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Merits of Posterior Cruciate Ligament Substitution in Total Knee Arthroplasty

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Introduction

The controversy regarding posterior cruciate ligament (PCL) retention and substitution is soon to enter its third decade. However, if one carefully considers the long-term follow-up data with either type of implant, it becomes clear that the arguments are primarily theoretical and academic, but clinically speaking, the results are quite comparable. For those of us who have had experience with both techniques, arguing for or against either technique is actually quite simple, particularly when considering there is “scientific” data to support either technique. It is simply being able to “tweak” that data that may help to make an argument on either side of the debate stronger.

This article presents the theoretical arguments in favor of cruciate substitution (Fig. 1). Specifically, I will use biomechanical data, kinematic analyses, histologic studies, gait analyses, and clinical studies to support my bias in favor of posterior cruciate substitution.

At the outset, it is important to clarify that this article focuses specifically on cruciate substitution designs, disregarding cruciate-sacrificing designs (i.e., total condylar designs), even though both require removal of the PCL. The earlier total condylar cruciate-sacrificing total knee arthroplasties (TKA) proved quite durable with a survivorship of approximately 90% percent at 10–15 years [1,2]. Despite the durability of cruciate-sacrificing knees, its designers developed a cruciate-substituting knee, introducing a post and cam mechanism in 1978 to improve motion, prevent posterior subluxation, and enhance kinematic function [3].

Function of the PCL in Normal Knees

The complex concert of motions in the normal knee include not only flexion and extension, but also rolling, sliding, gliding, and rotation [4]. Rollback and rotation are the result of asymmetry between the medial and lateral femoral condyles and variable tension in the anterior cruciate ligament (ACL) and PCL as the knee bends. The unique relationship between the ACL and PCL has been likened to a four-bar linkage construct and is responsible for the complex dynamics observed in the knee as it moves through an arc of motion [5] (Fig. 2).

Femoral rollback is a necessary condition to maximize flexion and avoid impingement of the posterior femur on the posterior tibial lip beyond 105 degrees of flexion. Posterior displacement of the femur also lengthens the quadriceps lever arm, enhancing extensor mechanism power.

The four-bar linkage also provides restraint against anterior and posterior subluxation. The morphology of this linkage system will vary through the arc of motion. It is likely that as the ligaments age and degenerate, the theoretical benefits of the four-bar linkage system deteriorate, altering kinematics of the knee and shifting loads on the articular cartilage. Similarly, in TKA, which now is almost universally performed with ACL sacrifice, the four-bar linkage system is immediately and irrevocably compromised.

Rationale for Posterior Cruciate Substitution

Kinematic arguments

Controlled femoral rollback, for increasing flexion and enhancing quadriceps strength, is a key feature in TKA as well. With the four-bar linkage system disrupted in TKA, retention of the PCL has not created predictable posterior rollback of the femur. Additionally, retention of the PCL has been advocated to allow anterior tibiofemoral contact during extension, which may enhance the heel-strike phase of gait [6].

Unfortunately, the anticipated theoretical benefits of cruciate retention have not been borne out. Using fluoroscopy to study the in vivo kinematics of cruciate-retaining implants, Stiehl et al. [7] demonstrated a consistent posterior tibiofemoral contact point in extension and paradoxical roll forward in flexion which was quite different from fluoroscopic kinematics identified in normal knees. Subsequently, Dennis et al. [8] corroborated the paradoxical anterior femoral slide with PCL-retaining knees and noted more normal kinematics with PCL-substituting designs. These two studies have been the most influential forces in my practice that

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Fig. 1. a-d: Preoperative and postoperative radiographs of a knee in a 74-year-old woman with severe osteoarthrosis and a 25-degree varus deformity. Note large medial and posterior condylar osteophytes and posteromedial tibial bone stock deficiency. Successful TKA with a posterior-stabilized implant. Posteromedial defect was filled with cement reinforced with screws.

