Role of the Posterior Cruciate Ligament in Total Knee Arthroplasty

Mark W. Pagnano, MD, Fred D. Cushner, MD, and W. Norman Scott, MD

Abstract

Since the introduction of condylar knee designs, total knee arthroplasty has become a remarkably successful and durable procedure. Improvements in instrumentation systems, fixation, and patellar resurfacing have been widely applied and have made total knee arthroplasty a reproducible procedure. The appropriate role for the posterior cruciate ligament in total knee arthroplasty, however, continues to be debated. Proponents of both cruciate substitution and cruciate retention can point to excellent clinical and radiographic results in the literature with knee designs of both types. Recent research findings in the areas of biomechanics, histology, and gait analysis, combined with refinements in intraoperative technique, have further sharpened the focus of the posterior cruciate ligament debate.

J Am Acad Orthop Surg 1998;6:176-187

Few controversies in orthopaedic surgery have been argued as fervently or for as long as the debate over the role of the posterior cruciate ligament (PCL) in total knee arthroplasty (TKA). The excellent long-term results of TKA performed with use of cemented condylar knee components of cruciate-sacrificing, cruciate-substituting, and cruciate-retaining implants ensures that this debate will continue.[1-3] Some in the orthopaedic community have grown tired of the PCL controversy and may feel that "a condylar knee is a condylar knee." Others have pursued the issue further and have presented important new data from the biomechanics,[4,5] histology,[6] and gait-analysis laboratories,[7] the radiology suite,[8] and the operating room.[9,10]

A portion of the literature regarding the role of the PCL in TKA has been framed inappropriately. A number of earlier studies compared cruciate-retaining knees with cruciate-sacrificing total condylar knees. Although the cruciate-sacrificing total condylar knee has proved very durable, with a rate of survivorship free of revision of 90.8% at 21 years, its developers quickly recognized the limitations of the design and moved to increase range of motion, improve stair-climbing ability, and prevent posterior subluxation by introducing the concept of cruciate substitution, in the form of a post-and-cam mechanism, with the posterior-stabilized condylar knee in 1978.[1] Since the introduction of the posterior-stabilized design, few surgeons have advocated routine sacrifice of the PCL without prosthetic substitution.

This article will focus on the relative merits of the cruciate-retaining and posterior-stabilized designs. Each of the major areas of discussion will contain a review of the theoretical concerns and early clinical data; a summary of the latest research, with particular attention to direct comparisons of cruciate-retaining and posterior-stabilized designs; and a look at areas of agreement and future research directions.

Historical Overview

Many present-day total knee implants are derivations of the total condylar prosthesis, which was introduced in 1974.[1] That device was a cemented, cruciate-sacrificing, tri-

Dr. Pagnano is Senior Associate Consultant, Department of Orthopedic Surgery, Mayo Clinic and Mayo Foundation, Jacksonville, Fla. Dr. Cushner is Director, Insall-Scott-Kelly Institute, Beth Israel Medical Center, New York, NY. Dr. Scott is Chairman, Department of Orthopedic Surgery and Director, Insall-Scott-Kelly Institute.

Reprint requests: Dr. Pagnano, Department of Orthopedic Surgery, Mayo Clinic Jacksonville, 4500 San Pablo Road, Jacksonville, FL 32224.

The authors or the departments with which they are affiliated have received something of value from a commercial or other party related directly or indirectly to the subject of this article.

compartmental prosthesis, with a relatively conforming tibiofemoral articulation. The total condylar prosthesis relied on soft-tissue balance in flexion and extension and moderate conformity of the tibiofemoral articulation for stability, as the PCL is excised without substitution. In subsequent years, the terms "total condylar" and "condylar" have become generic terms for any surface-replacement knee design that accommodates patellar resurfacing and includes a one-piece tibial component with a central stem or keel.

To improve range of motion and stair-climbing ability and to prevent posterior subluxation of the tibia, the total condylar prosthesis was modified to the posterior-stabilized design in 1978. The posterior-stabilized femoral component incorporates a cam designed to articulate with a central polyethylene post arising from the tibial component (Fig. 1). This post-and-cam mechanism acts as a functional substitute for the PCL. The original total condylar and posterior-stabilized tibial components were all-polyethylene designs. In late 1980, metal backing was added to the tibial component, and by late 1981 the metal-backed tibial component was exclusively used at the Hospital for Special Surgery. The posterior-stabilized design was subsequently modified to a modular posterior-stabilized design in 1987. The tibiofemoral articulation in both the posterior-stabilized and the modular posterior-stabilized designs has remained moderately conforming in both the frontal and sagittal planes.

Cruciate-retaining knee designs of various types can be traced back to the 1940s. Gunston's work in the 1960s with the polycentric knee incorporated early attempts to promote femoral rollback and a moving instant center of rotation and was designed to be inserted with cement. The Mayo Clinic experience with the bicondylar version of the polycentric knee provided the impetus for the development of the geometric knee. These early knee designs were supplanted shortly thereafter by condylar knee designs, such as the duopatellar and posterior-cruciate condylar implants, which included an anterior femoral flange for articulation with a resurfaced patella. Although the posterior-cruciate condylar implant maintained a moderately conforming tibiofemoral articulation, similar to that of the total condylar implant, many of the subsequent cruciate-retaining knee designs did not.

The experience with the geometric knee, which retained the PCL and was conforming in the sagittal plane, suggested that so-called kinematic conflict would occur in flexion: the PCL tightens above 90 degrees, which encourages femoral rollback, but because of the posterior lip of the tibial component, the femur rolls up this inclined plane, leading to further tightening of the PCL. In an effort to promote more normal knee kinematics, particularly femoral rollback, cruciate-retaining designs of the early 1980s moved away from conformity at the tibiofemoral articulation. Relatively high contact stresses resulted from this lack of conformity, however, and when these nonconforming designs were coupled with thin and heat-pressed polyethylene inserts, reports of marked polyethylene wear with TKA emerged.

Through the late 1980s and early 1990s, polyethylene wear became the predominant concern in both hip and knee arthroplasty. The superior wear characteristics conferred by moderate conformity in both the coronal and sagittal planes became recognized, and we have witnessed the reemergence of moderate conformity in conjunction with cruciate-retaining knee designs. Advocates of cruciate-retaining designs have chosen to address the problem of kinematic conflict by means of surgical technique, employing selective release or recession of the PCL, rather than through further changes in implant design.

