The Journal of Arthroplasty Vol. 11 No. 7 1996

Proprioception Following Total Knee Arthroplasty With and Without the Posterior Cruciate Ligament

Scott Simmons, MD,* Scott Lephart, PhD,† Harry Rubash, MD,‡
Paul Borsa, MS,† and Robert L. Barrack, MD*

Abstract: Proprioception was measured in two groups of patients following successful total knee arthroplasty (TKA). In one group, the posterior cruciate ligament was retained and an unconstrained cruciate-retaining total knee component was used; in the other group, the posterior cruciate ligament was excised and a cruciate-substituting design was implanted. Threshold to detection of passive motion was quantified as a measure of proprioception. The degree of preoperative arthritis was objectively classified according to Resnick and Niwoyama. There was no difference in threshold to detection of passive motion in cruciate-retaining versus cruciate-substituting TKA. In patients with a moderate grade of arthritis before surgery, the postoperative scores were virtually identical. When the grade of preoperative arthritis was severe, patients with cruciate-substituting TKAs performed significantly better than those with cruciate-retaining TKAs. **Key words:** proprioception, total knee arthroplasty, posterior cruciate ligament, threshold to detection of passive motion.

Mechanoreceptors have been demonstrated in human cruciate ligaments and studies have indicated that knee ligaments provide proprioceptive input [1,2]. Mechanoreceptors responsible for proprioception have been found in the entire capsuloligamentous complex of the knee, including the posterior cruciate ligament (PCL) [3–11]. Proprioception, however, declines with normal aging [12–14] and, to a greater degree, with degenerative arthritis [14,15]. This sensory loss appears to occur early in the degenerative process [14,16] and has even been implicated as a possible etiology of osteoarthritis [13,14]. The altered gait seen in many individuals with degenerative knees may in fact be an attempt to enhance proprioceptive feedback in addition to mitigating pain [17].

Maintenance of proprioception input from the PCL has been suggested as a potential benefit potential benefit of PCL retention during total knee arthroplasty (TKA) [18–22]. Retaining the PCL has been shown to produce a more normal gait pattern, especially during stairclimbing [18]. Whether the PCL retains its mechanical or proprioceptive role in the osteoarthritic knee, however, is uncertain [6,11,23–25]. The purpose of this study was to quantify whether a difference in proprioceptive ability could be detected between PCL-retaining TKA and PCL-substituting TKA.

Materials and Methods

All unilateral PCL-retaining and PCL-sacrificing TKAs performed between 1990 and 1993 by the

*From the *Department of Orthopaedic Surgery, Tulane University School of Medicine, New Orleans, Louisiana, †Sports Medicine Section, Department of Orthopaedic Surgery, University of Pittsburgh, and ‡Division of Adult Reconstructive Surgery, University of Pittsburgh, Pittsburgh, Pennsylvania.*

Supported in part by a grant from Zimmer (Warsaw, IN) and University Orthopaedics Pittsburgh, Pennsylvania.

Reprint requests: Robert L. Barrack, MD, Department of Orthopaedic Surgery/SL32, Tulane University School of Medicine, 1430 Tulane Avenue, New Orleans, LA 70112.