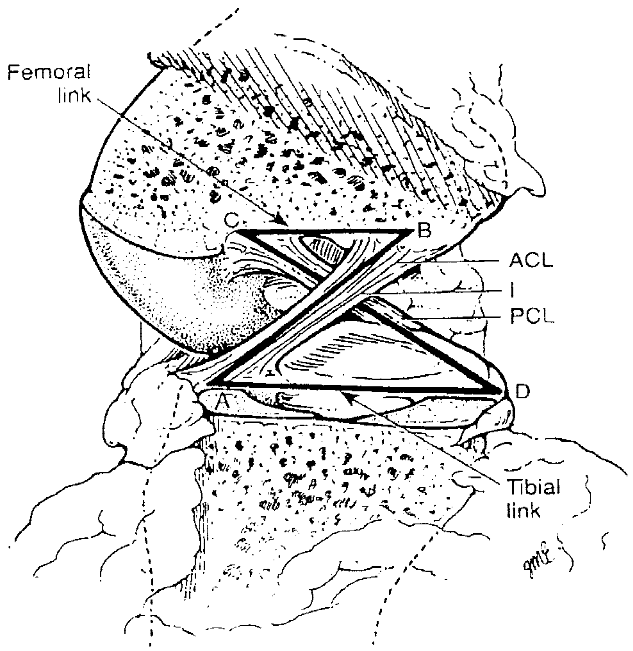

Fig. 2. Schematic of the four-bar linkage system of the knee. (Reprinted with permission from Fu FH, Harner CD, Vince KG (eds). *Knee Surgery.* Baltimore: Williams and Wilkins, 1994.)

have fostered a switch from performing PCL-retaining TKAs to PCL-substituting TKAs.

In a biomechanical study, Mahoney et al. [9] found consistent deficiency in femoral rollback and extensor mechanism strength in both cruciate-retained and cruciate-substituted knees compared to normal controls. The differences were significantly more noticeable in the cruciate-retained knees, with substituted knees more closely reapproximating normal kinematics. They found that femoral rollback was decreased by 36% ($p = 0.004$) with cruciate-retained designs and by 12% ($p = 0.774$) with posterior-stabilized knees. There was a comparable decrease in extensor mechanism strength, 15% ($p = 0.003$) in the cruciate-retained group and 12% ($p = 0.02$) in the substituted group [9].

The posterior-stabilized design, introduced in 1978, consisted of a polyethylene tibial post that articulated with a femoral cam to substitute for the PCL and enhance femoral rollback. Some have expressed concern that the post and cam mechanism of posterior cruciate-substituting TKAs may potentially accelerate prosthesis loosening because of increased stresses at the implant interfaces. However, in properly designed implants, the resultant net force vectors tend to be directed distally, resulting in compressive rather than shear forces (Fig. 3) [3]. This scenario seems to be supported clinically, based on long-term data of posterior substituting knees.

Gait analysis

Gait analysis studies have failed to clearly demonstrate significant benefits of one design over another. A well-cited study by Andriacchi et al. [10] suggested that more normal gait was achieved in cruciate-retaining knees with greater abnormalities noted during stair climbing. The forward lean commonly observed in patients with posterior-stabilized knees was considered to result from relative quadriceps inefficiency from the loss of femoral rollback when the PCL was sacrificed. However, the authors found abnormalities in gait with level walking regardless of the implant used, including shorter stride length, reduced midstance flexion, and abnormal patterns of flexion and extension moments at the knee. Some of Andriacchi et al.'s findings have been refuted. Stiehl et al. [7] and others [8,11] have identified improved femoral rollback in cruciate-substituting knees with paradoxical roll forward in cruciate-retained knees.

Gait analysis performed by Wilson et al. [12] in 16 patients with posterior-stabilized implants failed to show any significant differences between replaced and normal knees with regard to studied gait variables, range of motion during stair climbing, or in isokinetic muscle strength testing. A direct comparison of bilateral paired posterior cruciate-retaining and posterior cruciate-substituting TKAs has not yet been published. However, Becker et al. [13], evaluating clinically bilateral paired cruciate-retaining and cruciate-substituting knees, found no clinical advantage of one design over the other, or differences in patient preference for stair climbing.