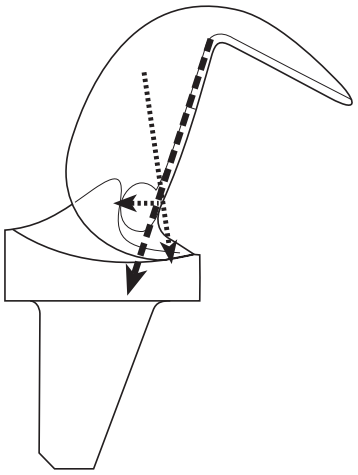

Fig. 1 The introduction of a tibial post designed to interact with a cam on the femoral component has allowed the substitution of PCL function and promotion of rollback of the femur on the tibia in flexion. Because of the design characteristics of this interaction, the net vector of forces passes distally, leading to compression at the bone-cement-prosthesis interface. (Adapted with permission from Insall JN, Lachiewicz PF, Burstein AH: The posterior stabilized condylar prosthesis: A modification of the total condylar design—Two to four-year clinical experience. *J Bone Joint Surg Am* 1982;64:1317-1323.)

Kinematics

Earlier Thoughts and Data

Preservation of the PCL in TKA has been proposed as a means to reproduce more normal knee kinematics, preserve anatomic femoral rollback, and increase knee range of motion.[2,3,10] In the normal knee, femoral rollback moves the tibio-

femoral contact point posteriorly and results in a 30% increase in the quadriceps lever arm. By increasing quadriceps efficiency, femoral rollback may improve the ability to climb stairs. On the basis of both anatomic and theoretical models, several investigators have stated that femoral rollback will occur with cruciate-retaining knee designs. Retention of the PCL has also been advocated as a means of preserving anterior tibiofemoral contact during extension, which may be important during the heel-strike phase of gait.[3]

The kinematics of the posterior-stabilized knee are predictable and are dictated by the conforming geometry of the tibiofemoral articulation and the interaction of the tibial post and cam.

Newest Knowledge

Stiehl et al[8] used fluoroscopy to study the in vivo kinematics in 5 normal knees and 47 knees with cruciate-retaining implants of five different designs. During a single-stance deep knee bend, normal kinematics were not reproduced in any of the cruciate-retaining knees. In contrast to the normal knee, cruciate-retaining TKAs demonstrated a tibiofemoral contact point that was posterior in extension and translated anteriorly with knee flexion. While the normal knees in that study demonstrated smooth motion during the flexion cycle, the cruciate-retaining TKAs had a discontinuous or "jerky" motion.

A subsequent study by Dennis et al[11] also showed that cruciate-retaining designs demonstrated paradoxical anterior femoral translation with knee flexion. Those authors were concerned about the role of this paradoxical femoral translation in promoting premature polyethylene wear in cruciate-retaining implants (Fig. 2). They did note that posterior-stabilized implants more closely replicated normal knee kinematics, but that neither cruciate-retaining nor posterior-stabilized designs fully duplicated normal posterior femoral rollback.

The biomechanical study of Mahoney et al[4] suggested that both cruciate-retaining and posterior-stabilized knee designs result in less femoral rollback and less quadriceps efficiency than occurs in the normal knee. In that study, femoral rollback was decreased by 36% (P=0.004) with cruciate-retaining designs and by 12% (P=0.774) with posterior-stabilized designs. Extensor mechanism efficiency declined by 15% (P=0.003) and 12% (P=0.02), respectively. Those authors were surprised by the increased rollback of the posterior-stabilized design relative to the cruciate-retaining design and expressed disappointment with the consistent loss of extensor mechanism efficiency seen with cruciate-retaining designs.

Current Consensus and Controversy

Ritter et al[12] and Scott and Thornhill[10] have emphasized the role of partial PCL release or recession in achieving balance of the PCL. What role this technique, particularly in conjunction with more conforming tibial inserts, will have on the kinematics of the cruciate-retaining knee remains unstudied.

Range of Motion

Earlier Thoughts and Data

A number of researchers have evaluated the range of motion obtained with various total knee designs[9,12-33] (Table 1). The original cruciate-sacrificing total condylar design produced a mean maximum flexion of 90 to 95 degrees, which is near the theoretical limit for a knee lacking femoral rollback.[1,14-17] The posterior-stabilized design with a post-and-cam mechanism subsequently has allowed flexion to improve to a mean of 105 to 115 degrees.[9,21,22,25,26,34,35] Early results with cruciate-retaining devices also demonstrated an improvement over the cruciate-sacrificing total condylar design, with a mean maximum flexion of 100 to 110 degrees.[2,9,29,33]

Newest Knowledge

One prospective series of 242 TKAs compared cruciate-retaining, cruciate-sacrificing, and posterior-stabilized knee designs.[9] The knees with posterior-stabilized implants in that study demonstrated a mean range of motion (112 degrees) that was significantly greater than that obtained with the cruciate-retaining (104 degrees) and cruciate-sacrificing total condylar (103 degrees) implants. In addition, the posterior-stabilized knee group was the only group in which the 95% confidence limit for mean motion was above 90 degrees.

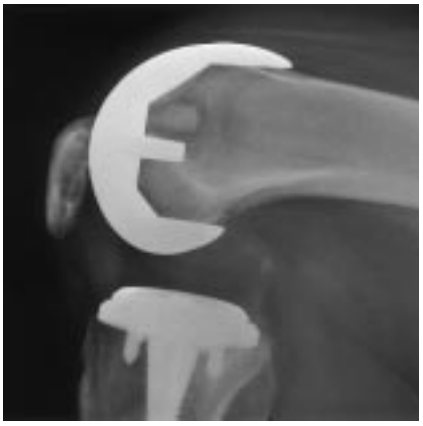

Fig. 2 Although preservation of the PCL has been proposed as a means of promoting femoral rollback in TKA, paradoxical femoral roll-forward can be seen in this cruciate-retaining knee.

