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SYMPOSIUM: CURRENT ISSUES IN KNEE RECONSTRUCTION

Functional Performance with a Single-radius Femoral Design Total Knee Arthroplasty

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Abstract

Background Better muscular recovery of the extensor mechanism after TKA is claimed by femoral designs based on a sagittal single radius.

Questions/purposes We aimed to compare postoperative knee performance through the Knee Society scores, flexor and extensor muscle function, stability, and gait of a series of patients receiving a posterior stabilized, cemented TKA, with a single-radius femoral design.

Methods We compared a series of patients treated with a single-radius femoral design TKA to a simultaneous series of patients receiving a multiradius femoral design. Both groups were similar in demographics and preoperative Knee Society scores. The clinical pathways were identical. Outcome assessment included Knee Society scores, isokinetic assessment, stabilometry, and gait cycle analysis.

Results We observed higher functional Knee Society scores (86.6 ± 1.89 versus 80.3 ± 1.90), fewer physiotherapy sessions (19.9 ± 4.65 versus 22.2 ± 3.34), and less time with two crutches (3.5 ± 1.2 versus 5.2 ± 1.04 weeks) for patients receiving the single-radius design. Isokinetic evaluation showed decreased flexion peak torque (40.3 ± 7.9 versus 48.7 ± 9.6), increased extension peak torque (77.2 ± 16.1 versus 69.1 ± 14.4), and lower flexor/extensor ratio (0.5 ± 0.08 versus 0.7 ± 0.1) in patients with the single-radius design. Stabilometry showing less relative oscillation, and gait cycle indirectly confirmed better support in the limb with the single-radius design.

Conclusions The studied single-radius femoral design showed better functional short-term outcome and better extensor performance.

Level of Evidence Level III, therapeutic study. See the Guidelines for Authors for a complete description of levels of evidence.

Introduction

The extensor mechanism is the fundamental dynamic support of the knee during both stance and locomotion. Among the most frequent causes of failure of TKA, problems with the patellofemoral joint are the stated reason for revision in as high as 30.9% of registry diagnoses [19]. Different aspects in TKA design and surgical technique have been proposed to better cope with extensor mechanism demands, while trying to reproduce femorotibial anatomic displacement based on the implant design. However, most total knee systems fail to reproduce the extensor moment arm of the anatomic knee during flexion, which is a complex challenge especially when the cruciate ligaments are sacrificed.

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Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

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The posterior-stabilized (PS) prosthesis, sacrificing the PCL, incorporates a central post in the polyethylene insert to substitute its control of posterior tibial displacement during flexion. In this case, the absence of both cruciate ligaments allows anterior displacement of the femorotibial contact with higher knee flexion [5, 18]. This displacement moves the point of femorotibial contact closer to the tibial insertion of the patellar tendon, thus decreasing the moment arm and, secondarily, the performance of the extensor mechanism. Therefore, the effective extensor moment may be reduced after TKA [28], influencing the behavior of the prosthetic patellofemoral joint. This may occur even if the hamstrings, physiologic antagonists of the quadriceps, tend to minimize the anterior tibial displacement and extensor moment arm decrease as seen in ACL-deficient knees [24]. Femoral roll-back has been invocated as an optimizer of muscle function, and PS designs have shown a consistent roll-back compared with cruciate-retaining designs [8].

Many contemporary femoral designs attempt to reproduce normal knee kinematics using different rotation axes of knee flexion and extension. Condylar radius forces vary in the femoral component to accommodate this multiaxial requirement in the multiradius (MR) designs, while patellar symptoms are minimized by more anatomic designs of the femoral trochlea. In contrast, single-radius (SR) systems pursue a longer extensor moment arm by incorporating a femoral design with a single radius of knee flexion and extension through a more distal and posterior axis [6]. The purported advantages of the SR design include a decrease in the patellar load due to an increased extensor moment arm; a decrease in the required muscular strength for knee extension, and a better ligament stability based on a maintained isometry during the whole ROM (related to a single radius in the sagittal, distal femur). We predict these design features should improve extensor strength, and knee stability should accelerate and enhance the rehabilitation after PS TKA.

