Improvement in hamstring and quadriceps muscle strength following cruciate-retaining single radius total knee arthroplasty

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Background: The ability to reach full functional capacity following total knee arthroplasty (TKA) is reliant on the strength of the quadriceps and hamstring muscles. Weakness of these muscles can persist anywhere from 1 to 3 years post-operatively. There remains considerable controversy as to what factors influence restoration of muscle strength after TKA. Implant designs have been implicated in the ability of patients to recover. Currently there is a paucity of literature available describing the influence of patient characteristics, surgical factors, and clinical outcomes on quadriceps and hamstring muscle strength following TKA with a cruciate-retaining, single radius (SR) implant. For this reason, we sought to investigate TKA patients for: (I) quadriceps muscle strength; (II) hamstring muscle strength; (III) flexion/extension (F/E) ratio; (IV) clinical outcome scores; (V) influence of patient characteristics on muscle strength at one-year post-operatively.

Methods: A review of TKA patients who were assessed for hamstring and quadriceps muscle strength was conducted. A total of 39 patients (26 men and 13 women), who had a mean age of 68 years (range, 51 to 88 years) were included. Isokinetic dynamometer testing at 180 degree/second for 3 sets of 10 repetitions in extension and flexion were performed by an independent physical therapist to assess dynamic concentric torque of the hamstrings and quadriceps muscle. F/E ratios were calculated. TKA was performed via subvastus (n=20) or midvastus (n=19) approach. Subgroup analysis for surgical approach, concomitant spinal pathology (n=11), gender, age and body mass index (BMI) were performed. Knee Society Scores (KSS) and range of motion (ROM) were assessed at each visit. Comparisons of groups were performed using paired *t*-tests.

Results: Mean postoperative relative extension torque was 23 Nm/kg (range, 9 to 43 Nm/kg), representing a mean increase of 38% (range, –16% to 100%; P=0.0267) from pre-operative status. A mean increase of 27% (range, –15% to 100%; P=0.0433) in flexion strength and mean relative flexion torque of 19 Nm/kg (range, 8–37 Nm/kg) was observed. Pre-operative mean F/E ratio was 0.8 and 0.9 post-operatively (P=0.3028). Men demonstrated significantly greater improvements in flexion compared to women (22% *vs.* 12%; P<0.0001), but gender had no influence on improvement in extension (27% *vs.* 15%; P=0.0537). Postoperative F/E was similar for males (0.8) and females (0.9; P=0.4454). Surgical approach did not influence quadriceps muscle strength (P=0.1786) or hamstrings muscle strength (P=0.9592). History of spine pathology had no impact on muscles strength (hamstring, P=0.5684; quadriceps, P=0.7221). For the overall group, a mean KSS pain score was 96 points (range, 84 to 100 points), KSS function was 96 points (range, 80 to 100 points), and mean ROM of 0 to 114 degrees.

Conclusions: Restoration of quadriceps and hamstring muscle strength can be expected at 1 year post-operatively regardless of gender, surgical approach or concomitant spinal pathology. Further comparative investigation on the impact of implant design on hamstring and quadriceps muscle strength is warranted. However, the use of a SR, CR TKA system demonstrated significant improvements post-operatively in quadriceps and hamstring strength.

Keywords: Total knee arthroplasty (TKA); quadriceps strength; hamstring strength; single radius (SR); cruciate retaining

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Introduction

Although total knee arthroplasty (TKA) have been shown to alleviate pain and improve function, a large percentage of patients remain dissatisfied after their procedure (1-3). In the current healthcare climate, patient satisfaction following this procedure has become further scrutinized. Despite improvements post-operatively, up to 20% of patients report persistent muscle weakness as the primary reason for their dissatisfaction (4,5).