Table 1
Reported Range of Motion for Three Types of Total Knee Designs*

Total Knee Design and Study	Follow-up	Design	No. of Knees	Flexion, degrees	Good or Excellent Results, %	Survivorship
Cruciate-sacrificing						
Hirsch et al[9]	2.7 yr	Total condylar	77	103	. . .	. . .
Font-Rodriguez et al[13]	Survivorship	Total condylar	215	. . .	. . .	91% at 21 yr
Goldberg et al[14]	9 yr	Total condylar	109	101	64	. . .
Insall et al[15]	6.5 yr	Total condylar	100	89	94	. . .
Ranawat[16]	5-10 yr	Total condylar	100	96	91	. . .
Ranawat et al[17]	13.2 yr	Total condylar	62	99	92	94% at 15 yr
Scuderi et al[18]	Survivorship	Total condylar	224	. . .	. . .	91% at 10 yr and 15 yr
Cruciate-substituting						
Aglietti et al[19]	5.5 yr	Insall-Burstein	73	96	93	. . .
Emmerson et al[20]	12.7 yr	Kinematic stabilizer	109	98	. . .	95% at 10 yr 87% at 13 yr
Font-Rodriguez et al[13]	Survivorship	Insall-Burstein				
		All-polyethylene	265	. . .	. . .	94% at 16 yr
		Metal	2,036	. . .	. . .	98 % at 14 yr
Hanssen and Rand[21]	3 yr	Kinematic stabilizer	79	101	85	. . .
Hirsch et al[9]	2.7 yr	Insall-Burstein II	85	112	. . .	. . .
Insall et al[22]	2-4 yr	Insall-Burstein	118	115	97	. . .
Insall et al[23]	3.5 yr	Insall-Burstein	303	112	94	. . .
Rand and Ilstrup[24]	Survivorship	Multiple designs	. . .	. . .	. . .	97% at 5 yr
Ranawat et al[25]	4.8 yr	Press-fit condylar	125	111	93	97% at 6 yr
Stern and Insall[26]	10 yr	Insall-Burstein	289	. . .	86	94% at 13 yr
Cruciate-retaining						
Dennis et al[27]	11 yr	Cruciate condylar	42	104	92	. . .
Hirsch et al[9]	2.7 yr	Press-fit condylar	80	104	. . .	. . .
Lee et al[28]	9 yr	Cruciate condylar	144	106	95	. . .
Malkani et al[29]	10 yr	Kinematic condylar	119	105	87	96% at 10 yr
Rand[30]	10 yr	Cruciate condylar	78	102	93	96% at 10 yr
Rand and Ilstrup[24]	Survivorship	All with metal-back tibias	3,907	. . .	. . .	91% at 10 yr
Ritter et al[12]	1 yr minimum	Anatomic graduated				
		PCL recessed	78	114	. . .	. . .
		PCL not recessed	82	107	. . .	. . .
Ritter et al[31]	Survivorship	Cruciate condylar	394			97% at 12 yr
Rosenberg et al[32]	3.5 yr	Miller-Galante	116	105	88	6% revision rate
Scott and Thornhill[10]	2 to 7 yr	Press-fit condylar				
		(PCL recessed)	100	112	. . .	. . .
Weir et al[33]	12 yr	Kinematic condylar	208	. . .	. . .	92% at 10 yr 87% at 12 yr

*Ellipsis points indicate that data are not available.

Recent attention has been given to balancing or recessing the PCL in cruciate-retaining TKA[10,12] (Fig. 3). Several large studies of cruciate-retaining implants report mean flexion of 110 to 115 degrees with the use of recession techniques.[10,12]

Current Consensus and Controversy

With careful attention to balance of the flexion space, both cruciate-retaining and posterior-stabilized implants appear capable of reliably producing mean maximum flexion of 110 to 115 degrees.

Wear

Earlier Thoughts and Data

The cruciate-sacrificing total condylar design employed a moderately conforming tibiofemoral articulation, in part to confer a degree of anteroposterior stability to the implant.[1] Early concerns with this design focused on the increase in shear force seen with sacrifice of the PCL and the effect of shear and frictional forces on the conforming articulation and the prosthesis-bone interface. Most, but not all, cruciate-retaining knee designs have utilized less conforming articular geometries (Fig. 4, A). Designs that are "flat on flat" in the coronal plane are subject to edge loading (Fig. 4, B). Designs that are relatively nonconforming in the sagittal plane are subject to high contact stresses.

Sagittal-plane conformity was for some time thought to be ill advised in conjunction with use of cruciate-retaining designs. The concern was that curved or dished tibial inserts would act as a restraint against femoral rollback and result in kinematic conflict with progressive tightening of the PCL in flexion[10] (Fig. 4, C).

Newest Knowledge

Most reports in the literature regarding polyethylene wear in TKA involve cruciate-retaining designs with a flat-on-flat articulation, thin tibial inserts, and/or heat-pressed polyethylene.[36,37] Overtightening of the PCL at the time of arthroplasty has also been implicated as the cause of marked posteromedial polyethylene wear in cruciate-retaining knees.[36] Most advocates of cruciate-retaining designs now emphasize intraoperative techniques to balance the PCL and specifically to avoid overtightening of the ligament.[2,10,12] Total knee designs that retain the PCL but employ a moderately conforming articular geometry, as seen in the posterior-cruciate condylar design, have had few problems with excessive polyethylene wear.[2,3] Polyethylene wear has not proved to be a major clinical problem when moderately conforming articular surfaces are combined with a posterior-stabilized knee design.[25,34]

