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Biomechanics of the Patellofemoral Joint

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The biomechanics and kinematics of the patellofemoral joint are the result of a complex assortment of static and dynamic conditions. This article will present a review of our basic understanding of these conditions and place them in the context of necessary information required when considering surgical interventions. The importance of this information becomes highlighted when one considers that the knee is a coupled mechanical system, and changes in any single component of the system can affect any of the remaining parts of the system.
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Introduction

The biomechanical characteristics of the patellofemoral joint are the result of a complex interplay of components. The statics and dynamics of this articulation involve the geometries of the patella and the trochlea, the passive soft tissue restraints of capsule and retinaculum, and the coordination of the quadriceps. Additionally, angular and rotational limb alignment can affect patellofemoral mechanics and kinematics. The bottom line is that it is all about balance—balance of the extensor mechanism of the knee. As we proceed through this article, we should take note of some advice I received many years ago from an engineering and research colleague. "The knee is a coupled mechanical system. One cannot change any 1 part without affecting the remaining parts of the system" (Tony Valdevit, personal communication). Many of the subsequent studies referenced within this article will support the advice I had received. Finally, the biomechanical descriptions to follow will be generally qualitative interpretations and I would refer to the appropriate studies referenced for more quantitative data.

Relevant Osseous Anatomy

The patella has been considered to be a large sesamoid bone lying within the extensor mechanism of the knee. The posterior surface consists of 2 major concave facets, medial and lateral, with a small convex medial "odd facet." The lateral facet is typically larger, although Wiberg[1] has described a classification of patellar shape that generally fits most presentations (Fig. 1). Type 1 describes a patella with equal size of medial and lateral facets. Type 2 has the lateral facet larger than the medial, and Type 3 depicts a large lateral facet with a small, more vertically oriented medial facet. And then as we will subsequently see, there is a very small vertically oriented "odd facet" that is adjacent to the medial facet that makes contact only in deep flexion. Panni et al[2] have described the increased prevalence of the Type 3 patella in patients with recurrent dislocations of the patella and the association with certain types of trochlear dysplasia. The thickest articular cartilage in the body is found within the patellofemoral joint. On the patella, it can measure 4-6 mL in depth and is progressively thicker proximally.[3-5]

The trochlear geometry has been studied extensively.[6-11] Amis and his colleagues have determined that the primary restraint to lateral translation of the patella, once engaged within the trochlea and beyond 30° of flexion, is the slope of the lateral wall of the trochlea.[11] Dejour and Saggin[9] have developed a working classification of trochlear shape. Type A is characterized by a shallow trochlea and a positive "crossing sign" seen on the lateral radiograph. Type B has a shallow or flat trochlea, as well as a supratrochlear spur. Type C has a positive crossing sign and a double contour sign seen on the lateral radiograph, a convex lateral trochlear facet, and hypoplasia of the medial trochlear facet. Type D has everything that Type C has, plus a supratrochlear spur and marked hypoplasia of the medial trochlear facet.

Relevant Soft Tissue Anatomy

The extensor mechanism of the knee is composed of the quadriceps muscles and their respective tendons, the patellar

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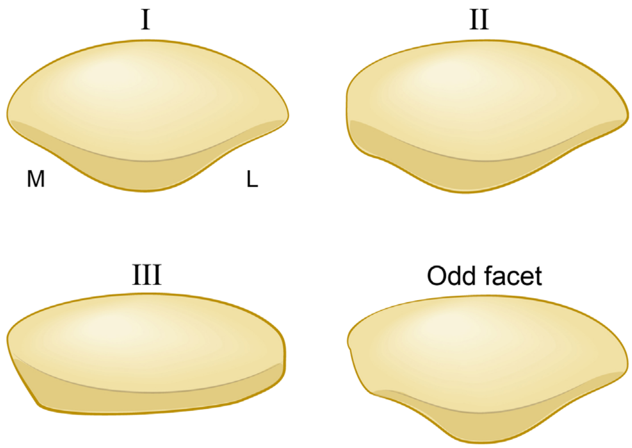

Figure 1 Wiberg has described 3 general morphotypes of the patella. A small more vertically oriented "odd facet" articulates with the trochlea in deep flexion. L, lateral; M, medial. (Color version of figure is available online.)

tendon, and the medial and lateral retinaculum. The vastus medialis extends further distally on the patella than the tendon of the vastus lateralis. The vastus medialis oblique (VMO) insertion has a more horizontal rather than vertical orientation. A small component attaching to the proximal or lateral boarder of the patella can be referred to as the vastus lateralis oblique and has muscular origins from the lateral intermuscular septum. Farahmand et al[11] have described the relative influences of the components of the quadriceps muscles. They estimated force contributions based upon cross-sectional areas. On that basis, they felt that the rectus femoris and vastus intermedius contribute 35% of total quadriceps strength, the vastus medialis contributes 25%, and the vastus lateralis (although the most variable in cross-sectional area) contributes 40%.