Department of Orthopaedic Surgery, University of Pittsburgh Medical Center, were retrospectively reviewed. Subject inclusion criteria included those individuals between the ages of 50 and 80 with a good clinical result. A good clinical result was defined as a range of motion of at least 5° to 90° with no instability or significant pain and a good or excellent result on The Knee Society score. Testing was performed at least 6 months (mean, 23 months; range, 6–47 months) before surgery to allow patients to reach a plateau in terms of pain relief, range of motion, strength, and lack of effusion. Only those with osteoarthritis or traumatic arthritis were included. Subjects with a peripheral neuropathy, cerebral vascular accident, insulin-dependent diabetes mellitus, or rheumatologic disorders were excluded. Preoperative radiographs were also evaluated for the presence of significant preoperative knee deformity. Those with a varus or valgus deformity greater than 15° or a flexion contracture greater than 15° were excluded from the study to avoid selection bias. As cruciate-sacrificing or -substituting TKA is performed more often in patients with more severe degrees of deformity, this could preselect for patients with more advanced degrees of arthritis before surgery. The intention was to enroll patients who were good potential candidates for either cruciate-retaining or -sacrificing TKA. Twenty-eight unselected patients who met all of our inclusion criteria were evaluated. All patients signed an informed consent approved by the review boards of both participating institutions (Tulane University and University of Pittsburgh). Thirteen of these individuals had a PCL-sacrificing TKA and 15 had a PCL-retaining TKA. Ten were men and 18 were women, with a mean age of 69. The degree of arthritis in the preoperative and nonoperative knee was then graded radiographically by the criteria of Resnick and Niwoyama [26,27] (Table 1). A majority of the knees that underwent TKA were grade 2, whereas the contralateral, nonoperative knees were mostly grade 1 (Table 2). In general, the preoperative arthritis in the PCL-sacrificing TKA group was more severe compared with the PCL-retaining TKA group. Patients with grade 2 arthritis were more likely to have a cruciate-retaining prosthesis (Miller–Galante II, Zimmer, Warsaw, IN), whereas those with grade 3 arthritis more frequently had a cruciate-substituting implant (Insall–Burstein II, Zimmer) (Table 3). Prior to proprioception testing, all subjects underwent clinical evaluation with completion of The Knee Society rating score. The postoperative knee scores were virtually identical for the cruciate-retaining and cruciate-sacrificing groups (mean, 93 for both groups; range, 82–98 and 80–97 for the two groups, respectively).

Table 1. Degenerative Grading Scale Based on Resnick and Niwoyama's Criteria [26]

Grade 0 (no DJD)	No arthritic changes
Grade 1 (minimal DJD)	Minimal narrowing of joint space, mild sclerosis, no appreciable changes
Grade 2 (moderate DJD)	Moderate narrowing of joint space, osteophyte formation, no bony collapse, moderate subchondral sclerosis, intraarticular osseous bodies, moderate bony aberration
Grade 3 (severe DJD)	Marked joint space narrowing to obliterated joint space, bony collapse, severe subchondral sclerosis, intraarticular osseous bodies, marked deformity or angularity, severe bony aberration

DJD, degenerative joint disease.

Once the pretesting evaluation was complete, the subjects were instructed about the proprioception testing device (PTD) (Fig. 1) and its purpose along with the testing format and patient expectations. This apparatus had been validated on a number of test groups of normal subjects as well as patients following knee ligament injury and surgery [2]. Subjects were then placed in the PTD. The PTD was controlled and operated by a "direct control system." This consisted of a motor, which rotated the device at a constant angular velocity (0.5°/s), and an optical encoder, which measured angular displacement of the knee in degrees. Proprioception is mediated by mechanoreceptors such as Ruffini end organs, which are most specifically stimulated by slow, steady change in position. They respond with a change in the rate of impulses elicited. The impulse generation persists even when a stimulus ends, conveying conscious awareness of joint position. This is in contrast to "rapidly adapting" receptors in which the number of impulses rapidly declines to zero with stimulus removal. These "slowly adapting" receptors are most appropriately examined with a slow constant

Table 2. Severity of Arthritis in Operative and Contralateral, Nonoperative Knees

	Arthritis Grade			
	0	1	2	3
Operative knee	0	0	17	11
Nonoperative knee	0	17	7	4

Table 3. Severity of Arthritis in Cruciate-retaining and Cruciate-sacrificing Knees

	Preoperative Arthritis Grade		
	1	2	3
Cruciate-retaining*	0	11	4
Cruciate-sacrificing†	0	4	9

*Miller–Galante II. †Insall–Burstein II.

angular velocity such as 0.5°/s [1,2,8]. This testing is performed with the joint unloaded, which is not physiologic but has the advantage of isolating afferent input, presumably from capsular and ligamentous structures. Proprioceptive measurement in the loaded joint has been described through the application of other techniques such as stabilometry that measure a composite of neurologic functions including afferent ligamentous input as well as efferent stimulation to muscle and tendon receptors. The test–retest reliability of the PTD had been previously established at $r = .92$ [2]. The subjects were blindfolded and subjected to low-intensity white noise to control for visual and auditory sensory input. To control for cutaneous sensory input, pneumatic boots were used to secure the lower extremities to the testing apparatus. The subjects were then tested for threshold to detect passive motion (TTDPM).

