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The Rationale for a Total Knee Implant That Confers Anteroposterior Stability Throughout Range of Motion

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Abstract: The topic at hand in this series of presentations concerns the design of total knee prostheses. This presentation concerns the rationale for an implant to confer anteroposterior stability without the need for a central "cam and post" mechanism, as is common in posterior cruciate–substituting total knee arthroplasty prostheses. **Key words:** total knee arthroplasty, joint stability, prosthesis design, gait, quadricep avoidance, paradoxical motion.

At the advent of total knee arthroplasty (TKA), the goal of the arthroplasty was pain relief. It was expected that, with pain relief, there would be improvement of function; however, the return of patients to such activities as recreational sports was not envisioned. Now, however, our patients expect not only pain relief, but also return to age-appropriate activities. The definition of "age-appropriate activity" is rapidly broadening to include increasingly higher levels of activity.

One of the guiding principles in the design of total knee prostheses and the operative technique is to create an "aligned and stable" joint [1]. Stability in the coronal plane has been defined in terms of varus and valgus, representing appropriate tensions in the collateral ligaments. Sagittal plane, or anteroposterior (AP) stability, has been predicated on either retention of the posterior cruciate ligament (PCL), both the anterior and PCLs, or resection and substitution for the cruciate ligaments.

Until relatively recently, the prevailing model for knee joint motion was the "crossed-four-bar link" model [2,3]. In this model of knee kinematics, the femur must move from front to back on the tibia as the joint flexes, and in the opposite direction as the knee extends. (This phenomenon is known as "rollback.") Knee joint designs deliberately have had little conformity between the femoral and tibia articular surfaces so as to eliminate "kinematic conflict" with the expected "physiologic rollback" predicted by the crossed four-bar link model. However, Komistek and Dennis [4,5] demonstrated through their studies of total knee joint motion that many subjects in whom a total knee joint has been implanted demonstrated not posterior motion with flexion, but rather anterior sliding of the femur on the tibia. (Because the generally accepted model predicted posterior displacement of the femur with flexion, the anterior sliding was termed "paradoxical motion.") When evaluating patients in gait, anterior or paradoxical motion of the femur has been seen in both posterior cruciate–retaining and posterior cruciate–substituting designs. This abnormal femoral-tibial motion may have significant implications for the functional result of a TKA.

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Fig. 1. At heel strike, the knee is in nearly full extension and the line of action of the body weight to the heel acts nearly through the center of the knee.

Fig. 2. At load acceptance in stance phase, as the foot is brought flat on the floor, the knee flexes. The line of action of the body weight acts behind the knee, tending to flex the joint. Quadriceps eccentric contraction counters this flexion moment.

Numerous studies have demonstrated that patients with TKAs walk differently than normal controls [6,7]. The abnormalities are manifest as slower walking speed, shorter stride length, less time spent in stance phase on the limbs with arthroplasties, and the use of a more "stiff-legged" gait. It is possible that failure to provide AP stability through prosthetic design contributes to these abnormalities.

To consider the potential effects of paradoxical motion on gait, it is useful to briefly review some aspects of stance phase. In normal gait, at heel strike, the knee is very nearly in full extension (Fig. 1). After heel strike, stance phase continues to foot flat and load acceptance through a combination of ankle plantar flexion and knee flexion. (The amount of knee flexion is at least 15° but may be more.) As full load is taken in stance phase in normal gait, the line of action of the center of mass of the body acts behind the knee, tending to flex the knee (Fig. 2). Further knee flexion is prevented at this phase of gait through quadriceps contraction to counter the moment trying to flex the knee. The femur stays centered in the medial plateau of the tibia; there is no sliding forward or paradoxical motion [8].