Improvement in function following TKA is largely attributed to restoration of strength of the extensor mechanism of the knee (6) Following TKA, quadriceps and hamstring muscle strength weakness can persist for up to 2 years post-operatively, translating into difficulty with activities of daily living such as stair climbing or walking (7-12). However, gaining post-operative improvements in quadriceps and hamstring muscle strength can be multi-factorial. Several factors including age, body mass index (BMI), surgical technique, and implant design may play a role (13-15). A single-radius prosthesis has been designed to improve the functional recovery after TKA. This implant type proposes several advantages when compared to a multi-radius design. With only one flexion-extension axis, stability is sustained throughout movement, and it requires less recruitment of quadriceps strength compared to multi-radius designs to perform activities of daily living (16-19). Furthermore, compared to multi-radius designs, single radius (SR) implants have been shown to offer a quicker time to recover (16,20). It has been postulated that these designs may aid in improvements of muscle strength, range of motion (ROM), and potentially patient reported outcomes.

Currently there is a paucity of literature available describing the influence of patient characteristics, surgical factors, and clinical outcomes on quadriceps and hamstring muscle strength following TKA with a cruciate-retaining, SR implant. For this reason, we sought to investigate TKA patients for: (I) quadriceps muscle strength; (II) hamstring muscle strength; (III) flexion/extension (F/E) ratio; (IV) clinical outcome scores; (V) influence of patient characteristics on muscle strength at 1-year post-operatively.

Methods

Patient selection

Following Institutional Review Board approval, 41 patients (41 knees) undergoing primary TKA from February 1st, 2006 to July 31st, 2013 were prospectively enrolled to evaluate quadriceps and hamstring muscle strength. All procedures were performed by a single, fellowship trained adult reconstruction orthopaedic surgeon at a single, high-volume institution. The following patients were considered for inclusion: (I) functionally intact PCL; (II) less than 15 degrees of varus; (III) minimum of 1-year post-operative follow-up; (IV) treated with the Scorpio CR (Stryker Orthopaedics, Mahwah, New Jersey, USA) implant. Patients who had less than 1-year post-operative follow-up or incomplete isokinetic strength testing data were excluded [two patients (2 knees)]. Post-operative range of ROM measurements were missing from two patients and were excluded from this sub-group evaluation as well.

A total of 39 patients (39 knees) who completed 1-year follow-up were included for analysis. The cohort consisted of 13 women and 26 men, who had a mean age of 68 years (range, 51 to 88 years) and a mean BMI of 32 kg/m^2 (range, 23 to 48 kg/m^2). There were 21 patients (54%) who that reported contralateral knee (n=17, 43%), hip (n=1, 2%) or both (n=3, 8%) pathology or prior arthroplasty. Eleven patients (28%) reported concomitant back pathology including lumbar spinal stenosis, lumbar degenerative disc disease, and chronic lower back pain. One patient (2%) underwent a revision surgery prior to isokinetic testing and was excluded from the analysis. There were no post-operative complications.

Study design

All patients who underwent a TKA received spinal anesthesia with a proximal femoral block. The procedure

was performed with a standard midline skin incision, utilizing a midvastus (19 patients) or subvastus (20 patients) approach. Following surgery, all patients were admitted and placed on a patient controlled analgesia (PCA) pump for the first 23 hours. Patients were given aspirin as venous thromboembolism (VTE) prophylaxis, along with intermittent pneumatic compression and early mobilization. Physical therapy began on the first postoperative day and continued for 6 to 12 sessions following discharge. All patients were discharged home within 48 hours of surgery.

Quadriceps and hamstring strength was assessed via an isokinetic dynamometer System 4 Pro (Biodex Medical Systems, Shirley, New York, USA) at the pre-operative and 1-year post-operative visit. Isokinetic dynamometer testing at 180 degree/second for 3 sets of 10 repetitions in extension and flexion was performed by an independent physical therapist to assess dynamic concentric torque of the hamstrings and quadriceps muscles. Clinical evaluations were performed using the Knee Society Score (KSS), as well as active ROM at pre-operative and 1-year post-operative (21).

Statistical analysis

All data was de-identified and imported into a Microsoft Excel (Excel; Microsoft, Redmond, Washington) spreadsheet. Statistical analyses were performed using SPSS Version 23 (IBM Corp., Armonk, New York, USA). Descriptive statistics were used to analyze the means and ranges for continuous variables. Comparisons of quadriceps and hamstrings muscle strength among groups were performed utilizing student *t*-tests. A P value of <0.05 was deemed statistically significant and 95% confidence intervals (CI) were used.