Current Consensus and Controversy

The concept of cruciate-supplementing TKA employing relatively

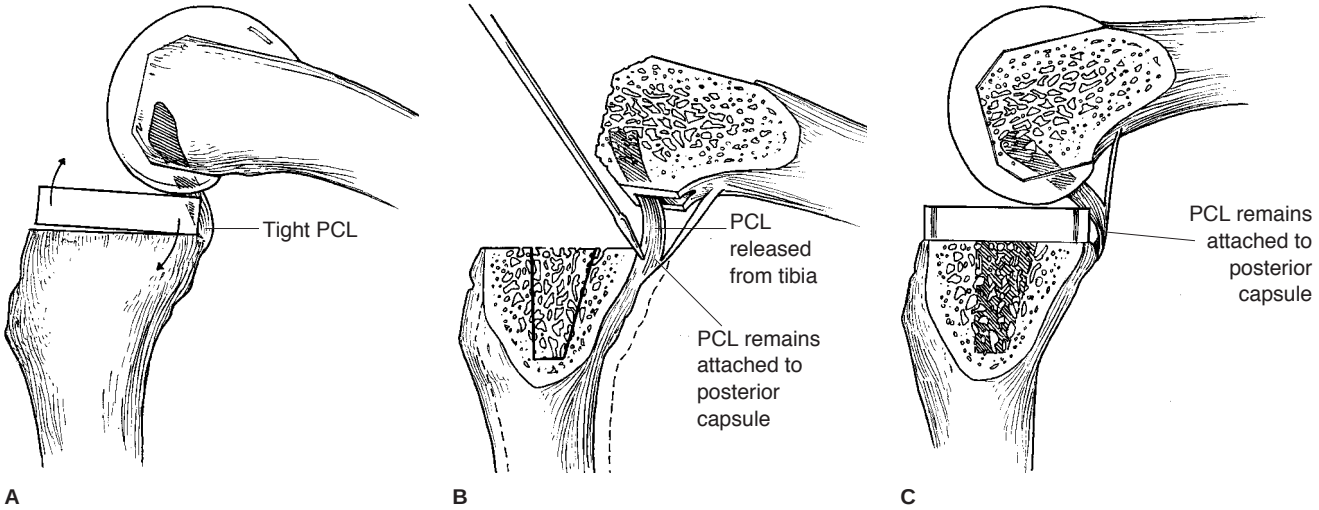

Fig. 3 **A,** An excessively tight PCL can be demonstrated intraoperatively by the tendency of a stemless tibial trial component to "book open" with knee flexion. **B,** When this occurs, most authors recommend that the PCL be balanced or be recessed if it is to be retained. Recession can be carried out by serially sectioning PCL fibers from their insertion on the tibia. **C,** Much of the PCL attaches distal to the articular surface and will remain in continuity with the joint capsule. (Adapted with permission from Insall JA, Windsor RE, Scott WN, Kelly MA, Aglietti P (eds): *Surgery of the Knee*, 2nd ed. New York: Churchill-Livingstone, 1993, vol 2, p 753.)

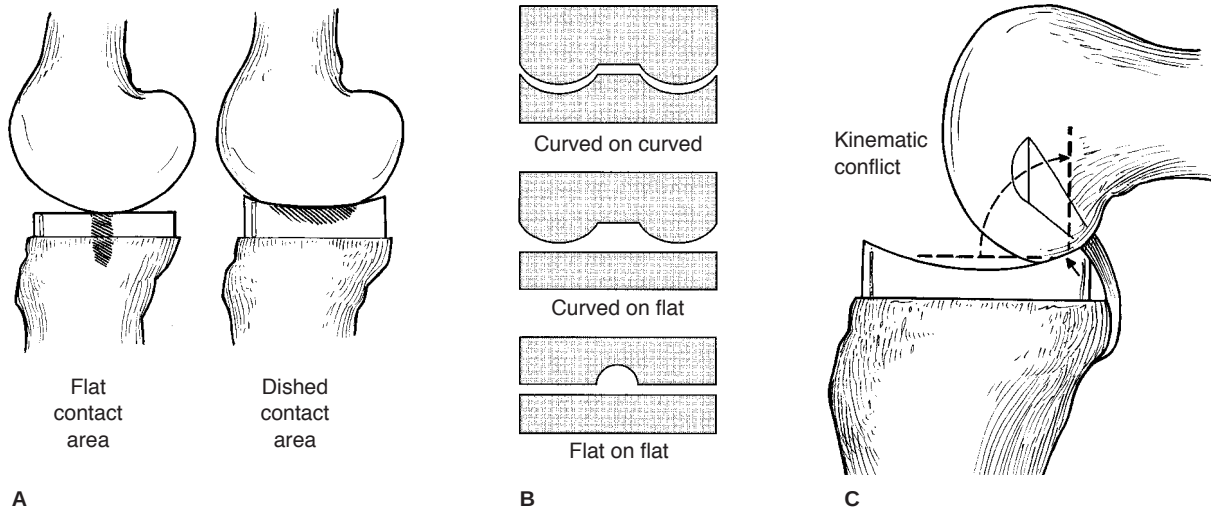

Fig. 4 **A,** The moderately conforming dished articulation provides a much greater contact area and hence lower contact stresses on the polyethylene surface. **B,** The more conforming articulations have larger contact areas and lower peak stresses at the polyethylene interface. In regard to coronal plane geometry, curved-on-curved articulations provide the best contact conditions, and curved-on-flat designs provide the worst. The flat-on-flat articulation provides a large contact area but is subject to problems from edge loading during twisting and leaning movements, which load one side of the joint or the other. **C,** Kinematic conflict may occur when the PCL is retained in conjunction with a conforming, dished tibial component. As the knee moves into flexion, impingement of the femur against the tibia occurs posteriorly, leading to tightening of the PCL. Tightening of the PCL would normally promote femoral rollback but is impeded by the posterior lip of the tibial component. (Adapted with permission from Insall JA, Windsor RE, Scott WN, Kelly MA, Aglietti P (eds): *Surgery of the Knee*, 2nd ed. New York: Churchill-Livingstone, 1993, vol 2, pp 677-718.)

conforming tibial inserts and posterior cruciate recession has been advanced.[10] Excellent range of motion and good early results have been reported with that technique. With 10 to 14 years of follow-up, the excellent wear characteristics of a moderately conforming tibial insert coupled with a posterior-stabilized device have been confirmed.[34]

Loosening

Earlier Thoughts and Data

It has been postulated that retention of the PCL can relieve stress from the cement-bone-prosthesis interface. The intact PCL can resist shear stresses that may be particularly harmful to the prosthesis interface. While the cruciate-sacrificing total condylar prosthesis did not demonstrate major problems with aseptic loosening, the designers of the posterior-stabilized knee were nonetheless pleased when biomechanical testing revealed that the post-and-cam mechanism resulted in net compressive forces being directed toward the tibial shaft.[1]

Newest Knowledge

Aseptic loosening of cemented condylar knees of cruciate-retaining, cruciate-sacrificing, and posterior-stabilized designs is a rare phenomenon at follow-up intervals of 15 years and more.[1] With use of a cemented, metal-backed tibial component, the original posterior-stabilized prosthesis has demonstrated 14-year survivorship of 98.1%. Ritter et al[12] reported a 96.8% 12-year survival for cemented posterior-cruciate condylar implants with an all-polyethylene tibial component. Malkani et al[29] noted a 96% 10-year survivorship with the cruciate-retaining kinematic condylar prosthesis with a metal-backed tibia.

Current Consensus and Controversy

At 10 to 15 years of follow-up, there is little in the literature to suggest a clinical difference in the durability of the bone-cement-prosthesis interface between cruciate-retaining and posterior-stabilized designs inserted with cement.

Proprioception and "Feel"

Earlier Thoughts and Data

Mechanoreceptors have long been known to exist in the anterior cruciate ligament and the PCL. It has been suggested that maintenance of the PCL may provide better proprioception after TKA. Reports that unicondylar knee ar-

throplasties have a more normal feeling to patients than TKAs have also appeared. Similarly, it has been suggested that cruciate-retaining knees may feel subjectively better to patients than designs that sacrifice or substitute for the PCL.