Consider what might happen in gait with a TKA that does not provide AP stability (Fig. 3A and 3B). At heel strike, the knee again is as far toward full extension as is possible. Heel strike can proceed to foot flat and maximum load as in the normal knee, but, at this point, there can be considerable difference. If the PCL is intact (as in a posterior cruciate–sparing total knee) and there is little conformity between the femoral and tibial components, the

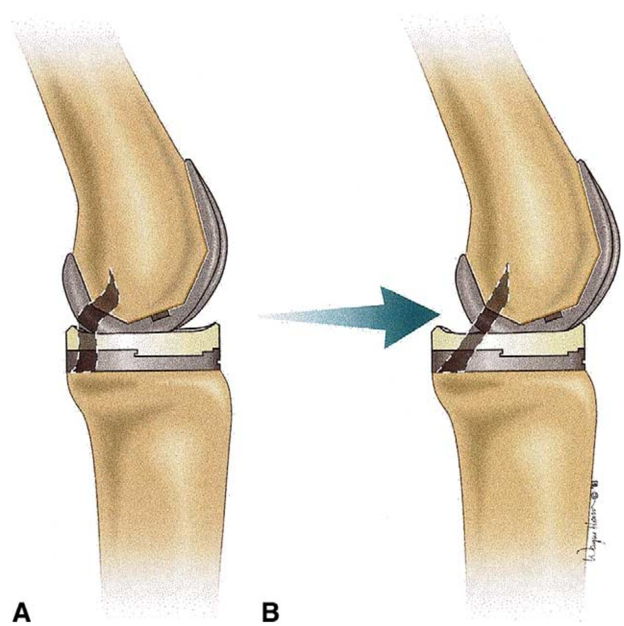

Fig. 3. (A) A PCL-retaining prosthesis just before load acceptance. The femoral component is contacting the tibia nearly in the center. (B) At load acceptance, the lack of conformity between the femoral and tibial components allows the femur to slide forward in "paradoxical" motion.

ligament is the only structure that can prevent paradoxical motion. In the normal knee, the PCL is not tight until at least 45° of flexion, so, unless the ligament has been tensioned too tightly, it cannot prevent the forward sliding. To prevent the sliding, the patient must employ strategies that limit the tendency of the femur to move forward (Fig. 4). First, the patient must limit knee flexion at load acceptance to limit the flexion moment and the force trying to cause anterior sliding. Second, the patient must lean forward to bring the center of mass forward and thus move the line of action of the body mass so that it acts through the knee and does not cause a flexion moment. This type of gait is known as a "quadriceps avoidance gait," because, by employing it, the need for quadriceps contraction in stance phase is limited or avoided altogether [7]. Walking slower, shortening stride length, and spending less time in stance phase also can be means of limiting paradoxical motion.

In a total knee joint designed for posterior cruciate substitution, the anterior sliding of the femur on the tibia can be prevented by the cam and post mechanism of the prosthesis. (Fig. 5A and 5B). Depending on design, this engagement is supposed to take place somewhere between 20° and approximately 65° of flexion, but forward sliding of the femur on the tibia can lead to engagement at the 15° range through some paradoxical motion. The amount of forward sliding that will occur is design-specific, dependent on the shape and position of the cam and spine mechanism of a given design and by the conformity of the condylar parts of the prosthesis. It is also implantation-specific, because the amount of posterior slope on the tibial cut will vary the effect that the anterior part of the prosthesis has in preventing forward sliding. Although PCL-substituting prostheses have been demonstrated to be stable in activities that involve significant flexion (such as deep knee bend) in gait, forward sliding of the femur and other kinematic abnormalities are similar to PCL-retaining prostheses [4].

In the experience of this author, patients do not like uncontrolled AP motion of a TKA. When the AP motion is severe, they complain that the knee feels like "walking on ice." If questioned, they will admit to difficulty getting out of a chair; difficulty ascending, and especially, descending stairs; difficulty walking on uneven ground; and a feeling of instability when performing activities such as playing golf. Our typical total knee scores, however, are not designed to distinguish the effects of AP motion in a total knee; therefore, these same patients will frequently score very well on, for example, the