Results

Quadriceps strength

Mean quadriceps muscle strength significantly increased from pre-operative evaluation at 19 Nm/kg (SD 1; range, 5 to 36 Nm/kg) to post-operative evaluation at 23 Nm/kg (SD 8; range, 9 to 43 Nm/kg; P=0.0001, 95% CI: –6.088 to –2.625). The mean pre-to-post operative improvement was 4 Nm/kg (range, –4 to 20 Nm/kg) representing a 37% (range, –16% to 100%) increase in quadriceps muscle strength.

Hamstring strength

Mean hamstring muscle strength significantly improved from pre-operative evaluation at 15 Nm/kg (SD 6; range, 6 to 29 Nm/kg) to post-operative evaluation, 19 Nm/kg (SD 8; range, 8 to 37 Nm/kg; P=0.0433, 95% CI: –6.307 to –0.099). This represents a mean of 3 Nm/kg (range, –5 to 14) or 26% (range, –22% to 100%) increase in hamstring muscle strength.

Flexion/extension ratio

There was a decrease from pre-operative F/E ratio of 0.88 (SD 0.2; range, 0.5 to 1.3) to post-operative F/E ratio of 0.83 (SD 0.2; range, 0.5 to 1.3; P=0.0936, 95% CI: –0.009 to 0.112).

Clinical outcomes scores

The mean pre-operative ROM was 5 (SD 3) degrees of extension to 97 (SD 9) degrees of flexion. Mean post-operative ROM was 0 (SD 1) degrees of extension to 117 (SD 8) degrees of flexion. Pre-to-post operative mean ROM improvement was 5 degrees of extension (P=0.0001, 95% CI: 4.07 to 6.25) and 20 degrees of flexion (P=0.0001, 95% CI: –23.51 to –16.39).

The mean KSS pain was 95 points (SD 4, range, 84 to 100 points) postoperatively and mean KSS function was 96 points (SD 6, range, 80 to 100 points) postoperatively.

Influence of demographics

Patients under the age of 65 years had significantly higher quadriceps muscle strength (26 *vs.* 21 Nm/kg, P=0.0443), and significantly higher hamstring muscle strength (22 *vs.* 16 Nm/kg, P=0.0092) post-operatively. However, no significant differences were noted in hamstring muscle strength (P=0.0837) or quadriceps muscle strength (P=0.0843) from pre-to-post operative based upon age (*Table 1*).

Male patients demonstrated greater post-operative extension and flexion strength than females (P=0.0001), however, there was no difference in pre-to-postoperative change in strength for extension or flexion based on gender (P=0.9668 for extension and P=0.9136 for flexion) (*Table 1*).

Sub-group analysis of BMI demonstrated that patients who had a BMI of >30 kg/m^2 had a significantly higher pre-to post-operative gain in flexion strength (P=0.0040, 95%

Table 1 Mean post-operative quadriceps and hamstring muscle strength (N/kg) by demographic variables

