Patello-femoral joint in total knee replacement

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Summary
Total knee arthroplasty (TKA) surgery is a widely used treatment and has a high success rate. Despite its success, the patello-femoral articulation has been overlooked as a contributor to the successful outcome of TKA. Patello-femoral complications remain the leading cause of failed knee replacement, accounting for up to 10% of complications. To understand the concept of patellar mal-tracking, we explore the normal anatomy and biomechanics of the patello-femoral articulation, and review the surgical factors and complications related to patellar tracking, with an aim to discussing the concepts on how to avoid such complications. Surgeons should be aware of the frequent occurrence of abnormal patellar tracking, and should pay particular attention to the patello-femoral component of knee replacement surgery.

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Introduction
The patello-femoral joint (PFJ) is a highly complex structure consisting of the patella and its counterpart, the patellar groove of the femur. Despite the success and satisfaction of primary total knee arthroplasty (TKA), patello-femoral complications remain the leading cause of revision, accounting for up to 10% of complications in TKA.1,2 The patello-femoral articulation is an aspect of TKA that is often neglected to secondary importance, and although the complications involving the PFJ are not devastating, they are frequent enough to warrant particular attention by the surgeon. Such complications include patellar fracture, impingement, patellar clunk syndrome, component failure, patellar maltracking and subluxation. Minor complaints such as clicking, catching and persistent anterior knee pain may actually affect a much higher number of patients.

This article reviews the anatomy and biomechanics of the PFJ, its implications and complications associated with TKA.

Anatomy and biomechanics
The patella is the largest sesamoid bone and forms the PFJ with the patellar groove of the femur, otherwise known as the trochlea of the femur. The articular surface of the patella consists of seven facets; three medial, three lateral and the "odd" facet on the medial border separated by a ridge from the medial facet proper.3 This articular surface is composed of thick hyaline cartilage, which provides an insensitive, avascular area specifically adapted to bearing high compressive loads.

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An elaborate system of intraosseous and extraosseous vasculature provides blood supply to the patella.\textsuperscript{4,5} A peri-patellar anastomotic ring consisting of six main arteries forms the extraosseous blood supply. These six main arteries supplying the ring are the articular branch of the descending genicular artery, the medial superior genicular artery, the medial inferior genicular artery, the anterior tibial recurrent artery, the lateral inferior genicular artery and the descending branch of the lateral femoral circumflex artery. The superior part of the ring passes anterior to the quadriceps tendon and the inferior portion passes posterior to the patellar tendon through the substance of the fat pad. The intraosseous system comprises mid-patellar, polar/patellar, and quadriceps tendon blood supplies.

The main function of the patella is to serve as a biomechanical lever arm, increasing the effectiveness of the quadriceps in knee extension. It also centralizes the divergent forces of the quadriceps muscle and transmits the tension around the femur to the patellar tendon.\textsuperscript{6,7} Such muscular activity around the patella produces the patello-femoral joint reaction force (PFJR) about the knee in flexion.\textsuperscript{3} Cadaveric studies have demonstrated that the first contact is made between 10\textdegree{} of flexion and reaches a maximum at 90 degrees of flexion, with approximately a 20 degrees of flexion along the inferior margin of the patella across both medial and lateral facets. As flexion proceeds, the contact area has been shown to move proximally on the patella, as well as involving a greater area of contact extending from lateral border (lateral facet) and the ridge of patella (including the medial facet proper). The “odd” facet only comes into weight-bearing contact with the trochlea when flexion proceeds to about 135 degrees. It follows that from extension to 90 degrees flexion, all the articular surface of the patella, save the odd facet, articulates with the femur. After 90 degrees, the tendinous band of the quadriceps begins to share in load transmission from the extensor mechanism, as well as the “odd” facet playing a role. Similar results have been reported by other authors; identifying that contact stress gradually increases during knee flexion and reaches a maximum at 90 degrees of flexion, with approximately the same pressure on the lateral and medial patellar facets. Huberti et al. further demonstrated that the tendo-femoral contact at greater degrees of knee flexion supported one-third of the total contact force on the patella, thus limiting the rise in PFJR force.\textsuperscript{10,11}

