high methodological quality of the reviewed data. Data from the selected literature were synthesized qualitatively, without quantitative pooling or meta-analysis.

3. Results

3.1. Impact of Component Alignment on Patellar Tracking

Correct multidimensional placement of the tibial and femoral parts of the TKA is crucial for proper patellar tracking. Given the scarcity of current literature on the impact of component alignment on patellar tracking and the lack of meta-analyses or systematic reviews to provide a definitive assessment, this analysis incorporates findings from both preclinical and cohort studies.

Regarding femoral component axial rotation, in a preclinical study Yamawaki et al. compared 8 standard Patellofemoral arthroplasty (PFA) knee models rotating the femoral component by 5° internally and externally relative to Whiteside line [14]. His study found that both internal and external rotation shifted the patella laterally (1.2–1.5 mm). Moreover, the patella tilted in the same direction as the rotated femoral component (up to 2.9° tilt). However, PFA in comparison to TKA is generally found to reproduce the patellar kinematics more naturally, which is evident by the patella offset remaining constant throughout the movement range in TKA [13]. This is particularly noticeable in a cadaveric study by Anglin et al. His findings indicate that the patella shifts and tilts in the same direction as the femoral component is rotated (by 5°), with significance only in early flexion (at 15° flexion) [15]. Applying preclinical results to clinical practice, Keshmiri et al. and Lustig et al. in clinical research did not assert any significant impact of these parameters on patellar tracking (based on axial X-ray and computer navigation system). Such a discrepancy between preclinical and clinical studies might be caused by soft-tissue balancing during surgery and active, motor-driven flexion cycles in cadaveric studies, which transmit more tension to the patella than passive intraoperative flexion assessments. Nevertheless, Lustig et al. emphasized that internal rotation is inadvisable, accepting up to 3–5° of lateral rotation to compensate for preoperative patellar subluxation [8,16].

In the coronal plane (0° in the line of the anatomical axis), 5° valgus alignment of the femoral component led to higher contact stress (contact pressure estimated by Fine Element Analysis) and risk of patellar instability because of 1.1 mm medial shift and 1.3° external tilt of the patella [7,14]. Based on current evidence, slight varus alignment is preferred over valgus alignment in TKA. Although it may contribute to lateral patellar shift and internal patellar tilt, it is associated with reduced joint contact forces [7,8,14].

In the sagittal plane, excessive flexion of the femoral implant provoked the patella to shift laterally (every 1° greater flexion shifted the patella about 0.5 mm) [7,16]. Additionally, according to Keshmiri et al., femoral flexion and increased tibial posterior slope (TPS) lowered the patellofemoral distance (both 1° increased flexion and TPS lowered the patellofemoral distance by 1.5 mm) [16]. As a result of decreased patellofemoral distance, contact force in the medial compartment of the knee significantly increases, leading to excessive component wear [16,17].

Rotational alignment of the tibial component also plays a prominent role in patellar kinematics. According to a simulation on eight fresh-frozen cadaveric knees, alteration of the rotation of the tibial component significantly affects retropatellar peak pressure.

In >80° flexion angles, it was increased by 0.2 MPa in tibial component internal rotation, whereas external rotation decreased it by 0.3 MPa (from 8.2 MPa in neutral position) [18]. Extrapolating this to clinical trials, Nakamura et al. (cohort of 115 knees) found that internal rotation of the tibial component causes significant lateral shift and tilt of the patella. Moreover, it increases the tibial tuberosity–trochlear groove (TT-TG) distance, known as a contributor to patellar complications. External rotation of the tibial component is negatively correlated with the risks previously mentioned [19].

In Table 1, we have compiled and presented a comparative review of publications that describe the influence of component setting on patellar tracking.

Table 1. Comparison of component placement impact on patellar tracking.

Article Author and Level of Evidence	Subject of the Study	Axial Rotation of Femoral Component	Valgus/Varus Placement of the Femoral Component	Flexion/Extension of the Femoral Component	Posterior Slope of the Tibial Component	Axial Rotation of the Tibial Component
Yamawaki et al. [14] (PFA *) Original research	Dynamic computer simulation software	Internal rotation: lateral shift and internal tilt, higher contact forces External rotation: lateral shift and external tilt	5° Valgus: medial shift (1.1 mm), external tilt (1.3°), higher contact forces Varus: lateral shift, internal tilt	Little effect on patellofemoral kinematics		
Anglin et al. [15] Original research	Cadaveric simulation	In early flexion (<15°) patella tilts and shifts in the same direction as rotated femoral component				
Keshmiri et al. [16] Prospective cohort study	Cohort of 40 patients	No significant effect on patellofemoral kinematics		Flexion: lateral shift, decreased patellofemoral distance (0.5 mm patellar shift and 1.5 mm patellofemoral distance reduction per 1° flexion)	Increased tibial posterior slope: decreased patellofemoral distance (1° TPS increase: 1.5 mm patellofemoral distance reduction)	No significant effect on patellofemoral kinematics
Lustig et al. [8] Narrative review		Internal rotation: unpreferable External rotation: no significant impact on patellar tracking, accepting 3–5° lateral rotation	Valgus: higher risk of patellar instability Varus: slightly varus alignment is preferable		No influence on patellar tracking	
Donell [7] Narrative review			5° Valgus: increased patellar stress	Flexion: increased lateral shift	Increased tibial posterior slope: slight change in patellofemoral distance, no significant effect	Internal rotation: greater patellar contact surface
Steinbrück et al. [18] Original research	Cadaveric simulation					3° Internal rotation: higher peak pressure 3° External rotation: lower peak pressure
Nakamura et al. [19] Retrospective cohort study	Cohort of 115 knees					Internal rotation: lateral tilt and shift, increased TT-TG distance
Summary		Patella tilts in the same direction as rotated femoral component External rotation causes lateral shift	Valgus alignment leads to higher contact forces and stress Varus is preferable over valgus	Excessive flexion of femoral component causes lateral shift in the patella	Increased tibial posterior slope: slightly lower patellofemoral distance, no significant effect on patellar tracking	Internal rotation: higher peak pressure, lateral shift and tilt

*—patellofemoral arthroplasty. Donell [7], Lustig, Servien and Batailler [8], Yamawaki, Kuriyama, Watanabe, Nakamura, Ohkoshi and Matsuda [14], Keshmiri, Maderbacher, Baier, Sendtner, Schaumburger, Zeman, Grifka and Springorum [16], Nakamura [19], Anglin [15], Steinbrück [18].