All these theoretical advantages remain to be clinically proven. We designed this observational, case-control study of a femoral SR, PS, cemented TKA system to assess the differences in functional recovery as evaluated by the Knee Society score (KSS) and the number of physical therapy sessions required for postoperative rehabilitation when compared to a commonly implanted multiradius design. We also measured muscular performance, stability of the PS TKA, and gait cycle and compared these with a control series of patients implanted with this well-known femoral MR, PS TKA system.

Patients and Methods

In this retrospective case-controlled study, 60 patients undergoing TKA at our institution were selected for study. Two TKA designs were utilized in our hospital during the study period (January 2006 through January 2007). These were the PS, cemented, Scorpio® system (SR femoral design) (Stryker Orthopaedics, Mahwah, NJ) or the PS, cemented, NexGen® system (MR femoral design) (Zimmer, Inc, Warsaw, IN). Surgeons selected the implant for each patient based on their preference. During this time period, 186 TKAs were performed at the hospital. Inclusion criteria for the study were surgical treatment for primary gonarthrosis between the selected dates, receiving as primary implant the Scorpio® system or the NexGen® implant. Strict inclusion and exclusion criteria were developed to create two very comparable study groups (Table 1). Sixty patients giving consent were recruited, with 30 receiving the SR femoral design and 30 receiving

Table 1. Inclusion and exclusion criteria

Criteria	Inclusion	Exclusion
Diagnosis	Primary gonarthrosis	Other TKA indication
Hip	No hip disorder or reconstruction	Coxarthrosis or THA
Contralateral knee	Asymptomatic or normal	Symptomatic or restricted function
Clinical pathway	Fully compliant	Noncompliant
Rehabilitation protocol	Completed	Uncompleted
Complications in followup	No	Yes
Flexion contracture	None or < 15°	> 15°
Flexion	> 90°	< 90°
Lower limb discrepancy	No	Yes
Able to walk without crutches at evaluation	Yes	No
Able to perform functional tests	Yes	No
Strength and equilibrium	No clinical impairment	Impairment

Table 2. Demographic and clinical variables

Variable	Total	MR	SR	P value*
Number of patients	60	30	30	
Age (years)†	73.2 (6.7)	73.7 (7.2)	72.7 (6.2)	0.557
Gender				
Men	30%	26.6%	33.3%	0.389
Women	70%	73.3%	66.6%	0.389
Weight (kg)†	75.9 (11.9)	74.6 (12.04)	77.2 (11.82)	0.408
Height (m)†	1.5 (9)	1.58 (9.2)	1.59 (8.8)	0.489
Laterality‡				
Right	28.3%	40% (22.4%–57.5%)	16.6% (3.3%–16.6%)	0.084
Left	71.6%	60% (42.4%–77.5%)	83.3% (70%–96.7%)	0.084
Patellar replacement‡				
Yes	20%	20% (5.6%–34.3%)	20% (5.6%–34.3%)	0.626
No	80%	80% (42.2%–77.5%)	80% (42.2%–77.5%)	0.626

* Student's t test for quantitative variables and chi square test for qualitative variables (comparison between control and evaluation groups); †values are expressed as mean, with SD in parentheses; ‡values are expressed as mean, with 95% confidence interval in parentheses; MR = patients receiving the multiradius design; SR = patients receiving the single-radius design.

the MR femoral design. Patients in the SR evaluation group did not differ from those in the MR group in any of the analyzed demographic variables (Table 2).

Operative and postoperative management was the same for both series. Surgical technique was paralleled in both series, including tourniquet use, parapatellar approach, patellar replacement in 20% of the cases in each group based on chondral lesions and tracking, wound closure in flexion, two drains during 48 hours, and postoperative compressive bandage. Postoperative management was performed following the hospital clinical pathway for TKA, from immediate postoperative analgesia to discharge. Postoperative rehabilitation in this pathway included cryotherapy [17, 30], physiotherapy [21], flexion contracture control [27], and patient information [29], but not continuous passive motion, electrostimulation, or orthesis, due to the insufficient evidence behind these techniques [25, 30].