The tested extremity was positioned on the PTD's moving bar, which measured angular displacement. Subjects were positioned in such a way to neutralize cutaneous compression or sensation. The TTDPM was tested from starting positions of 15° knee flexion (near-terminal range of motion) and 45° knee flexion (mid-range of motion). The PTD moved the knee randomly into flexion or extension at a constant angular velocity from the two starting positions. The subject signified the detection of passive motion by pressing a remote switch. After two practice trials, three randomized runs of the TTDPM were subsequently recorded with both flexion and extension from the two starting positions. One-way analysis of variance with repeated measures was completed for the involved/uninvolved TTDPM mean comparisons. A value of $P < .05$ was considered significant.

Results

There was no statistically significant difference between PCL-retaining and PCL-substituting TKAs in proprioception as measured. The mean TTDPM values for the two groups were 2.24 and 2.36, respectively. When comparing proprioception in the operative knee with that in the nonoperative knee, no statistically significant differences were

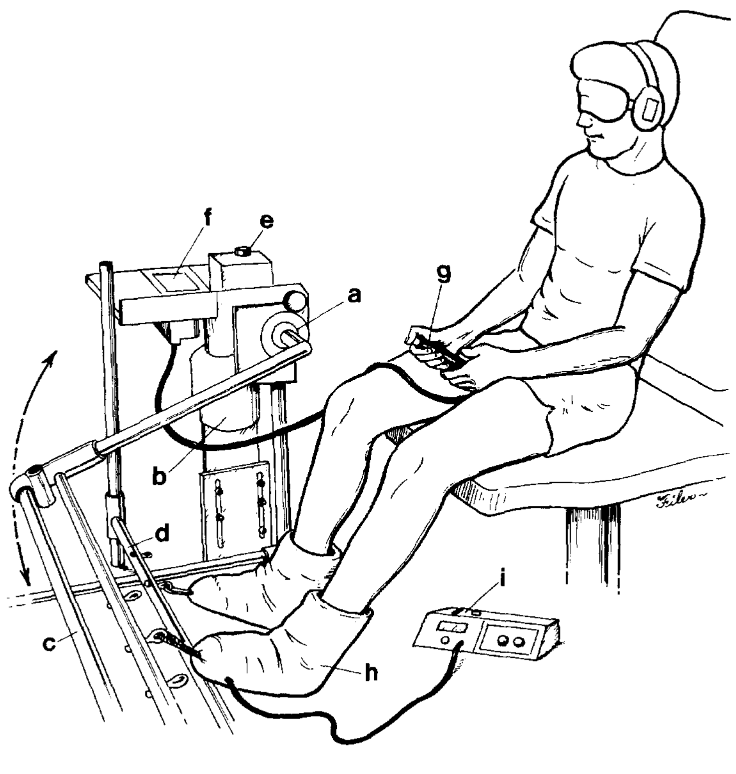

Fig. 1. Proprioceptive testing device: (a) rotational transducer, (b) motor, (c) moving arm, (d) stationary arm, (e) control panel, (f) digital microprocessor, (g) hand-held disengage switch, (h) pneumatic compression boot, and (i) pneumatic compression device. Threshold to detection of passive motion is assessed by measuring the angular displacement until the subject senses motion in the knee. From "Proprioception following anterior cruciate ligament reconstruction" by Scott Lephart et al., *Journal of Sport Rehabilitation,* (Vol. 1, No. 3), pp. 191. Copyright 1992 by Human Kinetics Publishers. Reprinted by permission.