3.2. Kinematic Alignment Versus Mechanical Alignment

Any analysis of patellar tracking necessarily requires consideration of the kinematic alignment (KA) and mechanical alignment (MA) of TKA. Mechanical alignment is a more conservative option and aims to create a neutral hip-knee-ankle (HKA) angle to minimize component wear. As most people have varus deformity, restoring the limb alignment to neutral is usually connected with an increase in the Quadriceps angle (Q-angle) [20]. Conversely, KA restores the patient's natural knee position, keeping the original Q-angle [20]. It has been found to preserve more of the original soft tissues and reduce ligamentous loosening, leading to physiological joint movement [21].

The Q-angle is an important indicator of patellofemoral joint stability and reflects the influence of the quadriceps muscle on the knee [22]. An increased Q-angle is a risk factor for patellar instability [23]. The normative Q-angle values have been established as 13.5° in men and 15.9° in women, based on measurements using a standardized protocol with a long-armed goniometer in healthy subjects without patellofemoral abnormalities [24]. Although the Q-angle is not routinely measured during TKA, some studies support its assessment during surgery. If the tibial component is placed too laterally or medially during TKA, or if the femoral component is malrotated, this can negatively affect the Q-angle and alter patellar tracking [25].

Concerning differences in patellar tracking between KA and MA, Kim et al. [26] conducted a cadaveric study, in which forty knees (20 cadavers) were evaluated. KA was randomly assigned to one knee of every cadaver, while MA was performed on the remaining knees. Pre- and post-operative patellar tracking patterns were grouped into separate clusters. After further analysis, the post-KA tracking pattern was found to be more similar to native movement than to MA [26]. In KA, moreover, a cadaveric study observed a reduction in quadriceps muscle loading (50–100 N) during knee extension within the range of 130° to 80° of flexion [27]. However, it is crucial to note that these biomechanical observations are derived exclusively from pre-clinical cadaveric models. Therefore, although they offer valuable anatomical insights, these models may not fully capture dynamic in vivo kinematics, and their findings should be extrapolated to clinical conclusions with caution.

An analysis of the available literature indicates that the Knee Society Score (KSS) and flexion range of motion (ROM) were significantly higher in patients who underwent KA. However, the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), the Oxford Knee Score (OKS), and the complication rate showed no statistically significant differences [28–30]. The mean difference in combined KSSs ranged from 9.1 to 17.8 points, with a follow-up duration of 6 to 60 months [28,29].

Furthermore, intra-operative lateral retinacular release (LRR) rate during MA was significantly higher (25.4% vs. 6.7%). It is especially significant, as the LRR group's postoperative OKS at 12-month follow-up was substantially lower (30.3 vs. 33.8) than in the non-LRR group [31]. Moreover, the KA procedure and recovery times were significantly shorter [30]. According to Lozano et al. MA may contribute to patellar maltracking by placing the prosthetic groove 3–4 mm more laterally [20]. KA strategy to keep the native trochlea and the prosthetic groove more radially, and to keep the patella more superficially, lowers the force needed to extend the limb generated by the quadriceps muscle [20,27].

3.3. Quadriceps Tendon Malalignment

The concept of quadriceps tendon malalignment (QTM) as a distinct pathomechanical entity in TKA is recent, with limited published data available for analysis. However, recent studies underscore the significance of quadriceps tendon biomechanics in influencing postoperative patellar maltracking following TKA. Talbot et al. reported that, in a retro-

spective analysis of 388 preoperative knees, 76 (19.8%) met the criteria for QTM, defined as a quadriceps tendon axial angle (QTAx) greater than 14°. QTAx represents the angle between the apex of the quadriceps tendon and the center of the femoral shaft [32]. When the tendon is externally rotated relative to the femoral shaft, a biomechanical mismatch occurs between quadriceps force vectors and the prosthetic trochlear groove, predisposing to patellar maltracking [32,33].

At 12-month follow-up, patients with preoperative QTM had significantly inferior outcomes across all patient-reported outcome measures (PROMs), including a lower Forgotten Joint Score (51.2 vs. 60.2, $p = 0.008$), EQ-VAS (75.7 vs. 81.3, $p = 0.009$), and KOOS-12 (73.3 vs. 80.3, $p = 0.001$), compared with patients without QTM. However, Talbot et al. demonstrated that patients with QTM who received more than 2° of additional external rotation of the femoral component beyond the native posterior condylar angle exhibited significant improvements in KOOS-12 scores at 12 months postoperatively (11.7 points, $p = 0.013$), in comparison to those who received 2° or less of rotation. Moreover, patients with QTM who received appropriate rotational correction achieved outcomes comparable to those without QTM [32].

In patients with QTM, no significant association was observed between the degree of femoral component external rotation and postoperative PROMs, including KOOS-12, at 12-month follow-up [32].