The details of this clinical pathway include sitting on the second postoperative day, standing on the third postoperative day, active and passive physiotherapy (including cryotherapy, patellar and tibiofemoral passive and active motion, strengthening against resistance both in flexion and extension with active isometric and isotonic exercises, under supervision and manual control from the therapist) in the department as inpatient on the fourth postoperative day, and gait reeducation with two crutches until negotiating stairs (six steps) between the fourth and seventh postoperative days. At this point, the patient was discharged and physiotherapy continued on outpatient basis, including aerobic exercise counseling, gait, and strengthening. The number of required physiotherapy sessions varied depending on the gains in the independent gait, the progression in the ROM, and the presence of functional limitations or complications. The requirements for sessions were determined by an independent physiotherapist, blinded to the group the patient was included in.

Assessment for this study was performed at a minimum of 7 months (average, 10.9 months; range, 7–13 months) after surgery in the control group and 9 months (average, 10.7 months; range, 9–14 months) in the evaluation group. Outcome measurement included clinical variables (KSS with both clinical and functional areas [15], number of required days of physiotherapy, number of postoperative weeks until one of the crutches was abandoned), isokinetic evaluation, stabilometry, and gait cycle evaluation.

Isokinetic evaluation was performed in an isokinetic dynamometer (Biodex Medical Systems, New York, NY) that undergoes monthly automatic calibration. After appropriate patient fixation with thigh, ankle, and thoracic belts and correct alignment of the knee axis with the dynamometer, the limb was weighted to correct the gravity, and the 0° to 90° interval was fixed. After several repetitions to teach and prepare the patient, five maximum flexion and extension continuous contractions were recorded at a speed of 60° of knee flexion and extension per second under verbal stimulation. Hamstrings/quadriceps ratio may vary, depending on the velocity of the isokinetic test. We thus selected 60° per second to avoid other confounders present at higher velocities [4, 13]. Tests were adjudicated if the variation coefficient was below 20%. Studied variables included weight peak torque (%) for knee extensor and flexor (weight-normalized values), work peak torque (%) for extensor and flexor (weight-normalized values), peak torque angle for extensor and flexor (normal value, 60°), peak force at 0.18

seconds of extension, and flexion/extension ratio (normal value, 0.62 [16]).

Stabilometry was performed in a dynamometric balance platform (Satel, Blagnac, France) with three electromagnetic gauges recuperating pressure variations at a frequency of 40 Hz, after appropriate alignment of the patient following feet templates. Recordings were taken for 51.2 seconds after preacquisition detection and compared to reference values [3]. Variables in the stabilogram included surface (90% of the stabilogram ellipse) (normal values, 79–638 mm^2), length (displacement of the center of pressure) (normal values, 346–880 mm), surface/length ratio, x axis average displacement (normal values, −10.5 to 11.1 mm), and y axis average displacement (normal values, −3.6 to −51.4 mm).

For gait cycle evaluation, longitudinal displacements of both feet during gait against time were recorded with a computerized locometer (Satel). Data were normalized for age, height, weight, and foot length against a published database [2]. Gait variables included asymmetry parameters comparing the limb having the index TKA with the contralateral one (% step length, % unipodal stance time, asymmetry in the unipodal stance %, asymmetry in complete foot stance %, swing time [normal values, 2.97–0.22 seconds], speed of foot advancement [foot swing displacement from toe-off to the body axis plane] [normal values, 2.97–0.22 m/second], speed of foot return [from the body axis plane to heel strike] [normal values, 3.59–0.35 m/second) and comparative gait performance parameters (gait performance %, step length %, and gait cadence % [all normalized for age and height values]).