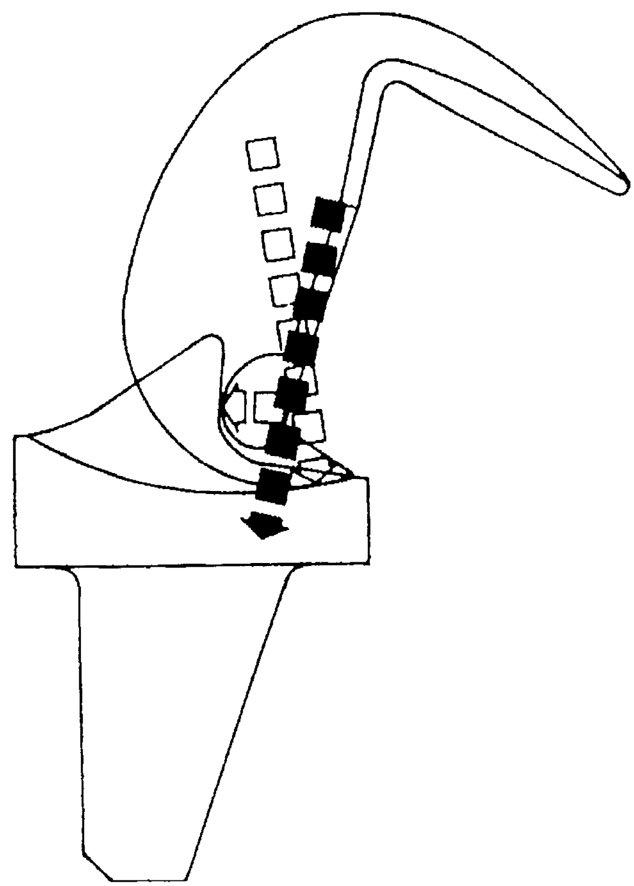

Fig. 3. Interaction of the post and cam mechanism of posterior cruciate- substituting TKA may enhance femoral rollback. In properly designed implants, the resultant net force vectors tend to be directed distally, resulting in compressive rather than shear forces. (From Insall et al. [3] by permission.)

Wear

Early on, cruciate-retaining knees employed flat articulating tibial surfaces because of the concern of a potential "kinematic conflict" that might result from femoral rollback against a posterior lipped or curved insert [14]. These flat inserts were exposed to high contact stresses and edge loading over a limited contact area, resulting in excessive rates of wear that were not seen to the same extent with the conforming inserts used in cruciate-substituting designs [15]. This accelerated wear in cruciate-retained knees has been minimized by increasing the conformity of polyethylene inserts and by appropriately recessing the PCL. Additionally, the kinematic conflict that Insall et al. [3] anticipated will likely not bear out considering the paradoxical slide forward that has been observed on the inverse perspective fluoroscopic studies by Stiehl et al. [7] and Dennis et al. [8] (although this phenomenon may cause other problems). Employing the concept of cruciate supplementation, with conforming inserts and cruciate recession, motion has been improved and the development of radiolucent lines reduced [16]. Conforming inserts, correction of coronal and sagittal plane deformity, optimal material properties and implant design, and well-performed TKAs are critical to minimize polyethylene wear in the long-term, regardless of the implant type used.

PCL Strain and Histologic Degeneration

The fallacy of cruciate balancing

Proponents of cruciate retention have argued forcefully that balancing or recessing the PCL may eliminate excessive forces in the PCL, control anteroposterior stability, and ensure reasonable flexion arcs. Strain gauge studies, however, have raised concern about our ability to accurately and reproducibly balance the PCL. Two independent studies [17,18] identified considerable variability in strain values with variable cruciate release. Additionally, the strain variability did not appear to be affected by insert contour or slope of the tibial cut [18]. In one study, of eight specimens tested [18], three ligaments were noted to be excessively taught after knee arthroplasty, three were slack, and two returned to baseline. In the other study, of 10 knees studied [17], six cruciate ligaments were considered lax, three were tight, and only one normalized. The implications of these studies are uncertain in the clinical realm, but they conjure questions about the predictability of "cruciate balancing," raising the dual concern of both accelerated wear and loss of motion when the ligament is "too tight" or conversely of flexion instability when the ligament is "too lax." These problems are not generally encountered with posterior-substituting designs.

Propioception

The argument has been offered that retention of the PCL may be important in optimizing propioception of the knee after joint arthroplasty. However, Kleinbart et al. [19] observed, histologically, age-related and arthritis-related degeneration of the nerve fibers within the PCL. Using a computer-assisted image analyzer, Franchi et al. [20] demonstrated a 50% reduction in the percentage of nerve receptors in the PCL of patients with osteoarthrosis compared to age-matched controls.