3.4. Robotic-Assisted Total Knee Arthroplasty

Robotically assisted technology is becoming increasingly popular in various surgical procedures and has found a place in TKA as well. Such tools provide improved planning and accuracy for surgeons.

Studies indicate improved patellofemoral joint kinematics with robotic-assisted TKA (R-TKA). A meta-analysis of four studies ($n = 1448$) showed that R-TKA resulted in better mechanical alignment than conventional TKA (RR = 0.05, $p < 0.00001$) [34]. Additionally, R-TKA was associated with better WOMAC scores than conventional TKA ($n = 1608$, MD = −1.19, $p = 0.04$) [34]. Despite these results, further studies are needed to evaluate the long-term benefits of robotic-assisted TKA. In addition to the lack of long-term follow-up, other limitations currently prevent accurate assessment of the use of robotic-assisted TKA. Below, we present two studies, which, although limited by a small number of participants, provide insight into the potential advantages of R-TKA and indicate possible avenues for its future refinement and development.

A contemporary study of 9 cases emphasizes that robotic-assisted technology enhances 3D planning, leading to more precise restoration of limb alignment and component orientation compared to non-robotic methods. The authors point out that the use of robotics enables integration of imaging data with dynamic soft-tissue assessment, thereby enabling more predictable reconstruction of the mechanical axis of the limb and control of femoral component rotation. The analysis also highlighted the importance of controlling the rotation of the femoral component relative to the transcondylar axis and the posterior line of the condyles, which has a direct impact on the patellar track and the risk of patellofemoral complications [35]. Achieving proper patellofemoral joint kinematics remains a major challenge during TKA. Currently, it is not possible to assess the patella's dynamic movement during TKA [36]. The use of robotic assistance and systems that map the patella, femur, and tibia would allow surgeons to evaluate the alignment of the components during the trial phase, thereby helping to avoid abnormal patellar tracking. Nevertheless, this method requires validation in clinical cases [36].

In a retrospective study, robotic-assisted TKA was performed in 20 patients (mean age 68 years) with varus deformity (HKA angle 176.3° ± 3.7°) using the MAKO robotic platform

planning software [37]. Preoperatively, patient-specific bone models were created from CT scans, and custom-fit implants were constructed based on these models. Importantly, current commercial robotic algorithms lack the capability to automatically integrate QTAx measurements. Surgeons must therefore calculate the QTAx preoperatively and manually enter the required rotational adjustments into the robotic interface. As a result, the prosthesis was positioned intraoperatively to restore the trochlear groove as close as possible to its native anatomical position. Patellar tracking was assessed intraoperatively, allowing for intraoperative corrections if necessary. The study was conducted on 20 patients, which limits the ability to draw definitive conclusions. The results of this study demonstrated that robotic-assisted alignment reduced the risk of unsafe coronal implant positioning to 3.2% of patients, compared with 13% reported for KA. Furthermore, the incidence of excessive internal rotation of the femoral component was reduced to 1.7%, compared with 25% observed with the KA technique [37]. The research should be expanded to include a larger patient group to confirm the outcomes presented below.

Despite the potential benefits of better tailoring the surgery to the patient, robotic TKA (R-TKA) is associated with some limitations. A meta-analysis of randomized controlled trials, including 2255 patients (25.1% male and 74.9% female; mean age 62.9 $\pm$ 3.0; mean BMI 28.1 $\pm$ 1.3), indicates that robotic TKA does not provide superior radiological or clinical outcomes compared to conventional TKA (C-TKA). Additionally, the operating time for robotic TKA was longer (MD = 15.3 min, p = 0.004) [38]. Another meta-analysis (including 1148 patients: 571 in the R-TKA group and 577 in the c-TKA group) found no significant difference in patient satisfaction rates between C-TKA (95%) and R-TKA (91%) [39]. However, it should be noted that the follow-up period was limited to a maximum of 2 years, and, in this case, there is a lack of studies comparing patient satisfaction over a longer-term period [39].

3.5. Patellar Resurfacing: To Surface or Not to Surface

The management of the patella during TKA remains a subject of debate. Performing patellar resurfacing is often associated with improved patellar alignment with the femoral implant, thereby reducing anterior knee pain [40].

A randomized study was conducted involving 250 patients who underwent TKA with either patellar resurfacing (PR, n = 125) or without resurfacing (PNR, n = 125) [41]. All surgeries were performed by two experienced surgeons using the same technique (a transquadriceps tendon approach), and all patients received the same prosthesis. A 12-month postoperative follow-up was carried out using the KSS. The frequency of anterior knee pain (AKP) was similar in both groups—11.9% of patients in the PR group and 13.5% in the PNR group (p = 0.688). It is noteworthy that AKP did not correlate with postoperative abnormal patellar tilt, which was observed in 43.1% of PR patients (mean 5.4 $\pm$ 9.2°) and 28.6% of PNR patients (3.7 $\pm$ 4.5°) (p = 0.025). Nevertheless, patients in the PR group reported pain when climbing stairs much less frequently (PR: 8.5%; PNR: 17.1%) [41]. Another meta-analysis, which included a 24-month follow-up, indicates that patellar resurfacing significantly improves patient outcomes. Patients with patellar resurfacing reported anterior knee pain less frequently. Additionally, resurfacing was associated with a lower rate of reoperation—1.79% in the resurfacing group compared to 6.22% in the patella-retaining group [40].

It is important to highlight that some authors suggest that the type of prosthesis used may be more important than whether patellar resurfacing is performed. This topic was addressed in a meta-analysis including 32 randomized cohort studies [42]. It showed that when modern "patellar-friendly" implants were used, the incidence of anterior knee pain was similar in both groups, with or without patellar resurfacing. Patients in the resurfacing

group achieved higher KSSs, but this was not statistically significant ($p = 0.59$). However, with older "less patellar-friendly" implants, resurfacing was associated with a significant improvement compared to no resurfacing (MD = 3.3, $p = 0.005$) [42].

