

PROPRIOCEPTION, KINESTHESIA, AND BALANCE AFTER TOTAL KNEE ARTHROPLASTY WITH CRUCIATE-RETAINING AND POSTERIOR STABILIZED PROSTHESES

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Background: The effect of total knee arthroplasty on proprioception, kinesthesia, and postural control remains controversial. It is argued that retaining the posterior cruciate ligament may help to preserve these sensorimotor functions and improve the longevity of the prosthesis and the functional outcome. We performed a prospective, randomized study to assess proprioception, kinesthesia, and balance following total knee arthroplasty with cruciate-retaining and posterior stabilized prostheses.

Methods: Twenty patients scheduled to undergo total knee arthroplasty were randomly assigned to receive either a cruciate-retaining or a posterior stabilized prosthesis. Joint-position sense, the threshold to detect joint motion, and the subject's ability to balance on an unstable platform were assessed prior to and at least six months after the operation. Paired two-tailed t tests (with a level of significance of $p < 0.05$) were used to assess the effect of the arthroplasty on the preoperative measures for all subjects. Analysis of covariance was performed to identify the effects of prosthetic design.

Results: Following total knee arthroplasty, patients detected motion significantly faster and reproduced joint position with less error. The balance index also improved significantly from the preoperative to the postoperative evaluation. The group treated with the posterior stabilized prosthesis more accurately reproduced joint position when the knee was extended from a flexed position.

Conclusions: Total knee arthroplasty results in mild improvements in proprioception, kinesthesia, and balance. These changes may result from the retensioned capsuloligamentous structures and reduced pain and inflammation. Retention of the posterior cruciate ligament does not appear to significantly improve proprioception and balance compared with those functions in patients with a posterior stabilized total knee design.

Level of Evidence: Therapeutic study, Level I-1a (randomized controlled trial [significant difference]). See Instructions to Authors for a complete description of levels of evidence.

Patients with severe degenerative joint disease often require total knee arthroplasty to reduce pain, improve stability, and restore function¹. Reestablishing joint sensation and the ability to balance are important for maximization of patient outcome²⁻⁵. Whether sensorimotor functions such as proprioception, kinesthesia, and balance are restored after total knee arthroplasty is one issue that has been debated when cruciate-retaining and posterior stabilized prosthetic designs have been compared. It has been theorized that preservation of the posterior cruciate ligament improves joint sensation and thus patient outcome⁶⁻⁸.

The posterior cruciate ligament has different types of mechanoreceptors that detect joint position (proprioception) and joint motion (kinesthesia)⁹⁻¹³. This information is used to regulate motor control and coordination^{10,14,15}. Diminished joint sensation may precipitate degenerative changes, and a strong association between decreased proprioception and function has been identified in patients with osteoarthritis^{2,16-20}. After total knee arthroplasty, joint sensation is partially restored, which may enhance motor coordination and functional stability of the knee⁶. However, the most effective prosthetic design (cruciate-retaining or posterior stabilized) is not known^{4,16}.

Some have suggested that preserving the posterior cruciate ligament for its neurosensory qualities may improve the outcome of total knee arthroplasty⁶⁻⁸. Several authors have investigated proprioception retrospectively, but the results have been inconclusive^{5,6,8,21,22}. If retaining the posterior cruciate ligament enhances joint sensation, this might explain the slightly improved functional scores for gait and stair-climbing associated with cruciate-retaining designs^{3,21,23,24}. However, proponents of posterior stabilized designs report excellent clinical results also, and subjective knee surgery outcome scores have not demonstrated a difference between these designs²⁵⁻²⁸.

The purpose of this study was to evaluate and compare the effects of total knee arthroplasty with cruciate-retaining and posterior stabilized prostheses by assessing proprioception, kinesthesia, and balance.

Materials and Methods

A pretest-posttest two-group design was employed for this study of a consecutive series of patients who underwent total knee arthroplasty from 1997 to 1998 and met the inclusion and exclusion criteria. Patients were offered enrollment in this study, and those providing consent in accordance with the requirements of the university's biomedical institutional review board were randomly assigned to receive a cruciate-retaining prosthesis (ten patients) or a posterior stabilized prosthesis (ten patients); the NexGen total knee prostheses (Zimmer, Warsaw, Indiana) was used in both treatment groups. The independent variables were total knee arthroplasty (all subjects) and prosthetic design (cruciate-retaining or posterior stabilized).