A variety of clinical studies have failed to show any propioceptive benefits of cruciate-retained knees or cruciate-substituting knees. Simmons et al. [21] found no difference in threshold to detection of passive motion in cruciate-retaining versus cruciate-substituting knees. However, in the most severe cases of osteoarthritis, patients with cruciate-substituting TKAs performed significantly better than those with cruciate-retaining total knees. Becker et al. [13] found no difference between cruciate-retaining and cruciate-substituting knees in patients who had undergone bilateral paired retaining and stabilized knees. The patients had equivalent postoperative function and preferences were split.

Clinical Results

The long-term results of PCL-substituting total knee replacements have established this technique as the "gold standard" against which other techniques are compared. The theoretical concerns about stress transfer to the prosthesis-bone or prosthesis-cement interfaces in cruciate-substituting knees have not been borne out. Loosening rates in substituting knees have been extremely low. Stern and Insall, reporting on the senior author's experience with one posterior-stabilized knee prosthesis at a mean follow-up of 13 years, found that 87% of 180 knees studied were clinically rated as good or excellent. Survivorship to revision was 94% with a 0.4% average annual failure rate [22]. Scuderi et al. [23] demonstrated that at a mean follow-up of 10 years, 97% of 289 all polyethylene posterior-stabilized tibias were considered good or excellent. At a mean 7-year follow-up, survivorship of 917 metal-backed posterior-substituted tibial components was 99%.

Average motion of posterior cruciate-substituting knees has generally been in excess of 110 degrees. This may be more difficult to achieve in cruciate-retaining knees. Hirsch et al. [24] compared the results of three groups of patients. One-third (77 patients) were treated with Press Fit Condylar total knee replacements with complete posterior cruciate release. A second group of 80 patients were treated with cruciate-retaining Press Fit Condylar knees. The third group of 85 patients was treated with posterior cruciate-substituting knees using the Insall-Burstein II TKA. At a minimum follow-up of 2 years, there were no significant differences found among the groups, except in range of motion. The PCL-retaining and PCL-sacrificing groups had 102 degrees and 103 degrees of motion, respectively. The PCL-substituting design averaged 112 degrees and was the only group in which the lower 95% confidence limit was greater than 90 degrees of flexion. Others [13] have not shown significant differences in range of motion between cruciate-retained and cruciate-substituted knees.

There are a variety of special circumstances in which accelerated failures have been observed in cruciate-retained knees. In these situations, posterior cruciate substitution may be more desirable.

Severe varus or valgus deformities

Not only is the PCL a tether that may compound imbalance between the flexion and extension spaces, it may also become contracted in coronal plane deformities. Scott and Volatile [25] have noted that in knees with severe angular deformity, the PCL may act as a tether and impede proper medial and lateral balancing despite appropriate soft tissue release on the concavity of the deformity. In such cases, cruciate balancing and recession may be necessary. In this special subset of patients, however, long-term results with PCL-retaining implants may be compromised. Laskin [26] reported that at 10 years, patients with posterior cruciate-substituting implants fared better than those with cruciate-retained designs in the setting of fixed varus deformity of at least 15 degrees. Specifically, he found an increased incidence of pain, interface radiolucencies, flexion arc limitations, and the need for revision when retaining the PCL in this subset of patients. Lonner and Scott [27] found that while correction of severe varus or valgus deformity is possible, nearly complete recession of the cruciate ligament may be necessary, and this may in fact increase the rate of complications. Evaluating two sets of patients, one with a minimum varus alignment in excess of 10 degrees and the other with a minimum valgus alignment of 15 degrees, using a cruciate-retaining knee with a sagittally curved or posterior lipped tibial insert, symptomatic coronal plane instability developed in 5% and flexion instability in 3%. Range of motion was comparable to that seen in standard cruciate-retaining and cruciate-substituting knees. Nonetheless, the incidence of these complications at a mean follow-up of 4 years is quite concerning.

These problems may be avoided with PCL substitution. However, Miyasaka et al. [28] observed a 24% incidence of coronal plane instability at 13.2 years after TKA with PCL substitution in 108 knees with preoperative valgus alignment in excess of 10 degrees, pointing to the inherent complexity encountered in this subset of patients.