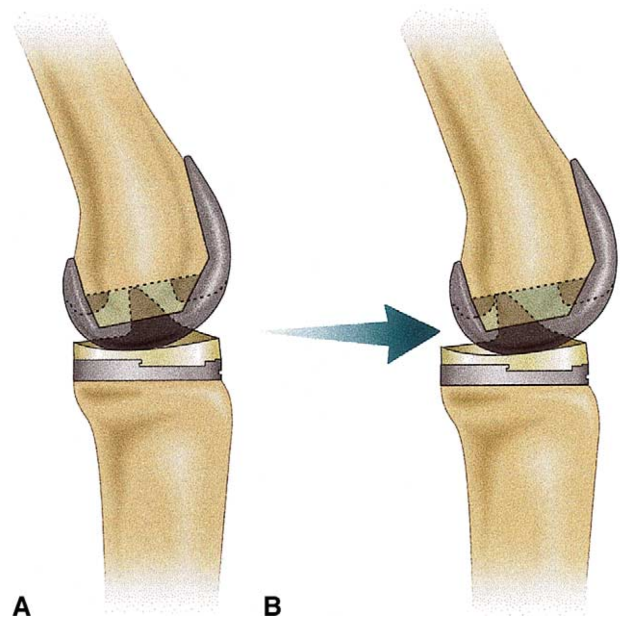

Fig. 5. (A) At the time of load acceptance, a PCL-substituting prosthesis does not have cam and spine engagement. (B) Forward motion of the femoral component can occur until the cam and spine engage. The amount of forward sliding of the femur is dependent on the design of the cam and spine, and, to a lesser degree, the position in which the component was implanted.

Fig. 4. In a "quadriceps avoidance" gait, the knee is allowed to flex only to a limited degree, and the trunk is moved forward. These strategies bring the line of action of the body weight through the center of the knee. The usual flexion moment is eliminated, and thus, the need for quadriceps contraction to counter that moment is eliminated.

Knee Society Score. If our goal is not only pain relief, but also the best possible function, then our total knee joint prostheses should be designed to limit or eliminate "paradoxical" motion.

Recent work on normal kinematics confirms long-published studies that have found that the knee does not work as a crossed-four-bar link. Rather, the knee normally moves with the medial side, staying very nearly stable like a ball-in-socket joint while the lateral side moves front to back, rotating around the center of the medial side [9–11]. A total knee joint prosthesis that is designed to have these same kinematics (a stable medial side combined with a lateral side that accommodates rotation of the tibia around the medial side) through the interaction of a spherical-shaped femoral component and a medially conforming tibial component, not only moves in a pattern like the normal knee, but confers stability like the normal (Fig. 6). At heel strike, the knee is in full extension, and at load acceptance, when the forces acting to cause anterior sliding of the femur on the tibia are greatest, the anterior part of the socket constrains these motions (Fig. 7). In fact, anterior sliding of the femur is constrained throughout the arc of motion from 0° to full flexion.

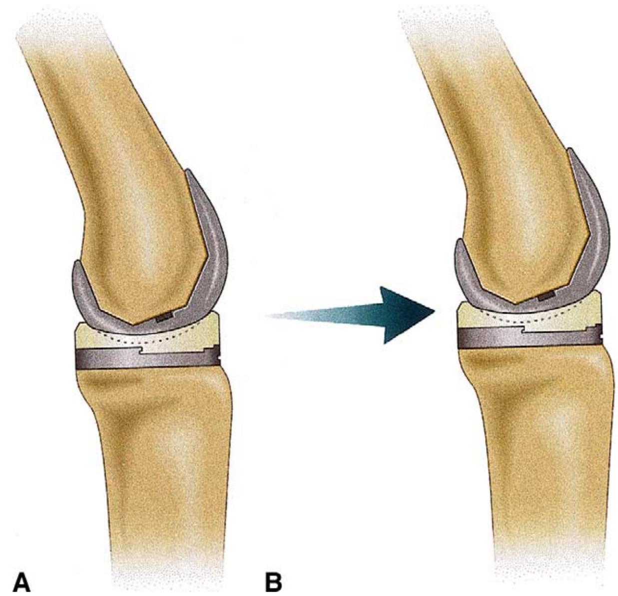

Fig. 7. The conformity of the medial ball-in-socket articulation prevents anterior slide of the femur on the tibia.