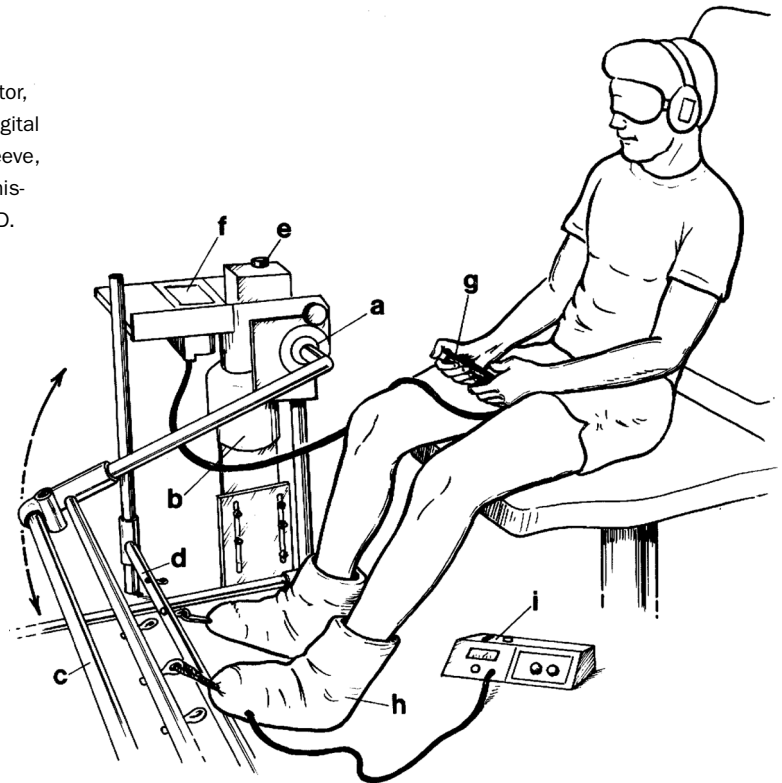
The three dependent variables were conscious awareness of passive joint position, threshold to detect passive motion, and standing balance on an unstable platform. All subjects were tested prior to the total knee arthroplasty (at mean of 1.5 months preoperatively) and at least six months after it (at a mean of 7.6 months postoperatively).

There were thirteen men and seven women. The mean age (and standard deviation) of the patients treated with the cruciate-retaining prosthesis was 71.1 ± 6.3 years, and the mean age of those treated with the posterior stabilized prosthesis was 69.4 ± 5 years. All patients had clinical and radiographic examinations (standing anteroposterior, lateral, and skyline radiographs), performed by one of the authors, to determine point tenderness, range of motion, stability, deformity, and level of function. All subjects had unilateral grade-2 or 3 arthritis according to the criteria described by Resnick and Niwayama²⁹. Subjects were excluded if they presented with varus or valgus deformity of $>10^\circ$, flexion contracture of $>10^\circ$, peripheral neuropathy, a history of cerebrovascular accident, insulin-dependent diabetes mellitus, a rheumatological disorder, or a prior total knee arthroplasty. Postoperative radiographs and clinical results were assessed according to Knee Society scoring systems and confirmed a good clinical outcome in all subjects³⁰.

Operative Procedures

A random-numbers list was used to assign subjects to one of the two groups. Patients were not informed of the knee arthroplasty design that would be used or made aware of it dur-

Fig. 1
Proprioception testing device. a = rotational transducer, b = motor, c = moving adapter, d = stationary arm, e = control panel, f = digital microprocessor, g = handheld on-off switch, h = compression sleeve, and i = pneumatic compression device. (Reproduced, with permission, from: Lephart SM, Kocher MS, Fu FH, Borsa PA, Harner CD. Proprioception following ACL reconstruction. *J Sport Rehab.* 1992;1:188-96.



ing the postoperative study period. Patients were informed of the type of implant only after the completion of the study. A standard total knee arthroplasty was performed with use of an extramedullary tibial guide and an intramedullary femoral guide^{31,32}. In no knee treated with the cruciate-retaining prosthesis was it necessary to balance or release the posterior cruciate ligament, and lateral release was not needed to balance the patella in any knee. All components were implanted with use of bone cement (Simplex P; Howmedica, Rutherford, New Jersey). Patients underwent a standard rehabilitation protocol that included early range of motion and weight-bearing as tolerated with crutch support for six weeks.

Assessment of Proprioception

Proprioception was assessed to determine the effect of total knee arthroplasty and prosthetic design (cruciate-retaining or posterior stabilized) on the patients' perception of joint motion and position. Testing procedures were identical to those used in our previous studies^{5,8} and followed the guidelines originally established by Barrack et al.^{16,17}.