revealed with the exception of the testing condition on 15° of flexion as the starting position moving into flexion (2.44° ± 0.34° vs 2.01° ± 0.27°, P = .04) (Table 4). A significant positive relationship (r = .58, $P < .05$) was revealed between the preoperative degree of osteoarthritis and poor proprioception values in the operative knee regardless of whether the PCL was retained or not. When patients with only a moderate arthritis (grade 2) were compared between cruciate-retaining and cruciate-sacrificing groups, there was no difference in their TTDPMs ($P > .4$). In patients with severe degrees of preoperative arthritis, however, those treated with a cruciate-sacrificing prosthesis performed significantly better than those treated with a cruciate-preserving design (Table 4).

Discussion

Whether retaining one or both cruciate ligaments imparts more proprioceptive input in knee arthroplasty remains a question [28–31]. One study of unicondylar knee arthroplasties reported that their patients had a "more normal-feeling" knee joint when compared with the TKA. Preservation of the cruciate ligaments and patellar surface was thought to be responsible for this increased joint awareness [31]. Proponents of PCL preservation in TKA believe that major advantages include more normal kinematics and gait when compared with TKA in which the PCL is sacrificed. Once again, proprioception has often been thought to play an integral role in obtaining these advantages.

Though proprioceptive input from the cruciate ligaments is well established [1,8,9], their contribution may be limited in the aged population [6,11,23]. A steady decrease of joint position sense with age in normal knees has been identified [13–15]. Degenerative changes in the knees further decrease proprioception [11,14,15]. Schultz et al. established histologically that mechanoreceptors were present in the human cruciate ligaments [23]. There was, however, a very small population of mechanoreceptors in the ligaments harvested during TKA. Alexiades et al. also established neurologic degeneration of the PCL with arthritis [6]. The lack of mechanoreceptors in the degenerative PCL may explain why no significant difference in proprioception between PCL-sacrificing and PCL-retaining TKAs was found. The fact that the contralateral nonoperative knees with very early stages of degenerative arthritis performed minimally better than the postoperative knees suggests that proprioceptive loss occurs very early in the degenerative process, as has been suggested by others [14–16]. Berman et al. reported that the abnormal gait pattern characteristic of the degenerative knee also occurs early preceding the subsequent radiographic changes [16]. This would explain the lack of any significant difference in proprioception in patients with early (grade 2) arthritis.

The finding of worse proprioception (TTDPM) in patients treated with cruciate-preserving TKA who had severe degenerative arthritis (grade 3) before surgery was a surprise. Apparently, any proprioception originating in the cruciate ligaments is lost early in the degenerative process, consistent with previous histologic studies [11]. Beyond this point, the capsular ligaments probably provide most of the proprioceptive input. In such a scenario, a component design that most effectively restores balance and tension to the capsular ligaments might perform better on proprioceptive testing.

Table 4. Proprioception versus Arthritis Severity in Cruciate-retaining and Cruciate-sacrificing TKA

	TTDPM for Patients With TKA With DJD Before Surgery			
	15° of Flexion	15° of Extension	45° of Flexion	45° of Extension
Moderate (grade 2) DJD				
IB-II (n = 4)	1.65 ± 0.49	1.05 ± 0.19	1.97 ± 0.61	1.40 ± 0.51
MG-II (n = 11)	1.45 ± 0.24	1.21 ± 0.17	1.55 ± 0.21	1.44 ± 0.71
	P = .07	P = .67	P = .42	P = .93
Severe (grade 3) DJD				
IB-II (n = 9)	2.78 ± 0.61	1.7 ± 0.19	2.79 ± 0.94	2.77 ± 0.28
MG-II (n = 4)	5.18 ± 0.99	3.8 ± 0.88	6.12 ± 1.50	4.75 ± 3.50
	P = .04	P = .008	P = .08	P = .15

TTDPM, threshold to detection of passive motion; DJD, degenerative joint disease; IB-II, Insall–Burstein II; MG-II, Miller–Galante II.