3.6. Surgical Treatment Options

An unstable patella after TKA may require repeat surgery. The most common invasive methods used to reduce this problem are anterior tibial tubercle mobilization and patellofemoral ligament reconstruction [8]. Another possible operation option is Lateral Retinacular Release, and the last, the most invasive-Revision Arthroplasty. Performing the procedure correctly and tailoring it to the patient is crucial to maintaining proper tracking of the patella. Below, we describe these surgical methods and their advantages and limitations.

3.6.1. Lateral Retinacular Release

LRR is a procedure for patients at increased risk of excessive lateral patellar displacement. The procedure involves cutting the lateral retinaculum of the patella, which reduces lateral tension and restores proper movement pattern.

Performing a lateral release of the patellar retinaculum may be necessary if the patella tends to deviate prior to TKA. LRR should be considered in patients with severe preoperative patellar displacement, particularly if the knee's preoperative condition meets established risk factors. Risk factors in addition to incorrect knee positioning include: preoperative patella displacement (>3 mm) and preoperative patella tilt (>10 degrees) [43]. Studies indicate that patients with Wiberg type 3 patellas, a patella displacement greater than 3.5 mm, and a convergence angle greater than 16° on axial X-ray view are more likely to require LRR. Additionally, the frequency of qualification for LRR is significantly higher in varus knees than in valgus knees [44]. Another study conducted on 212 patients who underwent TKA without patellar resurfacing confirms the necessity of evaluating radiological parameters before deciding on LRR. The authors identified the following factors as indications for additional LRR: Wiberg type III patella (OR 17.45), lateral facet thinning (OR 4.38), lateral patellofemoral osteoarthritis (OR 14.36), and coronal valgus deformity (OR 4.95). Assessment of these parameters and performing LRR in such cases reduces the risk of patellar maltracking after TKA [45].

To evaluate postoperative outcomes, a meta-analysis including 491 patients was conducted. Patients who underwent LRR achieved higher Knee Society Scores (KSS) than those without LRR (MD = 3.00, $p = 0.002$). Additionally, this patient group experienced a greater reduction in anterior knee pain (OR = 0.23, $p < 0.00001$) [46]. However, it is important to note that the study included both patellar-sparing ($n = 2179$) and resurfaced cases ($n = 1732$), and the results differed between these groups. Patellar resurfacing alters force transmission dynamics, leading to a higher incidence of complications in this group, such as patellar fracture (OR = 2.79) or loosening (OR = 2.16) [46].

In the case of TKA with patellar resurfacing, performing additional LRR does not significantly improve pain symptoms. In a similar prospective randomized study, 198 patients scheduled for a TKA procedure with patellar resurfacing were randomized to receive LRR or not. No differences were observed at the 1-year follow-up between the two groups (with or without additional LRR) in reported clinical complaints, including pain assessment using the Visual Analogue Scale (VAS) and Pressure Pain Threshold (PPT) scales (p = n.s) [47].

During the procedure, it is crucial to preserve the superior lateral genicular artery, which is primarily responsible for the blood supply to the patella. Damage to this vessel during LRR can result in ischemia and avascular necrosis of the patella [48]. Another

complication after the procedure may be excessive patellar mobility, which can cause pain and discomfort in the patient's knee.

3.6.2. Partial Lateral Patellar Facetectomy

Partial Lateral Patellar Facetectomy (PLPF) is a surgical method performed to correct patellar maltracking during TKA by removing approximately one-third of the lateral part of the patella. This technique is an alternative option for LRR and is proposed in some cases, as studies suggest it has potentially less complications than Lateral Release [49]. Compared to LRR, this procedure corrects the patella geometrically, reduces point pressure, and decreases the tendency for lateral displacement of the patella.

In the Lakstein study, PLPF was performed selectively in patients with intraoperative evidence of patellar maltracking, and in this subgroup, the procedure was associated with balanced tracking and a low rate of complications, suggesting that patients with significant lateral patellar overhang or maltracking may benefit from PLPF compared with LRR. Furthermore, the PLPF is a less aggressive procedure, which corresponds with shorter healing time. During the PLPF, the cut-off part of the patella should be selected carefully to optimize the procedure's goal and prevent medial tilt of the patella when excessively removed [49].

The Lakstein study [49] indicated that performing the PLPF during TKA has successfully corrected patellar maltracking in 96% of cases and proves it can be a sufficient alternative for Lateral Release in appropriately selected patients. Recent literature [50] highlights that although PLPF is increasingly used as an adjunctive procedure during primary TKA, the current level of evidence remains limited, with most studies being retrospective. Nevertheless, available data suggest that PLPF may reduce lateral patellofemoral contact pressures and decrease the need for LRR, resulting in lowering the risk of complications. PLPF is less invasive and should be considered in patients with degenerative changes in the lateral part of the patella and lateral knee overload. The choice of techniques should be assessed intraoperatively and adapted to the patella's tracking and the degree of damage to its lateral part [51]. On rare occasions, when the tracking remains unsatisfactory after PLPF, the LRR is the gold standard for re-revision.

3.6.3. Medial Patellofemoral Ligament Reconstruction

The medial patellofemoral ligament (MPFL) is a key stabilizing medial structure of the patella, restraining lateral translation and preventing subluxation or dislocation, especially during knee motion [2].

Medial patellofemoral ligament reconstruction (MPFLR) has emerged as an important surgical option to address patellar maltracking. Recent studies have explored its role in improving patellar stability following TKA [52].