The subject was seated on a proprioception testing device (Fig. 1) with the knee flexed to either 15° or 45°. The distal part of the leg was placed in a pneumatic sleeve, which was attached to the drive shaft of the device. Headphones and a blindfold were fitted to eliminate auditory and visual cues. Kinesthesia (joint motion) was measured as the threshold to detection of passive motion, and proprioception (joint position) was measured as reproduction of passive positioning. The starting knee-flexion angle and direction of movement were randomized. Previous studies employing the proprioception testing device¹⁴ revealed a test-retest reliability of $r = 0.92$.

The threshold to detection of passive motion was measured after three practice attempts. The subject signaled when he or she was ready, and within the next ten seconds the proprioception testing device passively rotated the subject's knee into flexion or extension at a velocity of 0.5°/sec. On perceiving motion, the subject disengaged the device by pressing a handheld switch, and the degree of rotation was recorded. This procedure was repeated a total of six times, with three repetitions measuring the threshold to detection of passive flexion and three measuring the threshold to detection of passive extension.

Reproduction of passive positioning was also assessed after three practice attempts. The subject's knee was rotated away from a reference position (15° or 45°) to a presented angle (approximately 10°) with the velocity of motion varied to nullify time cues. The subject was allowed to concentrate on the presented angle for ten seconds, after which the leg was passively rotated back to the reference position. The knee was then passively rotated at a constant velocity (0.5°/sec) back toward the presented angle. The subject was instructed to disengage the device by pressing the handheld switch when the knee position reproduced the presented angle. The difference between the presented angle and the reproduced angle was recorded in degrees. This procedure was repeated a total of four times, with reproduction of passive positioning moving into

flexion (one repetition) and extension (one repetition) measured from both of the reference positions (15° and 45°).

Assessment of Balance

The subject stood on a Biodex Stability System (Biodex, Shirley, New York), which is an unstable platform capable of tilting in the sagittal and coronal planes but not rotating in the transverse plane (Fig. 2). The level of difficulty while standing on the platform can be manipulated by altering the resistance of the platform to deviations. The balance test is most difficult when the platform provides the least resistance to tilting and is therefore the least stable. The unstable platform is interfaced with a data-reduction computer and monitor. A balance index is calculated by using the time and deviation (in degrees) of the platform away from a level position. For safety purposes, the system was equipped with a supportive upper-body harness and the subject was permitted to touch handrails, but only to reestablish balance during extreme postural deviations.

The subject was instructed to assume a bipedal stance on the platform while it was locked in a level position. The test pe-



Fig. 2
Subject positioned on the Biodex Stability System (Biodex, Shirley, New York). The unstable platform is used to measure postural control under dynamic conditions.

riod was commenced by unlocking the platform, and the subject then attempted to maintain his or her balance for twenty seconds. Each subject was allowed three practice attempts for familiarization purposes, and this was followed by three test trials at two different levels of difficulty. The less difficult condition (the more stable platform) was always performed first, and the foot position was recorded for the postoperative evaluation. The Biodex stability system has an interclass correlation coefficient ranging from $r = 0.6$ to $r = 0.96$ ³³.

Statistical Analysis

Paired two-tailed t tests (with a level of significance of $p < 0.05$) were used to determine the effects of total knee arthroplasty on the dependent variables, and one-way analyses of covariance were used to determine mean differences between cruciate-retaining and posterior stabilized treatment groups. The pretest values of the dependent variables were used as the covariate, and a probability level of 0.05 was considered to denote signifi-

cance. Variability of pilot data from the tests of reproduction of passive positioning yielded the most conservative estimate of the sample size for between-group comparisons. A minimum effect size of $\kappa^2 = 0.20$ between groups and a probability level of $\Delta = 0.05$ required ten subjects in each group for a statistical power of $p = 0.80$ ³⁴⁻³⁶.