Rheumatoid arthritis

Laskin critically evaluated his experience treating patients with rheumatoid arthritis with cruciate ligament retention and substitution. At a mean follow-up of 8.2 years, patients treated with cruciate retention had an increased risk of posterior instability and recurvatum deformity with an increased revision rate. Late attrition and rupture of the PCL may result in incapacitating flexion instability, which would be prevented with posterior cruciate substitution [29].

Rodriguez et al. [30] reported on 104 posterior-stabilized TKAs in patients with class 3 and 4 rheumatoid arthritis at an average follow-up of 12.7 years. Eighty-one percent were rated as good or excellent, with a survivorship of 91%.

Postpatellectomy

The patella represents an important structure for enhancing the extensor moment arm in both the native and replaced knee. The extensor mechanism also serves to stabilize the tibia from posterior instability. After patellectomy, both of these functions are lost. Paletta and Laskin [31] reported on their experience with cruciate retention and substitution after patellectomy. Using cruciate-retaining knees, the authors reported a very high rate of anteroposterior instability, recurvatum, and loss of active extension, compared to cruciate-substituted knees. It seems that in these patients, the post and cam mechanism of the PCL-substituting knee may provide significant stability and enhance the lever arm for quadriceps function.

Complications Unique to Cruciate-Substituting Knees

PCL substitution is by no means a panacea, nor is it free of risk. Resection of the PCL will immediately increase the flexion gap approximately 2–4 mm. A compensatory increase in the extension space with a more proximal resection of the distal femur than would otherwise be necessary if the cruciate ligament was preserved is necessary. This will result in elevation of the joint line by an average of 2–4 mm. The biomechanical implications of an elevated joint line is an important issue that should be considered. It is likely that altering the joint line less than 8 mm in either direction may be well tolerated [32]. Singerman et al. [33] found that elevation of the joint line up to 10 mm may actually reduce patellar strain by as much as 3% per millimeter of displacement. Obviously, joint line elevation should not be excessive. Significant patella baja may cause retropatellar impingement on the tibial insert, resulting in pain and flexion loss. While some degree of joint line elevation is inevitable in PCL-substituting TKA, it is generally well tolerated; joint line elevation should not be accepted in PCL-retaining knees, as this will place excessive stress on the PCL.

The so-called “patellar clunk syndrome” is another complication unique to posterior-substituting knee arthroplasties. Synovium or scar adherent to the undersurface of the quadriceps may catch within the box of the intercondylar notch of the femoral component in flexion, creating the characteristic “clunk” as the knee is extended [34]. The syndrome can be prevented by careful dissection and removal of synovial tissue and scar from the posterior aspect of the quadriceps tendon, particularly focusing on the 2 or 3 cm just proximal to the tendon’s insertion point on the proximal pole of the patella. Additionally, avoiding proximal overhang of the patellar component may lessen the risk. Patellar clunk may be quite disturbing and may be successfully treated with arthroscopic or open debridement (Fig. 4).

Another complication that tends to be unique to the posterior-stabilized knee system is the risk of “jumping of the post” and locking of the knee when the flexion gap is loose (Fig. 5). This problem can be avoided by careful balancing of the flexion and extension spaces and avoiding extreme