PFJ kinematics have been exhaustively studied, mostly using cadaveric studies, but some from imaging in vivo.\textsuperscript{7,12–14} Such tracking studies have found that the patella is pulled laterally in terminal knee extension, due to the lateral vector of the vastus lateralis component of the quadriceps muscles. This lateral vector arises as a result of the quadriceps (‘Q’) angle formed by the line of application of the quadriceps force and the direction of the patellar tendon.\textsuperscript{15} This lateral pull is resisted by the oblique fibers of the distal vastus medialis, the medial retinacular structures and the prominence of the lateral facet of the trochlea. As flexion proceeds, the patella gradually moves medially to enter the trochlear groove. The degree of knee flexion at which the patella engages the trochlea is dependent on the patellar tendon length, and has been noted to be approximately 20 degrees of flexion.\textsuperscript{7} After engaging in the trochlear groove, the patella moves laterally as the knee further flexes. The patella transits along the trochlear groove onto the distal aspect of the femur. Unlike the conventional understanding of the femoral geometry where the trochlear groove is symmetrically placed about the femoral condyles, the groove has been demonstrated to be lateral to the midplane, implicating that the patella will naturally track lateral to mid-plane as flexion progresses.\textsuperscript{16} The full course from extension to full flexion, is thus a gentle ‘C’ opened laterally.\textsuperscript{7} In addition to the lateral displacement, other aspects of PFJ kinematics in deep knee flexion include patellar tilt and medial-lateral rotation. Reports are contradictory, however, with differences in the method of measurement being an inconsistent factor reported in the literature. Nonetheless, such kinematics are of small magnitude and it therefore seems that the normal pattern of these movements may be unimportant in the dynamics of the PFJ.\textsuperscript{12}

The patello-femoral joint in total knee arthroplasty

Complications related to the extensor mechanism are the most common problem after TKA. Some series have attributed patello-femoral problems as the cause of revision TKA in as high as 50% of patients,\textsuperscript{17} although recent reports suggest patellar complications account for 1%–12% of cases.\textsuperscript{18–20} Factors that have been implicated as causes of patello-femoral complications after TKA include surgical techniques, component alignment and rotation, and prosthetic design.

Instability

Patellar subluxation and maltracking is the commonest complication following TKA. The reported incidence of instability following TKA has been as high as 29%.\textsuperscript{21} Tracking essentially concerns ‘Q’ angle, and as such, the causes of instability have been attributed to implant position, patella preparation, soft-tissue balance and tension, and prosthetic design. As discussed in the anatomical section, the ‘Q’ angle provides a resultant lateral force on the patella. Any increase in ‘Q’ angle results in an increased lateral vector, thus predisposing the patella to sublux.

Component malrotation is a leading cause of patellar instability.\textsuperscript{22} Internal rotation of the femoral component makes the patella laterally tilted, and medially displaced (Fig. 1). The net result is increase in shear stress on the patellar component, and an increase in ‘Q’ angle. Studies have shown that 5 degrees of internal rotation will cause 5 mm of medial displacement of the patella, thus significantly increasing the ‘Q’ angle and its propensity to sublux.\textsuperscript{23} Slight external rotation is thus preferred, and most prosthetic knee systems have built in 3 to 5 degrees of external rotation by using the posterior femoral condyles as a reference point. Other reference points have been illustrated, including perpendicular to Whiteside’s line, as described by Whiteside and Arima,\textsuperscript{24} while others have described the transepicondylar axis of the femur to provide
the optimal reference for femoral component rotation. External rotation of the tibial component should also be achieved. Like the femur, internal rotation of the tibial component results in a net external rotation of the tibia, causing a net increase in the 'Q' angle. Optimisation of tibial rotation can be achieved when the prosthesis is centred between the medial border and centre of the tibial tubercle. Other aspects of component placement have also been described, such as the avoidance of medial placement of both femoral and tibial components. Medialisation of the femoral component increases the 'Q' angle. A medialised tibial component, in effect, places the tibial tubercle in a relatively more lateral position. This position also has the effect of increasing the 'Q' angle.

Patellar preparation is equally important (Fig. 2). The patellar component should be medialized. Although a centered patellar component is an acceptable position for tracking, medialization of the patellar component will in effect lateralize the remaining patellar bone and this results in reduction of the 'Q' angle. Similarly, patellar height restoration plays a role in tracking. The patella lifts the capsule away from the femur, and thus the patellar height controls capsular tension. An overstuffed patella increases capsular tension, which translates into an increased lateral subluxation force on the patella. It is thus essential to restore the native patellar thickness, bearing in mind the suggested patella cut thickness.

Lateral release has been routinely advocated by some authors, suggesting that a tight lateral soft tissue sleeve can increase the risk of subluxation. However, the routine and unnecessary use of lateral soft tissue release should be avoided for fear of devascularizing the patella. Lateral release has been associated with sacrifice of the superior geniculate vessels, predisposing to patellar fracture and superficial wound infection.

Implant design has important implications for tracking. Eckhoff et al. described that the anatomically correct orientation of the trochlear groove is lateral to the mid-plane. As such, femoral components with lateralized trochlear grooves will accommodate the natural tendency for the patella to track laterally, as well as engaging the patella early in the flexion arc. Furthermore, studies have shown that a raised lateral flange and a deepened trochlear groove have the advantage of resisting lateral subluxation and engaging the patella in the groove respectively, thus minimizing subluxation and improving tracking. A further potential advantage of implant design is a trochlear groove that extends distally so that patello-femoral contact is possible in deep flexion.