Newest Knowledge

It appears that the degree of preoperative degenerative arthritis is an important determinant of joint proprioception. Neurologic degeneration has been identified within the PCL of arthritic patients, and Kleinbart et al[6] were able to separate out age-related changes by comparing PCLs from arthritic knees and from age-matched control specimens. Those authors found a statistically significant difference in the magnitude of degenerative changes between the arthritic and control groups. Warren et al[38] observed that an improvement in proprioception occurred after TKA with either a cruciate-retaining or a posterior-stabilized design. Those authors found that knees with cruciate-retaining implants had a greater degree of improvement. Another recent study correlated the degree of preoperative arthritis with postoperative proprioceptive skills and found that posterior-stabilized knees performed significantly better than cruciate-retaining knees when the degree of preoperative arthritis was severe.[39]

Becker et al[40] compared bilateral paired cruciate-retaining and posterior-stabilized knees for clinical function and found no significant advantage of one design over the other. When asked to express a preference, half of the patients in that series were unable to select one knee over the other. The remaining patients were equally divided between those who preferred the cruciate-retaining knee and those who preferred the posterior-stabilized knee.

Current Consensus and Controversy

The current literature does not support a marked advantage for either cruciate-retaining or posterior-stabilized knee designs in regard to patients' subjective preferences. Current tests for proprioception are unable to consistently demonstrate better proprioceptive abilities after implantation of one design or the other.

Gait Analysis

Earlier Thoughts and Data

The gait studies of Andriacchi and his colleagues have been influential in their demonstration that patients with cruciate-sacrificing total condylar or posterior-stabilized implants employed a forward lean of the body during stair climbing.[41] This posture was distinctly different from that used by patients with normal knees and those in whom a cruciate-retaining knee had been implanted. This was thought to reflect relative quadriceps inefficiency from the loss of femoral rollback when the PCL was not retained. With all knee designs, those authors also demonstrated gait abnormalities in level walking that included a shorter stride length, reduced midstance flexion, and abnormal patterns of flexion and extension moments at the knee.

Newest Knowledge

Wilson et al[7] studied 16 patients with posterior-stabilized knees and compared them with 32 age-matched control subjects on the basis of the results of comprehensive gait analysis and isokinetic muscle testing. In contrast to Andriacchi's studies,[41] no significant differences were noted between the posterior-stabilized knees and normal knees in regard to spatiotemporal gait variables. No differences in knee range of motion during stair climbing or in isokinetic muscle strength were found in the posterior-stabilized knees and the normal knees. When compared with historical controls, the posterior-stabilized design was judged to be equivalent to the cruciate-retaining design and was superior to the cruciate-sacrificing total condylar design.

Current Consensus and Controversy

Better stair-climbing ability has long been attributed to cruciate-retaining knees. The analysis of Wilson et al[7] calls this into question. The preliminary results of a bilateral matched study of cruciate-retaining and posterior-stabilized knees, utilizing the same comprehensive gait analysis and isokinetic strength testing, suggest no difference in gait or stair-climbing ability between cruciate-retaining and posterior-stabilized knee designs (Peter D. McCann, MD, oral communication, June 1997).

Correction of Deformity

Earlier Thoughts and Data

Some proponents of cruciate-retaining knee designs have noted that it is possible to correct fixed varus, valgus, and flexion deformities while still retaining the PCL.[12,42] Other authors, including some who have routinely utilized cruciate-retaining designs, have reported that correction of marked fixed deformities and subsequent medial and lateral ligamentous balance can be hindered by PCL retention.[2,3] Advocates of posterior-stabilized designs believe that excision of the PCL makes the ligamentous balancing of all knees technically easier.[1]

Newest Knowledge

Laskin[43] has reported on a group of patients with a preoperative varus deformity of at least 15 degrees who subsequently underwent TKA. At the 10-year follow-up, the 65 knees with a cruciate-retaining implant had more pain, an increase in radiolucencies beneath the prosthesis, a decrease in the final range of motion, and decreased survivorship when compared with 50 knees with posterior-stabilized implants.

Ritter et al[12] stressed the need to recess the PCL when a cruciate-retaining implant is used for patients with a fixed varus or valgus deformity. When PCL recession was employed routinely, those authors found no difference in the results obtained with cruciate-retaining implants in patients with fixed preoperative deformity and in those without preoperative deformity.

Current Consensus and Controversy

In the knee with a marked fixed angular deformity, retention of the PCL is technically possible but certainly makes subsequent ligament balancing more demanding than if the PCL had been removed and a posterior-stabilized implant had been utilized.[2,3,42,43] If the surgeon chooses to utilize a cruciate-retaining implant to correct a fixed deformity, recession of the PCL appears to be necessary to appropriately balance the knee in flexion and extension.[12]

Bone Loss

Earlier Thoughts and Data

To accommodate the post-and-cam mechanism, the posterior-stabilized implant requires bone resection from the intercondylar region of the femur. Concern has been expressed that the loss of this intercondylar bone may lead to further bone deficiency at the time of revision TKA.

Newest Knowledge

Mintzer et al[44] have demonstrated that pronounced stress shielding occurs beneath the anterior femoral flange irrespective of component design. This suggests that whatever bone remains in the notch region of the cruciate-retaining knee is of poor quality. Because most surgeons choose a posterior-stabilized knee for the typical revision TKA, the bone loss from the notch is most often inconsequential.

Current Consensus and Controversy

To our knowledge, no studies have suggested inferior results at the time of revision TKA because of intercondylar femoral bone loss from the use of a posterior-stabilized implant at the time of the primary arthroplasty. Modular metal augmentation wedges, stems, and blocks have greatly facilitated the management of bone deficiency in TKA.

Stability

Earlier Thoughts and Data

Activities of daily living place a high level of demand on the PCL. The cruciate-sacrificing total condylar implant used a relatively conforming articular geometry and careful balancing of the flexion and extension spaces to achieve stability. That conformity transfers much of the force to the bone-cement interface beneath the implant. Because the PCL is present in 99% of knees undergoing TKA, designers of cruciate-retaining implants have sought to unload forces from the implant interface and have them shared with the intact PCL. By employing less conforming articular geometries, however, particularly as the knee is flexed, cruciate-retaining implants require an intact PCL to prevent posterior subluxation.

Posterior-stabilized designs provide a passive restraint against posterior instability. Without appropriate balance of the flexion and extension gaps, however, the uncommon but disconcerting problem of dislocation with the posterior-stabilized knee is possible.[1] Closed reduction and bracing have been recommended as the initial treatment for posterior dislocation of a posterior-stabilized TKA. Recurrent dislocations may necessitate revision surgery.