In TKA, the medial structures are vulnerable to injury due to the medial parapatellar approach, patellar eversion, and inadequate closure, all of which may contribute to patellar maltracking or displacement [53].

Studies have shown that the patellofemoral realignment procedure combined with MPFLR is an effective intervention for managing symptomatic patellar subluxation or dislocation following TKA [2,52–54]. This approach yields excellent outcomes in restoring both clinical and radiographic patellar tracking (median patellar displacement improved from 29 mm (0–44) preoperatively to 0 mm (0–9) postoperatively). A significant improvement in functional outcomes was observed, demonstrated by increases in International Knee Documentation Committee (IKDC) and Kujala scores (up to 55 points), and by improvements in VAS scores for pain and for patient satisfaction (median 8 (5–9)), over follow-up periods ranging from 6 to 48 months. Additionally, the incidence of complications was low, with

no reported fractures, wound-related complications, or joint-related adverse events [52,53]. However, it is important to note that these specific outcomes derive from a single case series involving only six patients and therefore represent low-level evidence.

The most current MPFLR is performed by attaching the graft from the medial side of the patella to a site between the adductor tubercle and the medial femoral epicondyle. This approach ensures the optimal anatomical positioning and isometric characteristics of the reconstructed ligament [52].

The double fixation method constitutes a key element of MPFLR, as the combination of interference screw fixation with supplemental cortical suspensory fixation provides enhanced graft stability. In this technique, double fixation is achieved by combining interference fixation within the femoral tunnel with additional cortical stabilization using an endobutton. This approach addresses the problem of reduced bone quality frequently observed in the supracondylar femoral region following TKA, a factor known to compromise fixation strength. Previous studies have reported a decrease in bone mineral density of 20–45% in the supracondylar femoral area following TKA, underscoring the need for augmented fixation techniques [54,55].

MPFLR is an effective treatment for patellar maltracking following TKA, although it is only suitable for patients without prosthetic component malrotation. MPFLR should be considered only after CT imaging has ruled out abnormal internal rotation of the femoral component or an abnormal TT-TG distance, as these factors may render MPFLR alone insufficient to restore proper patellar tracking [52–54,56–58]. Importantly, current clinical recommendations regarding these specific contraindications still rely heavily on foundational studies, such as the work by Asada et al. [56]. The absence of recent, high-level evidence addressing MPFLR contraindications in the setting of TKA highlights a significant gap in the contemporary literature, underscoring the need for updated prospective investigations.

3.6.4. Tibial Tubercle Medialization/Tibial Osteotomy

The treatment approach for lateral patellar instability remains a subject of debate, even in native knees. A common question is whether to perform a tibial tuberosity osteotomy (TTO) as an additional procedure during MPFLR. In the treatment algorithm, particular consideration should be given to combining TTO with MPFLR when the TT-TG distance exceeds 17–20 mm. Tibial tuberosity osteotomy allows for anterior and medial or distal repositioning of the patella to correct its movement.

Performing TTO together with MPFLR has not yet been well described in the context of a prosthetic knee. Only a few cases of such treatment have been documented and published. In studies describing the use of this procedure, the indications for adding TTO to MPFLR include, among others, abnormal patella height and a positive grade 3 J-sign. If the MPFL is not strong enough to counteract lateral forces, this may become apparent in the presence of a positive J-sign. TTO shifts the tibial tubercle and the attachment of the quadriceps tendon, which allows the forces acting on the patella to be distributed more favorably. Nevertheless, the authors also report possible complications such as tibial fracture or delayed union (20 weeks) after TTO [54].

A significant challenge in performing this procedure is the reduced bone density (20–45%) in the femoral region after TKA. Despite this, the first successfully performed cases have been described. During follow-up, none of the 5 patients who underwent the procedure experienced recurrence of instability [59].

3.6.5. Revision Arthroplasty

Revision arthroplasty of TKA should be considered as a method of treatment of patellar tracking, especially in the case of rotational malalignment of tibial and femoral components of the initial prosthesis, either postoperative or posttraumatic. Excessive internal rotation of those components is particularly significant for patellar maltracking [2,58,60–63]. Generally, internal rotation of the femoral component results in medial shift in the trochlear groove and lateral tracking of the patella, while internal rotation of the tibial component leads to external tibial rotation during flexion, also causing lateral patellar tracking [8,15,18,19,58,60,63]. Prior to revision surgery, CT imaging using the Berger protocol should be performed to quantify the rotational degree and confirm malalignment of the prosthesis [2,63,64].

Research indicates that full prosthetic revision is a more appropriate approach than selective component exchange, given the potential for incompatibility between a retained tibial or femoral component and a newly implanted counterpart [2,61,63,64]. Additionally, patellar resurfacing is recommended if it was not performed during the first surgery and if the patella is sufficiently thick [61,63]. Furthermore, soft tissue balancing may be considered during revision based on the case's specific conditions [63,64].

According to Incavo et al. [61], Pietsch et al. [62], Rajgopal et al. [64], and Warschawski et al. [63], revision arthroplasty substantially increases the mean satisfactory rate based on Knee Society Score in comparison to pre-revision results. Their studies demonstrated improvement from 42 to 77, from 65 to 85 (mean follow-up 57 months), from 29 to 79 (mean follow-up 42 months), and to 86 (at 56 months follow-up), respectively, with the latter study lacking preoperative values. Following the same studies, it also improved the average ROM for patients whose ROM had been decreased before the revision. Pre-revision mean ROM varied from 79° to 86° (extension: 0–6°, flexion: 85–86°), whereas post-revision values reached 106° to 115° (extension: 0°, flexion: 106° to 115°) [61–64]. However, the results were beneficial for the patients, they remained inferior to those reported for primary TKA performed in the absence of component malrotation.