Overall, patellar maltracking and subluxation increases patello-femoral forces. Consequently, this may result in anterior knee pain, early prosthetic loosening, and increased risk of periprosthetic patellar fracture. It is important to restore the normal 'Q' angle in order to prevent patellar instability. Avoiding internal rotation of the tibial and femoral implants, achieving appropriate soft tissue balance, correct patellar preparation and a well designed trochlear groove will prevent most causes of instability.

**Patellar resurfacing**

Whether to resurface the patellar in primary TKA is a controversial topic that has generated much debate and research. In 1990, Picetti et al. reported on 100 TKA without patella resurfacing. Patients with low body weight did well, but at final follow-up, 29% had continued symptoms related to the patello-femoral joint. The recurrence of anterior knee pain and patellar mal-tracking in first generation knee implant designs led to the introduction of patellar resurfacing. However, resurfacing comes at a price. Potential complications include component failure and loosening, fractures, rupture of the patellar tendon, impingement and patellar clunk syndrome, and anterior knee pain. With this variety of complications potentially requiring re-operation, it has been proposed that resurfacing should be reserved for patients with inflammatory arthritis, severe preoperative patellar pain, large or thick patellae, or multiple previous knee operations, as well as for those who are overweight or poorly compliant.

Several randomized studies have tried to identify the benefits of resurfacing the patella, however, there have been conflicting results. In an attempt to consolidate the
findings, Pakos et al. in 2005 performed a meta-analysis of 1223 randomized knees and reported that the rate of re-operation was approximately 50% lower following total knee arthroplasty with patellar resurfacing than it is without resurfacing. Furthermore, the observed difference in the number of re-operations was more evident in studies with follow-up periods of five years or more. This implied that the patellar complications appeared in the long term, after the third or fourth postoperative year. Another recent meta-analysis supported the above findings. Nizard et al. reviewed 12 randomized studies (total of 1494 randomized knees), and identified that the incidence of re-operations for patello-femoral problems in the resurfaced group was 2.3%. This was 0.43 times lower than the non-resurfaced group. Similarly, prevalence of anterior knee pain was reduced with patellar resurfacing in both meta-analyses. However, as the authors illustrated, there were multiple confounding factors, differences in variables and bias among the individual trials, and thus the conclusions must be moderated. Further large scale and carefully designed randomized studies are required before a definitive conclusion can be made.

**Patellar fractures**

Periprosthetic patellar fracture is an infrequent complication following TKA [Figs. 3 and 4]. The literature has reported an incidence of 0.2% to 21% in resurfaced patellae, while the incidence of patellar fracture after revision TKA has been reported as nearly six-fold higher than primary TKA. Although patellar fracture after TKA can ensue at any time, most fractures occur within 1–2 years after arthroplasty. In a report from the Mayo Clinic, 2/3 of the fractures occurred within 2 years of arthroplasty. A wide range of aetiological factors have been identified. Patient factors including high activity level, higher body mass index and rheumatoid arthritis have been implicated to increase the risk of patellar fracture. Poor implant design such as metal backed uncemented patellae or large central pegs have been associated with increased patellar fracture, but these have been largely replaced with newer designs incorporating less bulky polyethylene implants.

However, reaction forces in the PFJ are probably the most important factor in extensor mechanism related complications. Component malalignment has been shown to increase contact forces, subsequently increasing the risk of fracture. Other technical factors reported to increase the risk of patellar fracture include component positioning. Studies have shown that the use of a large anteroposterior diameter femoral component, positioning of the femoral component in a flexed position or the laterally placed patellar component are all associated with patellofemoral malalignment and thus can increase patellofemoral joint reaction forces, predisposing the patella to fracture. The amount of bone resected from the patella is also an important determinant of fracture risk. Most surgeons believe that restoration of the original patellar thickness during TKA is most desirable. A cadaveric study showed that a thicker or thinner patella resulted in a smaller contact area and considerably increased joint reaction forces. Other studies have confirmed that under-resection of patella can result in "overstuffing" of the PFJ and tension within the quadriceps tendon, thus increasing the joint reaction forces. On the other hand, excess resection compromises the mechanical strength of the patella, thus further predisposing to fracture. Reuben et al. demonstrated that the patella is vulnerable to fracture because of bending in the sagittal plane when the knee is in flexion and the bone thickness...
is less than 12 mm. However, recent studies have shown that a residual patellar thickness of less than 12 mm did not affect clinical outcome. Asymmetrical patellar resection, particularly with excessive resection of the lateral facet, can also result in compromised mechanical strength of the patella, as well as maltracking and subluxation of the patella with subsequent increased joint reaction forces.