Newest Knowledge

Several recent biomechanical studies have suggested that a normal strain pattern in the PCL is difficult to achieve after implantation of a cruciate-retaining implant. In eight knees, Incavo et al[5] found that the PCL was too tight in three and too loose in three. Mahoney et al[4] tested eight knees with implants of several different designs and found that overtightening of the PCL occurred frequently and led to loss of flexion or ligament failure in cruciate-retaining knees.

In neither of those studies was an attempt made to recess the PCL. Several authors have employed PCL recession to avoid overtightening of the ligament. Ritter et al[12] specifically noted no problems with late rupture or instability with this technique. However, delayed rupture of the PCL and an unbalanced flexion space, leading to symptomatic flexion instability after cruciate-retaining TKA, have been reported by Pagnano et al[45] and Laskin.[43]

A number of case reports in the literature have served to highlight concerns about posterior dislocation with the posterior-stabilized

knee. In several recent large series of posterior-stabilized TKAs, posterior dislocation was reported in 2% to 2.6% of cases, and further revision surgery was carried out in 0.6% to 0.8% of cases.[25,34] Changes in the configuration of the post-and-cam mechanism, however, have further reduced the incidence of postarthroplasty knee dislocation.[1,25,34] Since the tibial spine was elevated in one of those designs, there have been no cases of dislocation in more than 500 TKAs that have been followed up for more than 2 years.[25]

Current Consensus and Controversy

To avoid overtightening of the PCL, particularly in conjunction with tibial inserts that are relatively conforming in the sagittal plane, balance or recession of the PCL appears necessary. While clinical results have been excellent, the reliability and reproducibility of the technique of PCL recession has not been established in the biomechanics laboratory. Balance of the flexion gap in both cruciate-retaining and posterior-stabilized knees is important for good TKA function. Furthermore, in the posterior-stabilized knee, it is necessary to avoid the possibility of dislocation.

The Patella and Joint Line

Earlier Thoughts and Data

In the original posterior-stabilized knee design, there were patellar complications, including fractures, in as many as 11.5% of knees.[46] A portion of these patellar complications included the so-called patellar clunk syndrome.[26] In that disorder, a prominent fibrous nodule develops at the proximal pole of the patella. As the knee is flexed, that nodule can become captured in the intercondylar notch of the femoral component. With subsequent extension of the knee, the nodule pops out of the intercondylar notch, resulting in the clunking sensation. Malpositioning of the patellar component, particularly proximal overhang of the button, can predispose to a patellar clunk. Conservative treatment typically is unsuccessful in eliminating patellar clunk syndrome. Arthroscopic debridement of the fibrous nodule has been recommended in cases in which malpositioning of the patellar component is not present.[47]

The level of the prosthetic joint line should be restored close to its preoperative position. Joint-line preservation is more important for cruciate-retaining knee designs because the PCL must be appropriately balanced to achieve a good range of motion postoperatively.[48] In posterior-stabilized designs, the joint line may be elevated as much as 10 mm without clinically significant effects on knee range of motion or patellofemoral function.[46]

Total knee arthroplasty in the postpatellectomy patient can be complicated by instability, residual anterior knee pain, and less satisfactory results. Early reports suggested that a hinged knee design was most appropriate for the postpatellectomy patient.[49]

Newest Knowledge

After identification of patellofemoral problems, including the patellar clunk, the femoral component of the original posterior-stabilized prosthesis was modified. Those modifications reduced the incidence of patellofemoral complications in knees with the posterior-stabilized design to 3%.[46] That rate of complications is similar to the rates of patellofemoral problems reported in large series of cruciate-retaining TKAs.[29,33]

The authors of several recent studies have reported satisfactory results with nonhinged knee designs in postpatellectomy patients. One study was a retrospective, matched-control analysis of the results of 22 TKAs performed after a previous patellectomy.[50] Nine of the patients had undergone insertion of a posterior-stabilized prosthesis, and 13 had undergone insertion of a cruciate-retaining implant. The authors of that study concluded that TKA produced good results in selected patients with a prior patellectomy. The use of a posterior-stabilized prosthesis provided predictably good results in regard to pain relief and function in patients who had undergone a patellectomy for patellar fracture. The cruciate-retaining prosthesis provided less predictable results than the posterior-stabilized prosthesis in regard to overall function postoperatively.

Another recent report detailed the results of 22 primary TKAs in patients who had undergone a prior patellectomy.[51] In that series, four types of prostheses were implanted. Those patients who had received a posterior-stabilized prosthesis had better scores for pain and function than did the patients with a cruciate-sacrificing total condylar implant ($P<0.01$).

Current Consensus and Controversy

Patellofemoral complications continue to compromise the results of 3% to 5% of TKAs performed with both cruciate-retaining and posterior-stabilized designs. There appears to be no clear advantage of one design class over the other in minimizing either the incidence or severity of patellofemoral complications. Restoration of the preoperative joint-line position appears to be more important when a cruciate-retaining prosthesis is employed.

Joint-line elevation by as much as 10 mm may be relatively well tolerated in conjunction with a posterior-stabilized implant.

Total knee arthroplasty in the well-selected patient with a prior patellectomy can give satisfactory results. Particular attention to soft-tissue balance in flexion is important to avoid postoperative instability and can make possible the use of a minimally constrained implant of either a cruciate-retaining or posterior-stabilized design. The posterior-stabilized prosthesis, however, may yield more predictably reliable results in regard to pain relief and function in the postpatellectomy patient.

Young or Active Patients

Earlier Thoughts and Data

In part because of concerns that the disappointing results of cemented total hip arthroplasty in the young patient would be replicated in the knee, most surgeons have been slow to expand the indications for TKA beyond the elderly or rheumatoid arthritic patient. Concerns about the possibility of aseptic loosening, both from the increased stresses at the bone-cement-prosthesis interface and from wear debris in the young, active patient, have been expressed.

Some authors have suggested that the benefits of PCL retention would be most evident in the young patient. Several studies reported in the mid-1980s noted good to excellent results for 95% of young (<55 years of age) patients with cruciate-retaining or cruciate-sacrificing total condylar knees at 3 to 5 years of follow-up. Those studies included only small numbers of patients with osteoarthrosis or posttraumatic arthrosis (4% to 16%), and most of the patients had a preoperative diagnosis of rheumatoid arthritis.