Implanting a cruciate-preserving component in a severely degenerated knee might not retain tension and balance in the capsular ligaments as effectively as implanting a cruciate-substituting design in which flexion–extension gap balancing is much more of an emphasis.

Scuderi and Insall reported on how difficult it is to obtain optimal tension on the retained PCL when performing TKA [24]. A PCL that is too tense can result in excessive rollback; if it is too loose, it can result in posterior sag. These deficient mechanical properties are more likely to be present in the knee with more severe preoperative degenerative changes. Joint laxity has also been associated with decreased proprioception [32]. Corces et al. found that a functional PCL was present only 1 of 10 times at the time of TKA [25]. Performing a cruciate-retaining TKA in this setting would be expected to result in some degree of laxity, with perhaps diminished stimulation of receptors in the remaining capsular ligaments and corresponding diminution in proprioception.

Other investigators have compared proprioception in the cruciate-retaining versus cruciate-sacrificing TKA. Faris et al. found no difference in proprioception comparing the two knee designs in the same patient [33]. Warren et al., on the other hand, evaluated 50 subjects comparing the two knee designs in different patients [34]. Though proprioception was measured differently from this study, they found that the PCL-retaining TKA had improved joint position sense. Neither of the previous studies, however, evaluated the degree of degenerative arthritis before surgery. If cruciate-sacrificing TKA is consistently performed on knees with more severe deformity and degenerative changes, those individuals might be expected to perform differently on proprioceptive tests on this basis rather than the status of the PCL. The degree of preoperative arthritis appears to be an important parameter that can affect proprioception and this may be a confounding variable in previous studies.

Conclusion

Retaining the PCL in TKA did not result in improved performance in proprioception testing as measured in this study. Attempting to retain the PCL may, in fact, be counterproductive in the severely degenerative knee. This conclusion, however, is based on comparisons of small subgroups of the overall study population and bears further investigation before drawing any definitive conclusions. Although retaining the PCL may improve kinematics and gait, maintenance of proprioceptive input is not supported by these results.

Acknowledgments

The authors thank Dr. Freddie Fu for his support in providing laboratory facilities, technical assistance, and expertise. They also acknowledge Dr. Larry Crossett for the use of some of his patients in this study.

References

1. Barrack RL, Skinner HB, Buckley SL: Proprioception in the anterior cruciate deficient knee. Am J Sports Med 17:1, 1989
2. Lephart SM, Kocher MS, Fu FH et al: Proprioception following anterior cruciate ligament reconstruction. J Sports Rehabil 1:188, 1992
3. Palmer I: Pathophysiology of the medial ligament of the knee joint. Acta Chir Scand 115:312, 1958
4. Kennedy JC, Alexander IJ, Hayes KC: Nerve supply of the human knee and its functional importance. Am J Sports Med 10:329, 1982
5. Schutte MJ, Dabezies MD, Zimny ML, Happel LT: Neural anatomy of the human anterior cruciate ligament. J Bone Joint Surg 69A:243, 1987
6. Alexiades M, Scuderi G, Vigorita V, Scott WN: A histologic study of the posterior cruciate ligament in the arthritic knee. Am J Knee Surg 2:153, 1989
7. De Avila GA, O'Connor BL, Visco DM, Sisk TD: The mechanoreceptor innervation of the human fibular collateral ligament. J Anat 162:1, 1989
8. Barrack RL, Skinner HB: The sensory function of knee ligaments. p. 95. In Daniel D, Akeson W, O'Connor J (eds): Knee ligaments: structure, function, injury, and repair. Lippincott-Raven, New York, 1990
9. Johansson H, Sjolander P, Sojka P: A sensory role for the cruciate ligaments. Clin Orthop 268:161, 1991
10. Katonis PG, Assimakopoulos AP, Agapitos MV, Exarchou EI: Mechanoreceptors in the posterior cruciate ligament. Acta Orthop Scand 62:276, 1991
11. Kleinbart FA, Bryk E, Evangelista J et al: A histological comparison of posterior cruciate ligaments harvested from arthritic and age-controlled knee specimens. Presented at 38th Annual Meeting of the Orthopaedic Research Society, Washington, DC, February 1992
12. Kokmen E, Bossemeyer RW, Williams WJ: Quantitative evaluation of joint motion perception in aging population. J Gerontol 33:62, 1978
13. Skinner HB, Barrack RL, Cook SD: Age-related decline in proprioception. Clin Orthop 184:208, 1984
14. Barrett DS, Cobb AG, Bentley G: Joint proprioception in normal, osteoarthritic, and replaced knees. J Bone Joint Surg 73B:53, 1991