Continuous variables were expressed as mean ± SD. Comparative statistical analysis for the two study groups was performed for quantitative variables, after assessing the normal distribution with the Kolmogorov-Smirnov test, with Student's t test. Comparative study of qualitative variables was performed with the chi square test. The alpha value was set at 0.05. A statistical package SPSS® 15.0 (SPSS Inc, Chicago IL) was used.

Results

The comparative analysis of clinical outcome variables showed a higher ($p = 0.022$) functional KSS for the patients receiving the SR design prosthesis than for the MR group (86.6 ± 1.89 versus 80.3 ± 1.90), with a mean increase of 6.3 points (95% confidence interval [CI], 0.96–11.7 points) in the evaluation group. However, the clinical KSS did not show any difference ($p = 0.437$) (92.4 ± 1.9 in the SR group versus 91.4 ± 1.18 in the MR group). Patients with the SR design required fewer ($p = 0.001$) physiotherapy sessions (19.9 ± 4.65 versus 22.2 ± 3.34), with a mean difference from the MR group of 4.67 sessions (95% CI, 2.58–6.76 sessions). Furthermore, the number of required weeks until removal of one crutch was lower ($p = 0.001$) with the SR design (3.5 ± 1.2 weeks) than with the MR design (5.2 ± 1.04 weeks), with a mean difference of 1.7 weeks (95% CI, 1.12–2.8 weeks).

The comparative isokinetic analyses revealed no differences in the peak angle in extension, but the peak angle in flexion was higher ($p = 0.001$) in the MR group, with a mean difference of 8.4° (95% CI, 2.6°–14.3°) (Table 3). More interestingly, the peak torque in extension was higher ($p = 0.045$) in the SR group, with a mean difference of 6.1% (95% CI, 0.2%–16%). In contrast, the peak torque in flexion was higher ($p = 0.001$) in the MR group, with a mean difference of 8.4% (95% CI, 3%–12%). Accordingly, the flexion/extension ratio (hamstrings/quadriceps ratio) was lower ($p = 0.001$) in the SR group than in the MR group, with a mean difference of 0.19 (95% CI, 0.1–0.2).

The stabilometry assessment (Table 4) showed the only difference found was in the ratio of surface/length, which was higher ($p = 0.001$) in the SR group (a mean increase of 0.35 over the MR [95% CI, 0.1–0.5]), expressing the relative decrease of the body center-of-gravity oscillation (length) related to the same total area of oscillation (surface).

When the gait cycle quantitative parameters were compared (Table 5), only the speed in the swing phase of

Table 3. Isokinetic evaluation

Variable	Normal values	MR	SR	P value*
Peak torque extensor angle (°)	60°	63.5 (6.5)	63.1 (5.8)	0.804
Peak torque flexor angle (°)	60°	54.3 (11.4)	45 (8.7)	0.001
Weight extensor peak torque (%)	80%	69.1 (14.4)	77.2 (16.1)	0.045
Weight flexor peak torque (%)	80%	48.7 (9.6)	40.3 (7.9)	0.001
Work extensor peak torque (%)	80%	68.2 (26.7)	68.5 (19.5)	0.961
Work flexor peak torque (%)	80%	41.2 (15.1)	35.1 (2.8)	0.92
Flexion/extension ratio	0.5–0.8 [16]	0.7 (0.1)	0.5 (0.08)	0.000

Values are expressed as mean, with SD in parentheses; *Student's t test between MR and SR; MR = patients receiving the multiradius design; SR = patients receiving the single-radius design.

Table 4. Stabilometric variables

Variable	Normal values*	MR	SR	P value[†]
Surface (mm^2)	79–638	288.5 (187.3)	280.2 (89.1)	0.527
Length (mm)	346–880	728.2 (350.2)	670.7 (208.5)	0.473
Surface/length ratio	0.72–1.39	0.9 (0.3)	1.3 (0.3)	0.000
Location of average displacement, x axis (mm)	−10.5 to 11.1	1.5 (9.8)	0.9 (7.7)	0.807
Location of average displacement, y axis (mm)	−3.6 to −51.4	−32.8 (17.1)	−34.9 (22.9)	0.596

Values are expressed as mean, with SD in parentheses; *normative database provided by manufacturer in the system, based on Bizzo et al. [3]; [†]Student's t test; MR = patients receiving the multiradius design; SR = patients receiving the single-radius design.