Results

Preoperative Values Compared with Those After Total Knee Arthroplasty

Two of the eight measures improved significantly ($p < 0.05$) between the preoperative and postoperative evaluations. Subjects detected knee flexion more quickly ($p < 0.01$) after the total knee arthroplasty (mean threshold to detection of passive motion, $1.3^\circ \pm 0.3^\circ$) than they had preoperatively (mean threshold to detection of passive motion, $2.0^\circ \pm 1.35^\circ$) during the test beginning at the 15° joint angle. The subjects also reproduced joint position more accurately ($p < 0.001$) af-

TABLE I Joint Motion and Position Sense Before and After Total Knee Arthroplasty

Test Condition	Preop.*	Postop.*	T Value	P Value
Threshold to detection of passive motion†				
15°				
Extension	1.7 ± 1.37	1.40 ± 0.69	1.03	0.314
Flexion	2.02 ± 1.35	1.31 ± 0.30	2.71	0.014†
45°				
Extension	2.60 ± 1.56	2.35 ± 1.24	0.66	0.517
Flexion	2.62 ± 1.48	2.20 ± 1.34	1.07	0.298
Reproduction of passive positioning§				
15°				
Extension	2.78 ± 1.87	2.06 ± 1.62	1.35	0.194
Flexion	2.75 ± 2.04	3.20 ± 1.74	-0.95	0.352
45°				
Extension	3.22 ± 2.02	1.66 ± 0.99	3.85	0.001†
Flexion	2.43 ± 1.71	1.95 ± 1.24	1.20	0.245

*The values are given as the mean and the standard deviation. †The values indicate the degrees of rotation before motion is detected. ‡Denotes a significant difference between groups ($p < 0.05$). §The values indicate the degrees of error.

TABLE II Reproduction of Passive Positioning According to Prosthetic Design*

Position	Cruciate-Retaining		Posterior Stabilized	
	Preop.	Postop.	Preop.	Postop.
15°				
Extension	2.96 ± 1.61	2.13 ± 1.79	2.59 ± 2.17	1.98 ± 1.52
Flexion	3.09 ± 2.43	3.50 ± 1.95	2.41 ± 1.63	2.91 ± 1.54
45°				
Extension	3.82 ± 2.12	2.24 ± 1.03	2.62 ± 1.81	1.03 ± 0.48†
Flexion	2.11 ± 1.99	2.01 ± 1.40	2.75 ± 1.41	1.94 ± 1.24

*The values are given as the mean and the standard deviation for the degrees of error. †Denotes a significant difference between groups after total knee arthroplasty ($p < 0.05$).

TABLE III Threshold to Detection of Passive Motion According to Prosthetic Design*

Position	Cruciate-Retaining		Posterior Stabilized	
	Preop.	Postop.	Preop.	Postop.
15°				
Extension	1.29 ± 0.60	1.41 ± 0.52	2.16 ± 0.56	1.38 ± 0.84
Flexion	1.83 ± 1.09	1.29 ± 0.43	2.18 ± 1.61	1.32 ± 0.74
45°				
Extension	2.40 ± 1.41	2.52 ± 1.53	2.79 ± 1.76	2.18 ± 0.91
Flexion	2.49 ± 1.53	2.19 ± 1.43	2.75 ± 1.49	2.20 ± 1.33

*The values are given as the mean and the standard deviation for the degrees of rotation before motion is detected.

TABLE IV Balance Index According to Prosthetic Design*

Level of Difficulty	Cruciate-Retaining		Posterior Stabilized	
	Preop.	Postop.	Preop.	Postop.
8 (easy)	2.83 ± 1.38	2.72 ± 1.31	2.79 ± 1.52	2.44 ± 1.00
6 (difficult)	4.60 ± 1.52	3.72 ± 1.93	4.68 ± 2.68	2.84 ± 1.24

*The values are given as the mean and the standard deviation. Larger values depict greater platform deviations.

ter the total knee arthroplasty (mean reproduction of passive positioning, $1.7^\circ \pm 1.0$) than they had preoperatively (mean reproduction of passive positioning, $3.2^\circ \pm 2.0^\circ$) during extension from the 45° angle (Table I).

A significant ($p < 0.05$) improvement in balance was also detected following total knee arthroplasty. The balance index scores showed that, after the total knee arthroplasty, the patients were able to stand on an unstable platform with less postural deviations (mean balance index, 4.6 ± 2.1 preoperatively compared with 3.2 ± 1.6 postoperatively) at the more difficult level but not at the easier level.