15. Skinner HB, Barrack RL: Joint position sense in the normal and pathologic knee joint. J Electromyogr Kinesiol 1:180, 1991
16. Berman AT, Zarro VJ, Bosacco MD, Israelite C: Quantitative gait analysis after unilateral or bilateral total knee replacement. J Bone Joint Surg 69A: 1340, 1987
17. Stauffer RN, Chao EYS, Gyory AN: Biomechanical gait analysis of the diseased knee joint. Clin Orthop 126:246, 1977
18. Andriacchi TP, Galante JO, Fermier RW: The influence of total knee-replacement design and walking and stair-climbing. J Bone Joint Surg 64A:1328, 1982
19. Dorr LD, Scott RD, Ranawat C: Controversies of total knee arthroplasty: Importance of retention of posterior cruciate ligament. p. 197. In Ranawat CS (ed): Total condylar knee arthroplasty. Springer-Verlag, New York, 1985
20. Dorr LD, Ochsner JL, Gronley J, Perry J: Functional comparison of posterior cruciate-retained versus cruciate-sacrificed total knee arthroplasty. Clin Orthop 236:36, 1988
21. Frymorer JW: Knee and leg: reconstruction. p. 608. In Frymorer JW (ed): Orthopedic knowledge update 4. AAOS, Rosemont, IL, 1993
22. Insall J: Surgery of the knee. 2nd ed. Churchill Livingstone, New York, 1993
23. Schultz RA, Miller DC, Kerr CS, Micheli L: Mechanoreceptors in human cruciate ligaments. J Bone Joint Surg 66A:1072, 1984
24. Scuderi GR, Insall JN: The posterior stabilized knee prosthesis. Orthop Clin North Am 20:71, 1989
25. Corces A: Strain characteristics of the posterior cruciate ligament in total knee arthroplasty. Orthop Trans Fall:527, 1989
26. Resnick D, Niwoyama G: Diagnosis of bone and joint disorders. WB Saunders, Philadelphia, 1981
27. Duwelius PJ, Connolly JF: Closed reduction of tibial plateau fractures. Clin Orthop 230:116, 1988
28. Cobb AG, Kozinn SC, Scott RD: Unicondylar or total knee replacement. J Bone Joint Surg 62B:166, 1990
29. Jefferson RJ, Whittle MW: Functional biomechanical results of unicompartmental knee arthroplasty compared with total condylar arthroplasty and tibial osteotomy. J Bone Joint Surg 72B:161, 1990
30. Laurencin CT, Zelicof SB, Scott RD, Ewald FC: Unicompartmental versus total knee arthroplasty in the same patient. Clin Orthop 273:151, 1991
31. Marmor L: Unicompartmental knee replacement. p. 245. In Rand JA (ed): Total knee arthroplasty. Lippincott-Raven, New York, 1993
32. Skinner HB, Barrack RL, Brunet ME, Cook SD: Joint laxity and proprioception in the knee joint. Physician Sports Med 11:130, 1983
33. Faris PM, Jiang CC, Otis JC, Manouel M: Proprioceptive input of the posterior cruciate ligament in knee prostheses. Trans Orthop Res Soc 13:358, 1988
34. Warren PJ, Olanlokun TK, Cobb AG, Bentley G: Proprioception after knee arthroplasty: the influence of prosthetic design. Clin Orthop 297:182, 1993