3.6.6. Comparative Chart of Surgical Methods

The diagram below (Figure 1) summarizes the surgical approaches to patellar maltracking in TKA reviewed in this article. The flowchart is organized around key clinical and radiographic criteria; it should be noted, however, that it is not a validated clinical algorithm but rather a conceptual framework depicting the relationship between preoperative findings and the corresponding surgical options. The proposed workup begins with CT assessment. When component malrotation is absent and the patella exhibits excessive lateral displacement, soft-tissue procedures (LRR or MPFLR) are the first-line approach. LRR is preferred in cases of excessive lateral retinacular tension, while MPFLR addresses medial soft tissue incompetence and recurrent subluxation. In more complex or refractory cases, or when structural deformities of the patellar articular surface are present, second-line options (PLPF or MPFLR combined with TTO) should be considered. When component malrotation is identified as the primary etiology, revision of the malpositioned implants is indicated.

3.7. Conservative Treatment Options

Conservative treatment is an option for patients suffering from patellofemoral pain when no cause is identified [4]. This line of treatment includes physical therapy, orthotic interventions, anti-inflammatory medication, and lifestyle adjustments [65]. However, such intervention is never used as an isolated therapy in patients with patellar maltracking after TKA and only as an additional method to help the patient deal with pain af-

ter the surgery [66]. Such management should be regarded as adjunctive rather than definitive therapy.

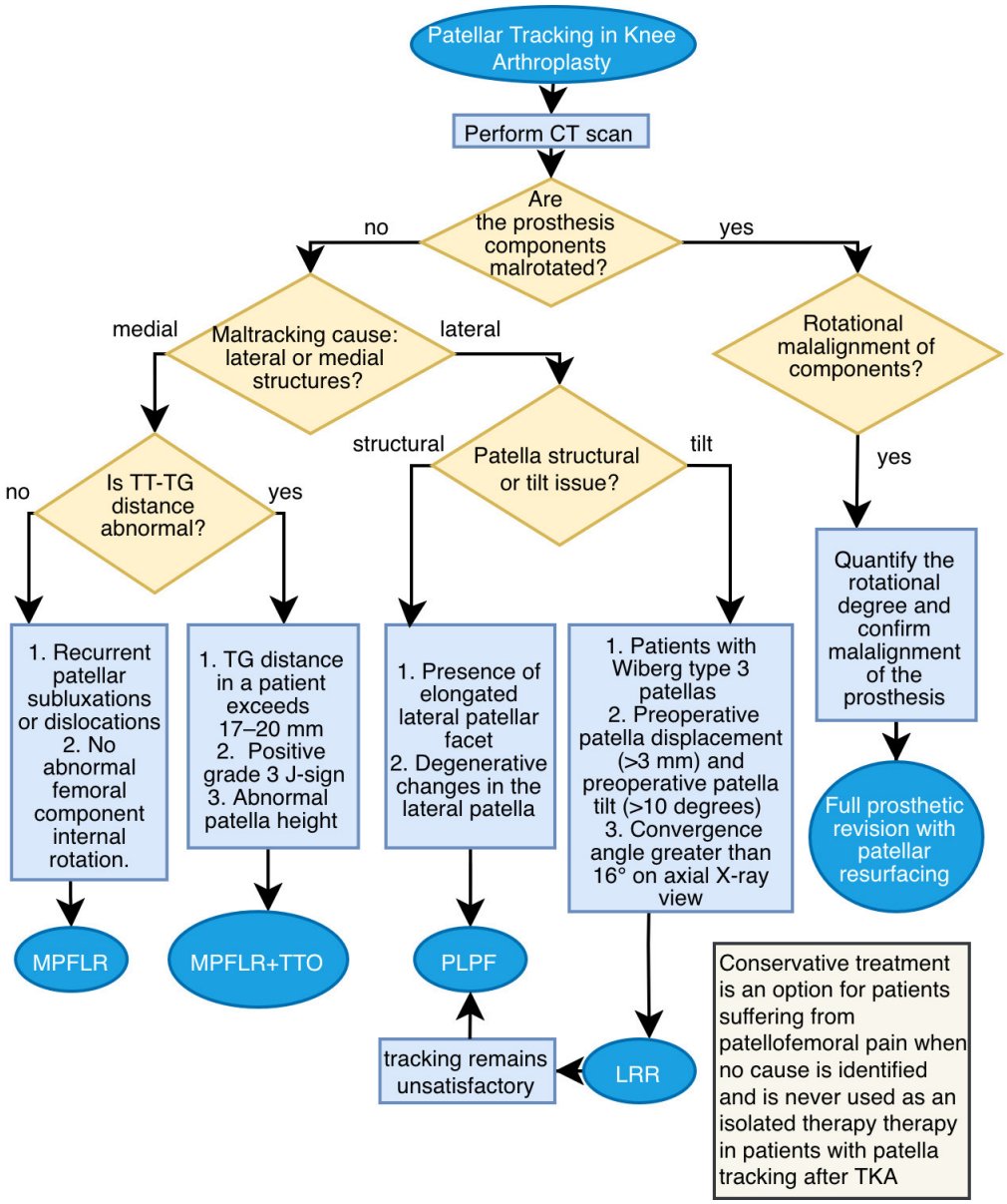


Figure 1. A conceptual flowchart outlining potential surgical interventions for patellar maltracking based on patient-specific clinical and radiographic findings. Disclaimer: This diagram is a visual summary of the current literature and is not intended to serve as a definitive clinical treatment algorithm.