Cruciate-Retaining Compared with Posterior Stabilized Prosthetic Design

Examination of joint position sense (reproduction of passive positioning) after the total knee arthroplasty revealed that the group treated with the posterior stabilized prosthesis reproduced joint position (mean error, $1.0^\circ \pm 0.5^\circ$) more accurately ($p < 0.05$) than did the group treated with the cruciate-retaining design (mean error, $2.2^\circ \pm 1.0^\circ$) (Table II), but only when the subjects attempted to reproduce the joint position from the 45° knee-joint angle, moving into extension. No significant ($p < 0.05$) group differences were identified for joint position sense when the subjects began at the 15° and 45° joint angles and moved into either flexion or extension. Between-group comparisons assessing the ability to detect joint motion (threshold to detection of passive motion) did not identify any significant differences at either of the two test angles (15° and 45°) moving into either flexion or extension (Table III). In addition, no significant differences in the balance measures were identified between the posterior stabilized and cruciate-retaining groups (Table IV).

Discussion

This study confirms that both joint proprioception and kinesthesia improve following total knee arthroplasty. Joint sensation is decreased in arthritic knees, but research by Barrett et al.⁶ and Warren et al.²¹ suggested that joint-position sense improves after total knee arthroplasty when compared with that of the contralateral limb and that in an osteoarthritic control group³⁷. In a prospective study, Attfield et al.³⁸ measured proprioception with use of a leg model and reported significant ($p < 0.01$) improvements six months following total knee arthroplasty. The mechanism for restoring joint sensation after total knee arthroplasty most likely involves the elimination of several deleterious factors in elderly and osteoarthritic patients^{17,20,39-42}. These patients have diminished joint sensation that can be linked to a loss of mechanoreceptors, pain, inflammation, laxity, decreased joint space, and physical activity levels^{16,42-48}. However, following total knee arthroplasty, the joint space and soft-tissue tension have been reestablished, pain and chronic inflammation are reduced, and activities of daily living can be resumed. These changes may modify the response characteristics of mechanoreceptors in both capsuloligamentous and musculotendinous structures, enhancing the perception of joint motion and position⁴⁹.

Cruciate-Retaining Compared with Posterior Stabilized Prosthetic Design

Previous arguments for selecting cruciate-retaining or posterior stabilized knee prostheses have focused on biomechanical issues, but the neurosensory contribution of the posterior cruciate ligament has also been considered to be an important factor in the selection of the implant design^{4,6-8,50}. Proponents

of cruciate-retaining designs have theorized that preserving the posterior cruciate ligament for its neurosensory properties is advantageous to patients and contributes to a more normal gait and "feel" of the knee after total knee arthroplasty; however, research substantiating these proprioceptive benefits with either prosthetic design has been contradictory^{6,7,21,22,27,51-55}.

The results of our study agree with those of Simmons et al.^{5,8} and others^{27,55} who could not identify any proprioceptive or kinesthetic advantages of preserving the posterior cruciate ligament. Sensory denervation of the posterior cruciate ligament begins early in the osteoarthritic knee. Consequently, the prospect that mechanoreceptors repopulate the posterior cruciate ligament and are responsible for enhanced joint sensation is limited^{13,16,37,41,56}. The improved scores following total knee arthroplasty could still be attributed to the reduction in pain, swelling, and deformity. Compensatory feedback from all of the capsular and musculotendinous receptors may also conceal sensory contributions from any single structure such as the posterior cruciate ligament. Our data suggest that decisions to select cruciate-retaining rather than posterior stabilized designs should not be based on joint sensations originating from the posterior cruciate ligament.

Balance

Joint motion and position sense also have an important role in the maintenance of balance. Diminished joint sensations are recognized as a factor contributing to balance deficits in the elderly, and patients with osteoarthritis of the knee present with worse balance than that demonstrated by age-matched controls^{47,57-59}. These balance deficits are associated with a loss of joint function and can be used to predict falls by the elderly; thus, they pose a serious health risk^{57,58}. The results of our study suggest that total knee arthroplasty significantly improves the ability to balance on an unstable platform but that neither cruciate-retaining nor posterior stabilized designs have a significant advantage over the other design.

The most plausible explanation for our results is that os-

teoarthritic pain, swelling, and instability compromise joint sensation and interfere with reflexive motor coordination prior to surgery⁶⁰. Our proprioception and kinesthesia test results demonstrate that total knee arthroplasty can reduce the adverse effects of arthritis, improving neuromuscular control and joint stability. The subjects' heightened appreciation of joint motion and position combined with the superior balance scores are evidence of enhanced sensorimotor function following total knee arthroplasty. The potential clinical impact of these results is promising and suggests that total knee arthroplasty restores sensorimotor characteristics necessary for balance and dynamic joint stabilization, reducing the risk of falls and subsequent injuries in this population. The lack of significant differences in balance between the cruciate-retaining and posterior stabilized treatment groups shows that both designs help to restore joint function. ■

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