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In vivo kinematic evaluation and design considerations related to high flexion in total knee arthroplasty

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Abstract

In designing a posterior-stabilized total knee arthroplasty (TKA) it is preferable that when the cam engages the tibial spine the contact point of the cam move down the tibial spine. This provides greater stability in flexion by creating a greater jump distance and reduces the stress on the tibial spine. In order to eliminate edge loading of the femoral component on the posterior tibial articular surface, the posterior femoral condyles need to be extended. This provides an ideal femoral contact with the tibial articular surface during high flexion angles. To reduce extensor mechanism impingement in deep flexion, the anterior margin of the tibial articular component should be recessed. This provides clearance for the patella and patella tendon.

An in vivo kinematic analysis that determined three dimensional motions of the femorotibial joint was performed during a deep knee bend using fluoroscopy for 20 subjects having a TKA designed for deep flexion. The average weight-bearing range-of-motion was 125°. On average, TKA subjects experienced 4.9° of normal axial rotation and all subjects experienced at least −4.4 mm of posterior femoral rollback. It is assumed that femorotibial kinematics can play a major role in patellofemoral kinematics. In this study, subjects implanted with a high-flexion TKA design experienced kinematic patterns that were similar to the normal knee. It can be hypothesized that forces acting on the patella were not substantially increased for TKA subjects compared with the normal subjects.

Keywords: High Flexion; Kinematics; Design; Knee Arthroplasty

1. Introduction

The goal of total knee arthroplasty is to restore normal knee function and kinematics. The factors affecting the range of motion are influenced by the patient, surgical technique, and implant design. After total knee arthroplasty (TKA) the commonly reported average peak flexion angle ranged from 100° to 110° (Dennis et al., 1998a). The factors that influence postoperative range of motion include any previous surgery, which may induce arthrofibrosis, as well as the severity of the joint degeneration associated with osteoarthritis, post-traumatic arthritis or inflammatory arthritis. Although the importance of the angular deformity has been considered an influencing factor on the range of motion, the most important factor is probably the preoperative range of motion.

Clinical experience has shown the need for high flexion in patients who have both high flexibility and a desire to perform deep flexion. High flexion after TKA means a flexion angle greater than 120°. There are some ethnic populations that require high flexion for social, religious or working activities. In order to achieve this high degree of flexion, there is typically a compensatory internal rotation of the tibia, as high as 25°.

The preoperative evaluation before the arthroplasty is then critical in order to identify the appropriate candidate for achieving high flexion after TKA in order to achieve the greatest potential for deep flexion. The patient must express the need and the willingness for high flexion activities, the thigh-calf index needs to be greater than 90° with a non-obese patient, and the

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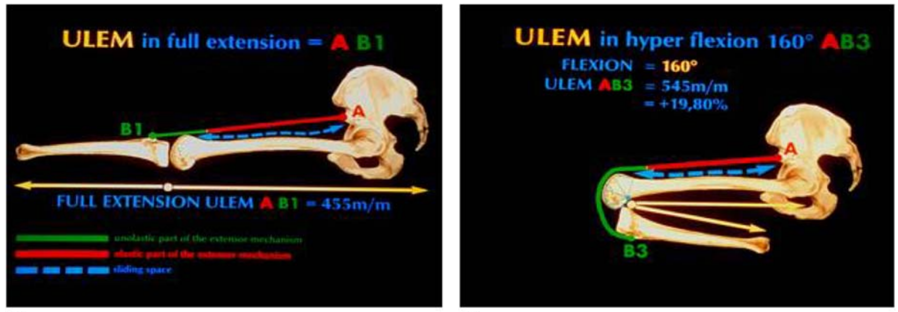

(a) (b)

Fig. 1. (a & b). The useful length of the extensor mechanism (ULEM) from extension to full flexion.

minimum preoperative flexion angle needs to be 100°. The clinical evaluation must also assess the useful length of the extensor mechanism to avoid cases with previous history of extensor mechanism lesions or patella infera (Fig. 1).

The specific points of the surgical technique for high flexion are the removal of the posterior osteophytes and the release of the posterior capsule. This is performed with the knee in flexion in order to increase the distance with the vascular structures, and the use of a distractor is helpful to expose the posterior aspect of the femur. Implant sizing is critical, especially on the femoral side to avoid overstuffing the joint. The principle of balanced flexion and extension gaps must be followed and the tibial component positioned with appropriate tibial slope (Callaghan et al., 2000).

1.1. Design considerations

The goal of high flexion implant design is to create a prosthesis that is durable, stable, and provides safe and adequate flexion. Several parameters influence this desire.

Since it has been shown that most posterior cruciate ligament retaining designs have erratic motion with potential for paradoxical roll forward, it is preferable to design a high flexion knee prosthesis with a posterior cruciate substituting articulation (Dennis et al., 1998b, 2001). Predictable femoral rollback has been well demonstrated with a posterior cruciate ligament substituting prosthesis (Dennis et al., 1998a). Continued predictable femoral rollback, throughout flexion, is attributed to the action of the tibial spine and femoral cam mechanism. Another important consideration in designing the tibial spine and femoral cam mechanism is the resistance to subluxation or instability at high angles of knee flexion. It is preferable that when the cam engages the tibial spine that the contact point of the cam move down the tibial spine. This provides greater stability in flexion by creating a greater jump distance and reduces the stress on the tibial spine (Fig. 2).

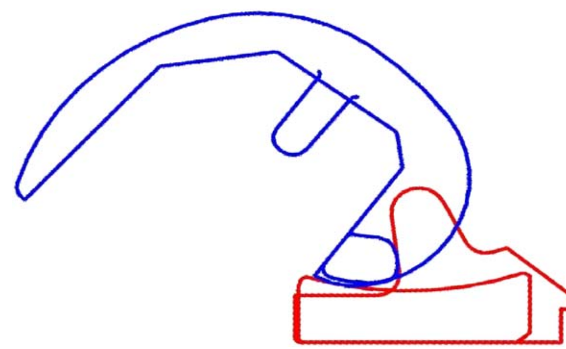

Fig. 2. The jump height distance of the spine/can mechanism in posterior stabilized total knee arthroplasty.

Another feature is conformity of the articular surface. A frontally conforming round on round articular surface increases the contact area and reduces the polyethylene contact stress. Femoral condylar lift-off following total knee arthroplasty has been demonstrated by fluoroscopic imaging (Stiehl, 2002). While this phenomenon can be reduced or eliminated by the surgical technique, if condylar lift-off does occur, it is beneficial to have a prosthesis that is designed with a conforming round on round frontal articulation, which will eliminate edge loading on the tibial articular surface.

In designing the sagittal geometry a femoral component with multiple radii has a distinct advantage. Maximum conformity can be achieved in full extension and early flexion during gait, comparable to the normal femur (Stiehl et al., 1997; Stiehl, 2002). A decreasing sagittal radius permits improved motion without the kinematic conflict of conformity and constraint with a single radius design (Stiehl et al., 1997, Stiehl, 2002). In order to eliminate edge loading on the femoral component on the posterior tibial articular surface, the posterior femoral condyles need to be extended. This provides an ideal femoral contact with the tibial articular surface during high flexion angles (Fig. 3).

Finally, the patellofemoral articulation should be designed to accommodate high angles of knee flexion.