Current evidence supports the use of physiotherapy protocols to improve quadriceps muscle and hip stabilizer strength. Such exercises are known to decrease pain and improve function in patients with diagnosed patellofemoral disorders. Furthermore, they may contribute to better patellar tracking by improved gait mechanics [67].

Other treatment options, such as bracing and patellar taping, might provide short-term pain relief by optimizing patellar alignment and reducing stress on the knee joint. Long-term effectiveness of this management remains limited [67]. Despite the potential benefits of conservative treatment, we must emphasize that such a solution does not correct mechanical abnormalities, such as component malposition or soft tissue stress. These

methods should be used as an additional method to help the patient deal with pain after the surgery [66].

4. Discussion

Abnormal patellar tracking is one of the most common causes of pain after TKA. As the priority of the TKA is to relieve pain and improve knee mobility, the surgery should not cause further functional issues. Therefore, several precautions must be taken to prevent patellofemoral stress and higher contact forces. Internal rotation, valgus alignment, and excessive flexion of the femoral component are unfavorable in TKA, as they contribute to the aforementioned disorders and ultimately to patellar maltracking. Internal rotation of the tibial component, leading to higher retropatellar peak pressure and lateral shift and tilt, should also be avoided [7,8,11,14,16].

Regarding the decision between alignment types, the current literature presents a complex picture. Although KA can improve certain functional outcomes, such as KSS and ROM, compared to MA, these differences must be interpreted cautiously. Moreover, the reported mean differences in KSS (9.1 to 17.8 points) often fail to exceed the Minimal Clinically Important Difference (MCID). Furthermore, several studies report no significant differences between KA and MA regarding the WOMAC, Oxford Knee Score, or overall complication rates. Nevertheless, KA remains a promising method in TKA that aims to restore the native trochlea and preserve the soft tissue envelope more efficiently. Consequently, it may help prevent patellofemoral complications, including excessive compression force, anterior knee pain, and patellar maltracking [28,29]. However, recent evidence underscores the relevance of quadriceps tendon biomechanics in determining postoperative outcomes following TKA. Preliminary data from Talbot et al. suggest that in patients presenting with preoperative QTM, standard surgical approaches might need to be carefully individualized. In patients with QTM, strict adherence to KA may preserve the native posterior condylar axis. This fails to correct abnormal joint biomechanics and risks inferior clinical outcomes [32]. It is important to note that the suggestion that standard approaches are inappropriate in these cases requires further prospective validation.

Conversely, external rotation of the femoral component by 3–5° relative to the posterior condyles in MA might incidentally benefit patients with QTM. However, excessive rotation in patients without a QTM may lead to medial patellar maltracking. This highlights potential limitations in selecting KA or MA based solely on the Q-angle, which assesses only bony landmarks. Therefore, to potentially improve postoperative TKA outcomes, assessing QTM preoperatively using QTAx measurements from CT scans has been proposed. Talbot et al. demonstrated in a retrospective cohort that patients with QTM who underwent >2° (more than the native posterior condylar angle) of additional external rotation of the femoral component achieved clinically significant improvement in KOOS-12 scores at 12 months postoperatively (11.7 points, $p = 0.013$), compared to patients who underwent ≤2° rotation [32]. While this suggests that QTM might be correctable, it must be viewed as a provisional observation from a single research group. The proposed >14° QTAx threshold and rotational corrections currently rely on limited retrospective data. Consequently, independent validation in prospective cohorts is strictly necessary before QTM-specific diagnostic and therapeutic strategies can be recommended for routine clinical practice.

The coexistence of preexisting QTM and postoperative component malrotation presents a particularly complex clinical challenge. Because both factors independently contribute to patellofemoral complications and quadriceps dysfunction, their combination severely compromises knee biomechanics [64,68]. Internal malrotation of the femoral component increases quadriceps force requirements and work during ambulation, particularly affecting the vastus lateralis, while preexisting QTM already predisposes to abnormal exten-

sor mechanism biomechanics [69]. When combined, these rotational deformities may create a synergistic negative effect on knee function. Rajgopal et al. demonstrated that combined component malrotation (both femoral and tibial) presented with knee stiffness as the most common failure mode, with patients presenting earlier (mean 2.3 years) than those with isolated malrotation [64]. While revision surgery for isolated component malrotation has shown favorable outcomes, the management of patients with both QTM and component malrotation remains unexplored in the literature [61,70].

For patellar management, the current literature supports resurfacing as a sound clinical strategy, particularly when older, less "patellar-friendly" implants are utilized [42]. Although its precise role in preventing generalized anterior knee pain requires confirmation in larger prospective trials, clear clinical advantages, such as decreased pain during stair climbing and lower revision rates, support its ongoing use [40,41]. The decision to resurface should therefore be tailored on a case-by-case basis, factoring in both the prosthesis design and the patient's functional expectations.

If the primary surgery resulted in patellar maltracking there are several approaches to restore proper movement in the patellofemoral joint. As conservative treatment is not effective as an isolated therapy, surgical treatment is suggested [66]. Critically, the treatment strategy must address the underlying cause, as failure to do so results in recurrent instability [58]. When component malrotation is present, revision surgery is the first-line treatment, whereas soft tissue procedures are appropriate only when components are correctly positioned [4,71].

The decision to apply a specific method should be preceded by appropriate physical (e.g., J-sign) and radiological examinations. It is also important to perform the necessary measurements (such as preoperative patellar displacement and preoperative patella convergence angle). Evaluating the patient's overall condition and their ability to recover after surgery is also crucial [54].

Among the most used invasive methods, LRR appears to be the best option for patients with patellar displacement greater than 3.5 mm, a convergence angle greater than 16°, and varus knees. However, damage to this vessel during LRR can result in ischemia and avascular necrosis of the patella [48].