Newest Knowledge

A recent report highlights the role of TKA in the younger patient with degenerative arthrosis. In that report, Diduch et al[35] presented data on 103 of 114 posterior-stabilized TKAs in patients under 55 years of age (range, 21 to 54 years; mean age, 51 years) at an average 8-year follow-up. Polyethylene wear, osteolysis, and loosening were not major problems for this group of relatively young, active patients in whom a moderately conforming, cemented, posterior-stabilized knee design was employed. This finding is particularly interesting because 24% of the patients reported regular participation in tennis, skiing, biking, or heavy farm or construction work.

Current Consensus and Controversy

When nonoperative management has failed, the young patient with osteoarthrosis appears to be an acceptable candidate for cemented, posterior-stabilized knee replacement. The available data do not allow us to comment further on the role of cruciate-retaining designs in this patient population. Total knee arthroplasty in the young active patient should still be undertaken with caution.

Summary

Early claims that retention of the PCL in TKA would allow better range of motion, better joint stability, more normal gait, and enhanced prosthetic longevity compared with PCL-substituting knee designs have not been supported by subsequent clinical and basic science research. The range of motion after TKA averages 115 degrees with both posterior-stabilized designs and cruciate-retaining designs coupled with the technique of PCL recession. In regard to stability after TKA, neither the cruciate-retaining nor the posterior-stabilized design provides any inherent varus-valgus stability.

In the anteroposterior plane, the rare problem of dislocation with the posterior-stabilized design is matched by the problem of late PCL rupture and subsequent flexion instability in the cruciate-retaining knee. Recent gait analysis and isokinetic muscle testing studies do not support a difference between posterior-stabilized and cruciate-retaining knees in regard to spatiotemporal gait variables, knee range of motion during stair climbing, or isokinetic muscle strength. Prosthetic longevity has been well established: the posterior-stabilized design with a metal-backed tibial component has demonstrated a 14-year survivorship of greater than 98%; the cruciate-retaining condylar implant with an all-polyethylene tibia has shown a 12-year survival rate of 97%; and the cruciate-retaining kinematic design with a metal-backed tibia has a reported 10-year survival rate of 96%.

References

1. Stern SH, Insall JN: Total knee arthroplasty with posterior cruciate ligament substitution designs, in Insall JN, Windsor RE, Scott WN, Kelly MA, Aglietti P (eds): *Surgery of the Knee*, 2nd ed. New York: Churchill Livingstone, 1994, vol 2, pp 829-867.
2. Rand JA: Posterior cruciate–retaining total knee arthroplasty, in Morrey BF (ed): *Reconstructive Surgery of the Joints*, 2nd ed. New York: Churchill Livingstone, 1996, vol 2, pp 1401-1408.
3. Barnes CL, Sledge CB: Total knee arthroplasty with posterior cruciate ligament retention designs, in Insall JN, Windsor RE, Scott WN, Kelly MA, Aglietti P (eds): *Surgery of the Knee*, 2nd ed. New York: Churchill Livingstone, 1993, vol 2, pp 815-827.
4. Mahoney OM, Noble PC, Rhoads DD, Alexander JW, Tullos HS: Posterior cruciate function following total knee arthroplasty: A biomechanical study. *J Arthroplasty* 1994;9:569-578.
5. Incavo SJ, Johnson CC, Beynnon BD, Howe JG: Posterior cruciate ligament strain biomechanics in total knee arthroplasty. *Clin Orthop* 1994;309:88-93.
6. Kleinbart FA, Bryk E, Evangelista J, Scott WN, Vigorita VJ: Histologic comparison of posterior cruciate ligaments from arthritic and age-matched knee specimens. *J Arthroplasty* 1996; 11:726-731.
7. Wilson SA, McCann PD, Gotlin RS, Ramakrishnan HK, Wootten ME, Insall JN: Comprehensive gait analysis in posterior-stabilized knee arthroplasty. *J Arthroplasty* 1996;11:359-367.
8. Stiehl JB, Komistek RD, Dennis DA, Paxson RD, Hoff WA: Fluoroscopic analysis of kinematics after posterior-cruciate-retaining knee arthroplasty. *J Bone Joint Surg Br* 1995;77:884-889.
9. Hirsch HS, Lotke PA, Morrison LD: The posterior cruciate ligament in total knee surgery: Save, sacrifice, or substitute? *Clin Orthop* 1994;309:64-68.
10. Scott RD, Thornhill TS: Posterior cruciate supplementing total knee replacement using conforming inserts and cruciate recession: Effect on range of motion and radiolucent lines. *Clin Orthop* 1994;309:146-149.
11. Dennis DA, Komistek RD, Hoff WA, Gabriel SM: In vivo knee kinematics derived using an inverse perspective technique. *Clin Orthop* 1996;331: 107-117.
12. Ritter MA, Faris PM, Keating EM: Posterior cruciate ligament balancing during total knee arthroplasty. *J Arthroplasty* 1988;3:323-326.
13. Font-Rodriguez DF, Scuderi GR, Insall JN: Survivorship of total knee arthroplasty. Presented before the Knee Society, Atlanta, February 1996.
14. Goldberg VM, Figgie MP, Figgie HE III, Heiple KG, Sobel M: Use of a total condylar knee prosthesis for treatment of osteoarthritis and rheumatoid arthritis: Long-term results. *J Bone Joint Surg Am* 1988;70:802-811.
15. Insall JN, Hood RW, Flawn LB, Sullivan DJ: The total condylar knee prosthesis in gonarthrosis: A five to nine-year follow-up of the first one hundred consecutive replacements. *J Bone Joint Surg Am* 1983;65:619-628.
16. Ranawat CS: The patellofemoral joint in total condylar knee arthroplasty: Pros and cons based on five- to ten-year follow-up observations. *Clin Orthop* 1986;205:93-99.
17. Ranawat CS, Flynn WF Jr, Saddler S, Hansraj KK, Maynard MJ: Long-term results of the total condylar knee arthroplasty: A 15-year survivorship study. *Clin Orthop* 1993;286:94-102.
18. Scuderi GR, Windsor RE, Insall JN: Observations on patellar height after proximal tibial osteotomy. *J Bone Joint Surg Am* 1989;71:245-248.
19. Aglietti P, Buzzi R, Gaudenzi A: Patellofemoral functional results and complications with the posterior stabilized total condylar knee prosthesis. *J Arthroplasty* 1988;3:17-25.
20. Emmerson KP, Moran CG, Pinder IM: Survivorship analysis of the Kinematic Stabilizer total knee replacement: A 10- to 14-year follow-up. *J Bone Joint Surg Br* 1996;78:441-445.
21. Hanssen AD, Rand JA: A comparison of primary and revision total knee arthroplasty using the kinematic stabilizer prosthesis. *J Bone Joint Surg Am* 1988;70:491-499.
22. Insall JN, Lachiewicz PF, Burstein AH: The posterior stabilized condylar prosthesis: A modification of the total condylar design—Two to four-year clinical experience. *J Bone Joint Surg Am* 1982;64:1317-1323.
23. Insall JN, Binazzi R, Soudry M, Mestriner LA: Total knee arthroplasty. *Clin Orthop* 1985;192:13-22.
24. Rand JA, Ilstrup DM: Survivorship analysis of total knee arthroplasty: Cumulative rates of survival of 9200 total knee arthroplasties. *J Bone Joint Surg Am* 1991;73:397-409.
25. Ranawat CS, Luessenhop CP, Rodriguez JA: The press-fit condylar modular total knee system: Four-to-six-year results with a posterior-cruciate-substituting design. *J Bone Joint Surg Am* 1997;79:342-348.
26. Stern SH, Insall JN: Posterior stabilized prosthesis: Results after follow-up of nine to twelve years. *J Bone Joint Surg Am* 1992;74:980-986.
27. Dennis DA, Clayton ML, O'Donnell S, Mack RP, Stringer EA: Posterior cruciate condylar total knee arthroplasty: Average 11-year follow-up evaluation. *Clin Orthop* 1992;281:168-176.
28. Lee JG, Keating EM, Ritter MA, Faris PM: Review of the all-polyethylene tibial component in total knee arthroplasty: A minimum seven-year follow-up period. *Clin Orthop* 1990;260:87-92.
29. Malkani AL, Rand JA, Bryan RS, Wallrichs SL: Total knee arthroplasty with the kinematic condylar prosthesis: A ten-year follow-up study. *J Bone Joint Surg Am* 1995;77:423-431.
30. Rand JA: Comparison of metal-backed and all-polyethylene tibial components in cruciate condylar total knee arthroplasty. *J Arthroplasty* 1993; 8:307-313.
31. Ritter MA, Herbst SA, Keating EM, Faris PM, Meding JB: Long-term survival analysis of a posterior cruciate-retaining total condylar total knee arthroplasty. *Clin Orthop* 1994;309:136-145.
32. Rosenberg AG, Barden RM, Galante JO: Cemented and ingrowth fixation of the Miller-Galante prosthesis: Clinical and roentgenographic comparison after three- to six-year follow-up studies. *Clin Orthop* 1990;260:71-79.
33. Weir DJ, Moran CG, Pinder IM: Kinematic condylar total knee arthroplasty: 14-year survivorship analysis of 208 consecutive cases. *J Bone Joint Surg Br* 1996;78:907-911.
34. Colizza WA, Insall JN, Scuderi GR: The posterior stabilized total knee prosthesis: Assessment of polyethylene damage and osteolysis after a ten-year-minimum follow-up. *J Bone Joint Surg Am* 1995;77:1713-1720.
35. Diduch DR, Insall JN, Scott WN, Scuderi GR, Font-Rodriguez D: Total knee replacement in young, active