The length of the patellar tendon can be variable. A number of methods of measuring patellar height have been validated.[12] Ranges of normal have been established. Indices that depict the patellar tendon as being too long are referred to as patella alta, whereas indices that demonstrate the patellar tendon as being too short are referred to as patella baja or patella infera. The effects upon patellofemoral loading will be discussed later.

Fulkerson and Gossling[13] have described the anatomy of the lateral retinaculum and demonstrated a thin, oblique component with a stout deep transverse component. A lateral epicondylopatellar ligament has been described with variable prevalence. The deep transverse lateral retinaculum takes its origin from the deep surface of the iliotibial band.

Warren and Marshall[14] described 3 fascial layers of the medial aspect of the knee. The most superficial layer encloses the vastus medialis and extends distally to be the sartorius fascia. The intermediate layer includes the medial patellofemoral ligament (MPFL) and distally includes the superficial medial collateral ligament. The deep layer includes the joint capsule. Considerable attention recently has been given to a whisp of a structure within the intermediate layer.[15-20] This has been defined as the MPFL with a variable length of attachment to the proximal half of the medial boarder of the patella and a femoral origin within a saddle between the adductor tubercle and the medial femoral epicondyle. Baldwin[15] has confirmed the transverse component of the MPFL originating between the adductor tubercle and the medial femoral epicondyle, and also an oblique extension that blends with the anterior boarder of the superficial medial collateral ligament. Proximally, the anterior half to two-thirds of the transverse band of the MPFL blends with the posterior surface of the VMO.

Whether it is the medial or lateral retinacular structures, it is important to understand their mechanical effects by viewing their orientations. We too often view their orientations in the coronal plane, but when viewed in the axial plane, it becomes more understandable how they both function to assist engagement of the patella within the trochlea (Fig. 2).

Mechanics

Ostensibly, the patella acts to enhance the pulley effect by increasing the moment arm distance from the extensor mechanism to the instant center of motion of the knee. Indeed, this effect can improve the efficiency of the quadriceps by as much as 50%.[3,21] The patella also serves to centralize the divergent forces of the quadriceps during flexion as the patella engages within the trochlea. With the knee in extension, the angle formed by the resultant quadriceps force and the patellar tendon is known as the quadriceps angle (Q-angle). This provides a force to laterally displace the patella, while at the same time counters external rotation of the tibia.[7,22] During knee flexion, the obligatory internal rotation of the tibia reduces the Q-angle and thus reduces the forces that produce

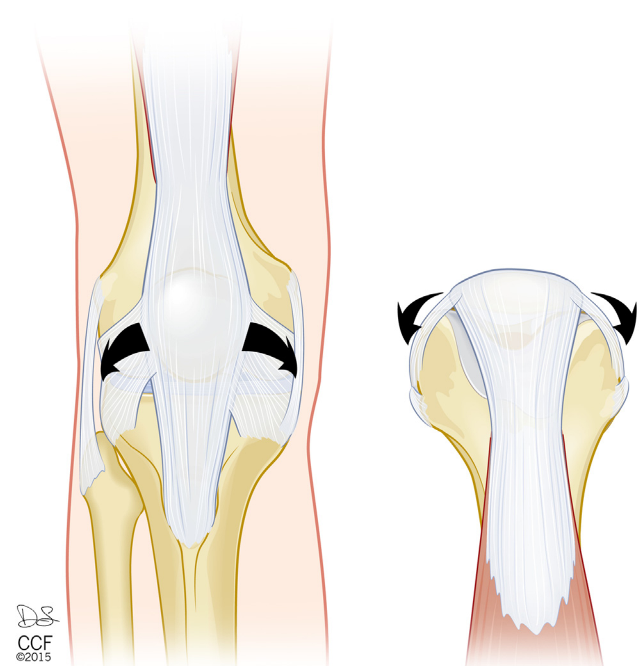

Figure 2 When viewed in the axial plane it is easier to understand the function of the medial and lateral retinaculum to engage the patella within the trochlea. (Color version of figure is available online.)