The management of periprosthetic patellar fracture is dependent on fracture configuration, intactness of the extensor mechanism and implant stability. In general, studies have reported that patients with stable implants and an intact extensor mechanism can be successfully treated conservatively with good results. Surgical treatment is indicated if there is loss of extensor mechanism, a loose patella component, or severe comminution. Every attempt should be made to preserve the patella to increase the mechanical advantage of the quadriceps mechanism. Patellectomy reduces the quadriceps lever arm and can result in marked quadriceps weakness, hence such a procedure should be reserved for patients with extremely poor bone stock and a fracture with a high degree of comminution. Partial patellectomy with insertion of a smaller component may on occasions be preferable to complete patellectomy.

**Avascular necrosis**

The manner in which the patella is treated during TKA is also a very important factor influencing the outcome. A considerable disruption of the blood supply to the patella occurs during a routine medial parapatellar approach to the knee. The medial superior and inferior genicular arteries are usually divided during the medial arthrotomy. The excision of the fat pad and aggressive lateral meniscectomy may compromise the lateral inferior genicular artery, whereas lateral release can result in sacrifice of the lateral superior genicular artery. This increases the incidence of avascular necrosis and periprosthetic patellar fracture, with subsequent loss of fixation of the patellar implant. The blood supply to the patella is likely to be compromised further during preparation of the patella for resurfacing, especially when using a single large central peg component that can disrupt the intrasosseous vascular supply. The fear of patellar fracture and other related complications prevents some surgeons from performing routine patellar resurfacing.

**Patellar component failure**

Early designs, particularly metal-backed patellar implants, had high percentage failure rates. In order to maintain normal thickness while having a metal backplate that is sufficiently thick that it will not suffer fatigue fractures in bending, the polyethylene has to be significantly thinner. This design predisposes the polyethylene to be vulnerable to fractures and failure. Although some dispute the idea that all-polyethylene patellar components are the answer, there is nothing in the remaining literature to suggest a move away from using all-polyethylene components.

Other modes of failure of metal-backed components include component dissociation of the polyethylene from the metal plate and lack of bone ingrowth for fixation. Most current all-polyethylene patellar components in use today are simple axisymmetric buttons. This particular geometry requires an exact match of contact between patellar component and femur to ensure accurate medial-lateral and tilting alignment. This is very difficult to achieve, especially in a patient who requires soft tissue realignment. With any lateral tilt, shear forces are substantially increased, predisposing to failure. Furthermore, in flexion the forces on the PFJ are large and act proximally. Patello-femoral contact forces exceed the yield strength of polyethylene, resulting in plastic deformation. In order to avoid excessive contact forces, the articular geometry should be conforming. Newer patellar component design features include saddle-shaped articular surfaces with similar curvature to the antero-distal femoral condylar surface, therefore being congruent across the whole surface. This allows the patellar component to maintain a large area of contact and minimizes contact stresses with knee flexion.

Other predisposing factors include overstuffing of the PFJ, excessive thickness of patellar composite and femoral components placed in excessive flexion. These result in increased joint reaction forces. Patellar maltracking and a predisposition for lateral subluxation with a resultant increase in patellar shear forces can lead to patellar component failure.

Component failure usually requires revision surgery, which can prove to be difficult, especially if there is inadequate remaining bone stock. In such circumstances, patelloplasty or patellectomy may be required. Alternatively, patellar bone grafting has been suggested, with promising early results.

**Impingement**

Soft tissue impingement can range from mild crepitus to grinding, but more importantly patella clunk syndrome. Excessive PFJR forces and chronic irritability of the PFJ can result in scar tissue formation with resultant impingement complications. Such problems are more common in certain femoral designs, particularly with femoral geometry with an open box design to accommodate the tibial post in posterior stabilized implants. With tissue hypertrophy, soft tissue becomes engaged in the intercondylar notch, causing painful catching at 30 to 40 degrees of knee extension. A recent study has demonstrated a significant reduction from 20% to 0% incidence of patellar crepitus or clunking by removing the femoral box in the femoral component, thus distally extending the trochlear groove and subsequently increasing patello-femoral contact in greater degrees of flexion.

Treatment of this problem can vary from open resection of the scar tissue to arthroscopic excision/debridement for symptomatic relief.

**Conclusion**

TKA, similar to any operative procedure, should be performed based on principles of providing the best possible outcome and avoiding complications. Critical factors influencing the outcome and patellar complication rate after TKA are the accuracy of soft tissue balancing and extensor
Mechanism alignment. Performing accurate bony cuts, the appropriate positioning of the components during TKA, and the occasional need for lateral release directly impact patellar tracking and the overall extensor mechanism alignment. Proper resection and resurfacing of the patella, maintenance of patellar vascularity, and the use of an implant with a well-designed patello-femoral joint helps to minimize complications. All efforts should be made to achieve symmetrical seating of the patella in the groove of the femoral component with appropriate patellar tracking.

References