Table 5. Gait cycle assessment, isolating unilateral data from the limb receiving TKA

Variable	MR	SR	P value*
Length of step asymmetry, unipodal (% of contralateral length of step)[†]	14.4 (44.6)	5.3 (26.6)	0.345
Time of support, unipodal (% of unipodal support versus normal)[‡]	7.2 (7.02)	5.4 (8.3)	0.354
Time of support asymmetry, unipodal (% decrease of contralateral foot support)[†]	2.7 (5.5)	0.8 (4.3)	0.146
Swing asymmetry (% increase of swing in the contralateral limb)[‡]	7.2 (10.8)	8.3 (5.7)	0.627
Speed of advance, contralateral limb (% speed of normal values in early swing)[‡]	32.17 (12.7)	39.6 (12.9)	0.013
Speed of return, contralateral limb (% speed of normal values in late swing)[‡]	60.13 (7.8)	65.20 (7.4)	0.018
Walking performance (% decrease of normal gait speed)[‡]	28.9 (14.9)	33.6 (16.8)	0.257
Stride length (% decrease of normal stride length)[‡]	17.03 (11.7)	21.40 (13.2)	0.184
Cadence (% decrease of normal gait cadence)[‡]	15.3 (11.9)	17.5 (10.6)	0.444

Values are expressed as mean, with SD in parentheses; *Student's t test for the comparison between MR and SR; [†]contralateral values were obtained for each patient; [‡]normal values to obtain the percentages included in the system and provided by the manufacturer; MR = patients receiving the multiradius design; SR = patients receiving the single-radius design.

the contralateral limb showed an increase in the SR group versus the MR group. A solid support is required for an adequate swing of the contralateral limb, so these were asymmetry variables that indirectly inform of the support phase in the limb with the implanted knee and were closer to normal in the SR patients than in the MR patients. The speed in the early swing, the so-called speed of advancement (from toe-off to the body axis plane), showed an increase ($p = 0.013$) of 7.43 m per second in the SR group compared to the MR group (95% CI, 4.19–12.4 m/second), and also the speed in the late swing, the so-called speed of return (from the body axis plane to heel strike), showed an increase ($p = 0.018$) of 5.07 m per second in the SR group compared to the MR group (95% CI, 1.12–9.01 m/second). Other variables of the gait cycle were not different (Table 5).

Discussion

In this observational, case-control study of a series of patients with a SR femoral system compared to a control MR femoral system, we assessed the functional and muscular recovery, stability, and gait cycle to determine whether the extensor performance of the knee was better with the SR design in a PS, cemented TKA.

Limitations of the study include the nonrandomization of patients, although a best scenario was intended by surgeon selection of the preferred system to be implanted, independent of the patient clinical profile. The relatively early timing of assessment may also be a limitation of the study. However, other authors studied the postoperative muscle changes at 3 and 6 months after surgery [20] and concluded parameters that decreased at 3 months postoperatively regained the preoperative level at 6 months. The evaluation could have been sequential to evidence postoperative gains. Instead, we compared final outcome between two groups in our study, based on paralleled demographic and clinical data in both series, under strict inclusion and exclusion criteria and a standardized rehabilitation protocol with physiotherapists blinded to the implanted system.