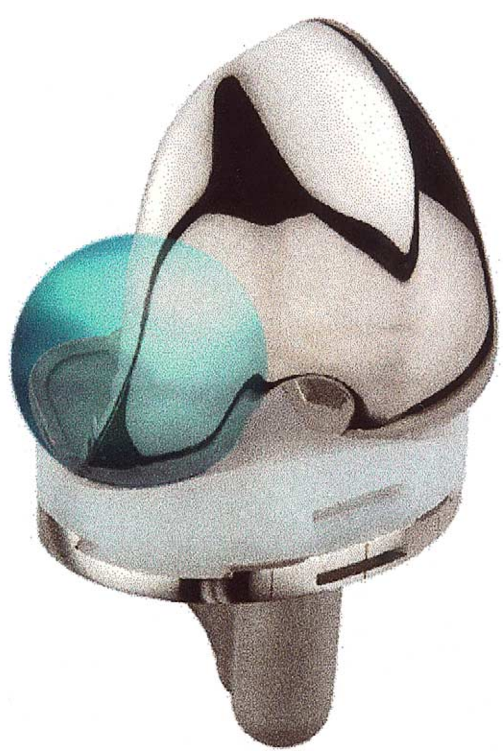

Fig. 6. The Advance Medial Pivot Prosthesis (Wright Medical Technology, Arlington, TN) is designed as a ball-in-socket on the medial side to mimic both the motion and stability of the normal knee. On the lateral side, the tibial component is cut in an arcuate trough to allow rotation of the tibia around the medial side.

In a study of 40 patients from 6 surgeons who had a medial pivot type of total knee on one side and a different type of prosthesis (some PCL-retaining, others PCL-sacrificing and -substituting) on the other, a majority of patients preferred the more stable implant. Although this is certainly not the ideal way to gather data about the differences in function between 2 type of implants, it nonetheless suggests that the patient's perception of function may be improved with an implant that is stable to AP translation throughout the range of motion.

So, to the point of the assigned title, "Well, Almost No Post Required," I reply that the post was a good approximation and that no one can argue with the design that John Insall brought to us. The "post in the middle," however, was a good first approximation that has been made better by moving the post to the medial side and incorporating it into a design that renders the medial side stable to mimic the normal knee.

References

1. Insall JN, Easley ME: Surgical Techniques and Instrumentation in Total Knee Arthroplasty. p. 1553. In Insall JN, Scott WN (eds): Surgery of the knee, ed 3. Churchill Livingstone, New York, 2001

2. O'Connor J, Shercliff T, FitzPatrick D, et al: Geometry of the Knee. p. 163. In Daniel D, Akeson A, O'Connor J (eds): Knee ligaments: structure, function, injury, and repair. Raven Press, New York, 1990
3. O'Connor J, Shercliff T, FitzPatrick D, et al: Mechanics of the knee. p. 201. In Daniel D, Akeson A, O'Connor J (eds): Knee ligaments: structure, function, injury, and repair. Raven Press, New York, 1990
4. Dennis D, Komistek R, Mahfouz M: In vivo fluoroscopic analysis of fixed-bearing total knee replacements. Clin Orthop 410:114, 2003
5. Komistek R, Dennis D: Fluoroscopic analysis of total knee replacement. p. 1695. In Insall JN, Scott WN (eds): Surgery of the knee, ed 3. Churchill Livingstone, New York, 2001
6. Insall JN, Clarke HD: Historic development, classification, and characteristics of knee prostheses. p. 1530. In Insall JN, Scott WN (eds): Surgery of the knee, ed 3. Churchill Livingstone, New York, 2001
7. Andriacchi T: Functional analysis of pre and post-knee surgery: total knee arthroplasty and ACL reconstruction. J Biomech Eng 115:575, 1993
8. Komistek R, Dennis D, Mahfouz M: In vivo fluoroscopic analysis of the normal human knee. Clin Orthop 410:69, 2003
9. Iwaki I, Pinskerova V, Freeman M: The shapes and relative movements of the femur and tibia in the unloaded cadaver knee. J Bone Joint Surg Br 82:1189, 2000
10. Hill P, Vedi V, Williams A, et al: Tibiofemoral movement 2: the loaded and unloaded living knee studied by MRI. J Bone Joint Surg Br 82:1196, 2000
11. Blaha J, Mancinelli C, Simons W, et al: Kinematics of the human knee using an open chain cadaver model. Clin Orthop 410:25, 2003