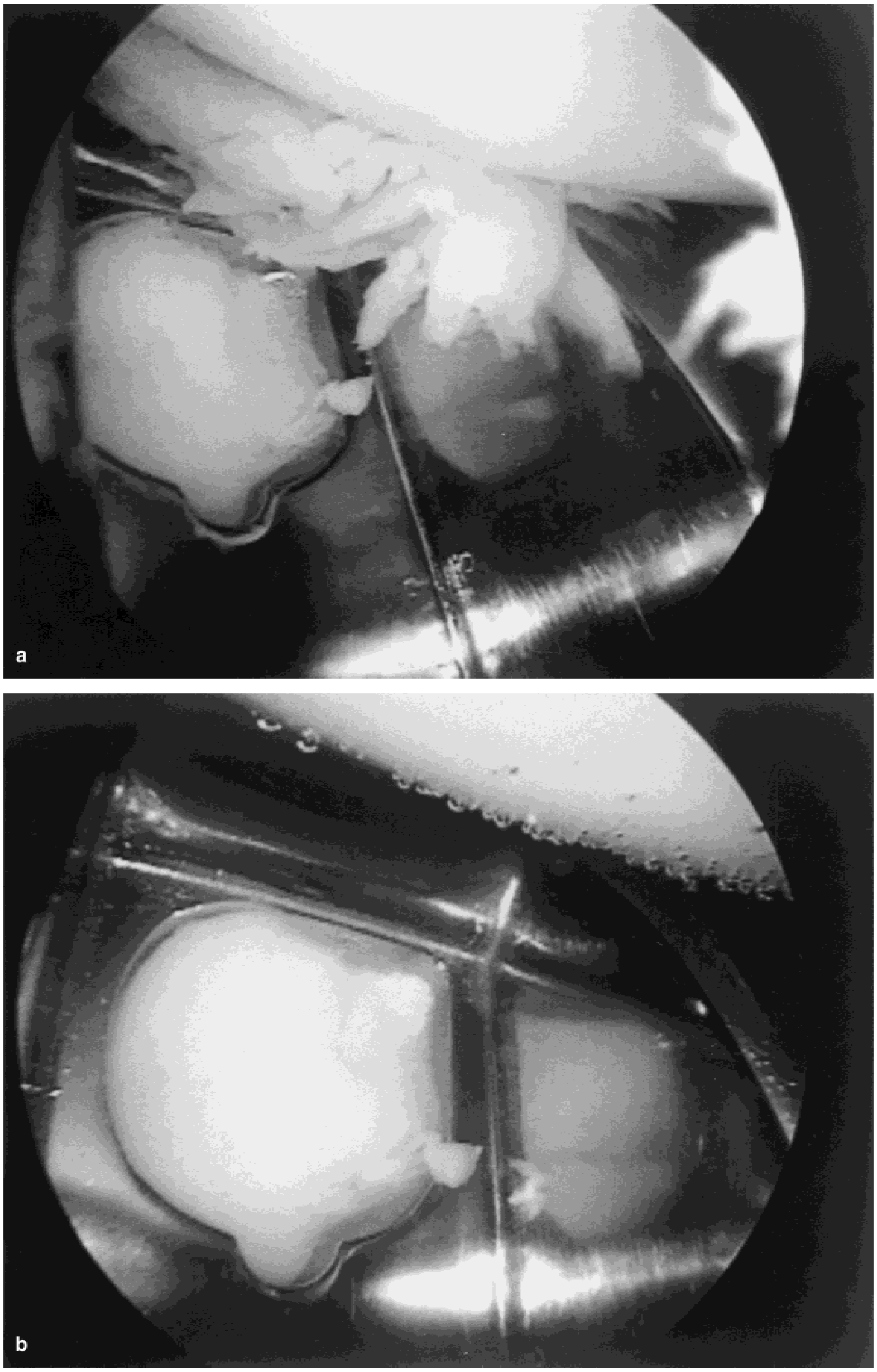

Fig. 4. a, b: Arthroscopic photographs of impingement of soft tissue within the femoral housing beyond 60 degrees of flexion that resulted in "patellar clunk." After successful arthroscopic debridement, the patient's symptoms resolved.

rotary instability. An insert exchange may sometimes suffice, although this may leave a residual flexion-extension mismatch. Often, revision arthroplasty with a more constrained implant is necessary. Finally, the central intercondylar box cut may create stress risers at the edges of the box, predisposing to fracture of the femoral condyle. This is particularly true in small patients with compromised bone stock, such as in rheumatoid arthritis when an overly sized intercondylar box is necessary. Several manufacturers are now producing posterior-stabilized knees with small intercondylar box dimensions to lessen the risk of this complication.

Summary

The long-term results of PCL-substituting TKAs are predictable. Long-term survivorship, stability, and clinical success may be more easily attainable in substituting designs than in cruciate-retaining designs. This article detailed many of the theoretical arguments in favor of cruciate sub-

Fig. 5. Lateral radiograph of a posterior-stabilized knee with laxity in flexion that resulted in "jumping" of the post, resulting in locking of the knee. This was treated with revision TKA.

stitution and against cruciate retention. Regardless of the design utilized however, results may be compromised by improper surgical technique, poor implant designs, or material flaws.

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