Postoperative function is the main goal of physiotherapy although its moderate effectiveness and only short-term benefits have been recently claimed based on a meta-analysis [22]. However, limited information is available for muscle strength. Quadriceps weakness is a frequent issue in knees receiving a TKA and has a substantial impact on the movement patterns and performance of the knee during functionally important tasks [23]. Although rarely evaluated, it should be the closest benefit of physiotherapy. In our study, we confirmed clear early functional gains with the SR design versus a contemporary MR design. Hall et al. [12] observed similar ROM and functional gain (to rise from a chair without assistance) after 1 year and concluded knee extensor mechanism function after TKA with either a SR (Scorpio®) or MR implant (PFC®; DePuy Orthopaedics, Inc, Warsaw, IN) was comparable in contemporary PCL-retaining TKA designs. In contrast, other authors [31] observed functional benefits to patients with a SR design, based on the sit-to-stand movement. Our study supports this latter conclusion in contemporary PCL-substituting TKA, based on the measured muscular performance of extensors by a reproducible isokinetic dynamometer and on the other outcome end points considered in our study that were not previously investigated.

About the isokinetic results, it should be noted the difference in the peak torque flexor angle may express this design difference, as the maximum tension angle of the hamstrings should vary with the differences in the flexor moment arm. The decrease of flexion torque is a frequent finding in TKA isokinetic studies [9] and was found here in both series, although more distinctively in the SR group. Instead, the extensor torque was higher in the SR group, and there was a substantial difference in the flexion/extension ratio. This last parameter best describes the recovery of the muscular function and has been proven to fall below healthy values in TKA patients with different designs even after long-term followup [14]. The obtained flexion/extension ratio of 0.5 with SR implants is within the best part of the range obtained in normal knees [16], while the ratio of 0.7 found with MR implants shows relatively weak extensors. A more favorable flexion/extension ratio depends not only on the increase of extensors but also on the decrease of flexors, and both changes converge when the radius is posteriorly located in the SR group, as proven in our study.

D'Lima et al. [6] showed in a cadaveric study patellofemoral forces were lower with the Scorpio® design than with the Osteonics 7000 knee (Osteonics Corp, Allendale, NJ) and hypothesized increasing quadriceps lever arm reduced quadriceps forces, which may result in reduced patellofemoral forces, which can have a beneficial effect on anterior knee pain, patellar component wear, and loosening. Although Epinette and Manley [7] failed to observe clinical differences in Scorpio® comparing resurfaced and nonresurfaced patellas, our results showing a clear muscular extensor advantage (as seen in the flexion/extension ratio) lead us to caution about not resurfacing the patella in this design, following Garneti et al. [11] who observed more anterior knee pain in nonresurfaced patellas with the Scorpio® design and suggested a more consistent outcome is achieved with patellar resurfacing.

In the stabilometric evaluation, we found no major differences between groups, indicating the differences in the proprioceptive input are not significant. Age and knee disturbances, including TKA, are associated with postural balance impairment [10]. Quadriceps recovery is a key aspect in knee and posture stabilization, and enough recovery was seen in both groups, but the better extensor recovery in the SR group may explain the finding of a relative decrease in the center-of-gravity oscillation (seen in the length of the stabilogram to the surface).

Gait cycle assessment has been performed in TKA patients using several technologies but converge in that gait differences persist in TKA patients up to 1 year after surgery compared to patients with normal knees [1], particularly in the speed, stride length, and cadence. This is congruent with our study, with notable variability present in both groups. No major differences in the studied parameters of the gait cycle were determined by the femoral design, as seen for the tibia design [26]. However, TKA patients showed a slower gait [26], but the speed during the swing phase of the contralateral limb in our series was better (expressed as % of normal values) in the SR group than in the MR group. Again, this indirect difference may be explained by a better quadriceps recovery, which can provide a better support in the implanted knee, thus allowing for the more physiologic biphasic gait. When the quadriceps is weaker, the gait becomes monophasic; thus asymmetry is increased and function is less adequate.

In conclusion, this study showed patients with a SR femoral design obtained better functional short-term outcomes in terms of reaching the postoperative goals with fewer physiotherapy sessions, requiring less time for first crutch abandonment, and obtaining better functional KSS before 1 year postintervention. In addition, a better extensor performance was shown in isokinetic testing, with slightly better posture stabilization and support during the gait cycle.

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