On the other hand, PLPF is considered a good alternative to LRR for patients who prioritize recovery time, as it is shorter compared to LRR. Additionally, PLPF is associated with a lower rate of complications [49].

When components are correctly positioned (confirmed by CT), MPFLR combined with LRR represents an effective first-line soft-tissue procedure, with studies demonstrating a reduction in median patellar displacement from 29 mm to 0 mm and high patient satisfaction (VAS 8/10) [52]. However, MPFLR is contraindicated in patients with component malrotation, where it fails to address the underlying mechanical cause [4,53,54,71].

There is often debate over whether MPFLR should be performed together with TTO. A high degree of J-sign symptoms may suggest the need for a combined procedure. Nevertheless, studies show that combining these methods significantly increases the risk of intraoperative complications [54].

Revision TKA is the first-line treatment when component malrotation is confirmed, achieving excellent functional outcomes (mean KSS 86.2) with low recurrence rates (4.5%). [63]. Although more invasive, revision addresses the underlying mechanical cause and demonstrates superior survivorship compared to isolated polyethylene exchange (99% vs. 92% at 2 years, $p = 0.024$) [72]. Soft tissue procedures alone in the presence of malrotation are associated with high failure rates [4,71].

Ultimately, treatment selection depends on the underlying cause: malrotation requires component revision, whereas correctly positioned components can be managed with soft

tissue procedures such as MPFLR, LRR, or TTO [58]. Therefore, a highly individualized approach is critical to restore native joint function. Robotic-assisted TKA has emerged as a promising tool for patient-specific surgery, offering improved accuracy in component positioning and reduced radiological outliers compared to conventional techniques [73]. However, current evidence from meta-analyses of randomized controlled trials indicates that these radiological advantages do not consistently translate into clinically meaningful improvements in patient-reported outcomes [73,74]. Although novel techniques for intraoperative patellofemoral assessment using robotic platforms have been described, these remain investigational and are not yet integrated into routine clinical practice [35]. Therefore, while robotic-assisted TKA holds potential for optimizing patellar tracking, its clinical superiority over conventional methods remains unproven, and larger prospective studies with longer follow-up are needed [74].

This narrative review has several limitations. While providing a broad clinical overview, the available literature is inherently heterogeneous, with many included studies providing low-level evidence due to methodological limitations. Especially, several emerging interventions, such as robotic-assisted TKA and specialized alignment strategies, rely on exceptionally small sample sizes (e.g., $n = 9$ and $n = 20$). These limited cohorts preclude the formulation of definitive clinical guidelines and highlight the need for larger, adequately powered prospective trials to substantiate preliminary findings. Furthermore, the scarcity of high-level clinical data necessitated the inclusion of pre-clinical cadaveric models to provide complementary biomechanical insights. However, these models cannot fully replicate dynamic in vivo joint kinematics or active muscle forces, and their findings should be extrapolated to clinical practice with caution. Additionally, the proposed diagnostic and therapeutic thresholds for QTM, such as the >14° QTAx cut-off, currently rely on retrospective data from a single research group and require independent prospective validation. Moreover, outcome assessment methods varied widely across studies, including the use of different patient-reported outcome measures (KSS, OKS, KOOS, VAS, WOMAC, Kujala, IKDC), as well as differing follow-up durations and timing of evaluations (ranging from short-term to long-term evaluations), limiting direct comparison of results. Finally, as a narrative review, this work is susceptible to selection bias, and despite a comprehensive search strategy, the absence of a quantitative meta-analysis means that the conclusions should be viewed as a qualitative synthesis of current trends rather than an absolute consensus.

5. Conclusions

In total knee arthroplasty, femoral component internal rotation, valgus alignment, excessive flexion, and tibial component internal rotation should be avoided to prevent patellar maltracking. While kinematic alignment may offer advantages in certain functional and satisfaction scores compared to mechanical alignment, its clinical superiority remains nuanced, and it might not be appropriate for patients with concurrent quadriceps tendon malalignment. Preliminary evidence suggests that CT-based quadriceps tendon axial angle measurements could aid in preoperative risk stratification. However, routine clinical implementation still requires further prospective validation. Furthermore, robotic-assisted systems currently represent an advanced and promising approach to tailoring surgical procedures to individual anatomy. When surgical intervention is required, treatment options must be highly individualized, considering the specific direction of patellar maltracking, component rotational malalignment, the patient's personal preferences, and rehabilitation potential.

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Abbreviations

The following abbreviations are used in this manuscript:

TKA	Total knee arthroplasty
PFA	Patellofemoral arthroplasty
TPS	Tibial posterior slope
KA	Kinematic alignment
MA	Mechanical alignment
HKA	Hip-knee-ankle
Q-angle	Quadriceps angle
KSS	Knee Society Score
ROM	Range of motion
WOMAC	Western Ontario and McMaster Universities Osteoarthritis Index
OKS	Oxford Knee Score
LRR	Lateral retinacular release
QTM	Quadriceps tendon malalignment
QTAx	Quadriceps tendon axial angle
PROMs	Patient-reported outcome measures
VAS	Visual Analogue Scale
PPT	Pain Threshold
PLPF	Partial Lateral Patellar Facetectomy
MPFL	Medial patellofemoral ligament
MPFLR	Medial patellofemoral ligament reconstruction
IKDC	International Knee Documentation Committee
TT-TG	Tibial tuberosity–trochlear groove
TTO	Tibial tuberosity osteotomy
MCID	Minimal Clinically Important Difference
R-TKA	Robotic-assisted TKA
C-TKA	Conventional TKA
AKP	Anterior knee pain

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