patients: Long-term follow-up and functional outcome. *J Bone Joint Surg Am* 1997;79:575-582.
36. Swany MR, Scott RD: Posterior polyethylene wear in posterior cruciate ligament-retaining total knee arthroplasty: A case study. *J Arthroplasty* 1993;8: 439-446.
37. Landy MM, Walker PS: Wear of ultrahigh-molecular-weight polyethylene components of 90 retrieved knee prostheses. *J Arthroplasty* 1988;3(suppl): S73-S85.
38. Warren PJ, Olanlokun TK, Cobb AG, Bentley G: Proprioception after knee arthroplasty: The influence of prosthetic design. *Clin Orthop* 1993;297:182-187.
39. Simmons S, Lephart S, Rubash H, Pifer GW, Barrack R: Proprioception after unicondylar knee arthroplasty versus total knee arthroplasty. *Clin Orthop* 1996;331:179-184.
40. Becker MW, Insall JN, Faris PM: Bilateral total knee arthroplasty: One cruciate retaining and one cruciate substituting. *Clin Orthop* 1991;271:122-124.
41. Andriacchi T: Gait analysis and total knee replacement, in Insall J, Scott W, Scuderi GR (eds): *Current Concepts in Primary and Revision Total Knee Arthroplasty*. Philadelphia: Lippincott-Raven, 1996.
42. Firestone TP, Krackow KA, Davis JD IV, Teeny SM, Hungerford DS: The management of fixed flexion contractures during total knee arthroplasty. *Clin Orthop* 1992;284:221-227.
43. Laskin RS: Total knee replacement with posterior cruciate ligament retention in patients with a fixed varus deformity. *Clin Orthop* 1996;331:29-34.
44. Mintzer CM, Robertson DD, Rackemann S, Ewald FC, Scott RD, Spector M: Bone loss in the distal anterior femur after total knee arthroplasty. *Clin Orthop* 1990;260:135-143.
45. Pagnano MW, Hanssen AD, Stuart MJ, Lewallen DG: Flexion instability following primary posterior cruciate retaining total knee arthroplasty. *Clin Orthop* (in press).
46. Scuderi GR, Insall JN: Performance of posterior cruciate ligament substituting total knee arthroplasty, in Insall JN, Scott WN, Scuderi GR (eds): *Current Concepts in Primary and Revision Total Knee Arthroplasty*. Philadelphia: Lippincott-Raven, 1996, pp 41-45.
47. Beight JL, Yao B, Hozack WJ, Hearn SL, Booth RE Jr: The patellar "clunk" syndrome after posterior stabilized total knee arthroplasty. *Clin Orthop* 1994;299:139-142.
48. Frymoyer JW (ed): *Orthopaedic Knowledge Update 4*. Rosemont, Ill: American Academy of Orthopaedic Surgeons, 1993, pp 603-624.
49. Bayne O, Cameron HU: Total knee arthroplasty following patellectomy. *Clin Orthop* 1984;186:112-114.
50. Paletta GA Jr, Laskin RS: Total knee arthroplasty after a previous patellectomy. *J Bone Joint Surg Am* 1995;77: 1708-1712.
51. Martin SD, Haas SB, Insall JN: Primary total knee arthroplasty after patellectomy. *J Bone Joint Surg Am* 1995;77:1323-1330.