Variables	Age, mean ± SD (range)			BMI, mean ± SD (range)			Gender, mean ± SD (range)		
	≤65	>65	P value (95% CI)	≤30	>30	P value (95% CI)	Males	Females	P value (95% CI)
Age	57	74	0.0001	73	64	0.0038	66	71	0.1610
Quadriceps	26.3±7.3 (15 to 43)	20.97±8.1 (9 to 35)	0.0443 (0.144 to 10.541)	23.9±7.1 (11 to 35)	22±8.8 (9 to 43)	0.6049 (–4.065 to 6.885)	26.9±6.2 (16 to 43)	15.36±5.7 (9 to 30)	0.0001 (7.314 to 15.679)
Quadriceps Δ	6.23±6.28 (–4 to 20)	3.18±4.4 (–4 to 10)	0.0837 (–0.43 to 6.5)	3±5.6 (–4 to 14)	6±4.9 (–3.5 to 20)	0.0897 (–6.454 to 0.486)	4.33±6 (–4 to 20)	4.4±3 (–0.1 to 9)	0.9668 (–3.802 to 3.648)
Hamstring	22.3±8.2 (14 to 37)	16.1±5.9 (8 to 32)	0.0092 (1.643 to 10.842)	17.28±6 (8 to 32)	19.2±8 (10 to 37)	0.4382 (6.943 to 3.070)	21.5±7 (12 to 37)	12±2.5 (8 to 18)	0.0001 (4.872 to 13.343)
Hamstring Δ	4.7±5.6 (–3.9 to 14)	2.2±3.2 (–4.6 to 9.4)	0.0843 (–0.355 to 5.352)	0.7±3 (–4.6 to 6)	4.7±4.4 (–2.6 to 14)	0.0040 (–6.676 to –1.370)	3.258±5 (–4.6 to 14)	3.1±2.4 (–1.2 to 6)	0.9136 (–2.901 to 3.232)
F/E	0.88±0.262 (0.5 to 1.3)	0.80±0.19 (0.5 to 1.3)	0.2728 (–0.066 to 0.226)	0.727±0.167 (0.5 to 1)	0.896±0.226 (0.5 to 1.3)	0.0168 (–0.306 to –0.032)	0.812±0.2 (0.5 to 1.3)	0.87±0.2 (0.5 to 1.3)	0.4454 (–0.209 to 0.094)
KSS pain	94.6±4.5 (84 to 99)	95.88±3.34 (90 to 100)	0.3445 (–3.77 to 1.35)	96.27±3 (90 to 100)	94.88±4 (84 to 100)	0.2753 (–1.16 to 3.94)	95.5±3.75 (88 to 100)	95.23±4.13 (84 to 100)	0.8392 (–2.40 to 2.94)
KSS function	97.2±4.5 (90 to 100)	95.4±6.58 (80 to 100)	0.3633 (–2.14 to 5.71)	95.33±6 (80 to 100)	97±5.6 (80 to 100)	0.5252 (–5.20 to 2.70)	95±6.5 (80 to 100)	98±3.7 (90 to 100)	0.0979 (–7.25 to 0.64)

Δ, change in quadriceps strength from pre-to-post-op. F/E, flexion/extension; KSS, Knee Society Scores.

Table 2 Mean post-operative quadriceps and hamstring muscle strength (N/kg) by demographic variables

Variables	Back issues, mean ± SD (range)			Contralateral problem, mean ± SD (range)			Incision type, mean ± SD (range)		
	Yes	No	P value (95% CI)	Yes	No	P value (95% CI)	SV	MV	P value (95% CI)
Age	70	67	0.4481	66	70	0.1908	68	69	0.7245
Quadriceps	22.3±8 (11 to 35)	23±8 (9 to 43)	0.7221 (–6.979 to 4.881)	22±9 (9 to 43)	24±7 (13 to 33)	0.4382 (–7.375 to 3.261)	21±8 (9 to 43)	25±8 (9 to 35)	0.0836 (–0.643 to 9.843)
Quadriceps Δ	6.6±6 (–3 to 20)	4±5.8 (–4 to 20)	0.1755 (–1.366 to 7.217)	5±6 (–4 to 20)	3±5 (–4 to 11)	0.1308 (–0.810 to 6.011)	5±6 (–4 to 20)	6±5 (–3 to 20)	0.7275 (–3.00 to 4.25)
Hamstring	17±7.5 (11 to 32)	19±7.5 (8 to 37)	0.5684 (–6.977 to 3.890)	19±8 (10 to 37)	17±6 (8 to 31)	0.3783 (–2.729 to 7.020)	18±8 (10 to 37)	18±8 (8 to 37)	0.9592 (–5.162 to 4.907)
Hamstring Δ	3±2.7 (–2 to 8)	3±5 (–4.6 to 14)	0.8597 (–3.494 to 2.930)	4±4 (–4 to 13)	2±5 (–5 to 14)	0.0941 (–0.432 to 5.258)	4±4 (–1 to 14)	4±4 (–2 to 13)	0.9126 (–2.80 to 2.51)
F/E	0.818±0.24 (0.5 to 1.3)	0.836±0.21 (0.5 to 1.3)	0.8254 (–0.177 to 0.142)	0.9±0.2 (0.5 to 1.3)	0.733±0.2 (0.5 to 1)	0.0472 (0.002 to 0.274)	0.9±0.2 (0.5 to 1.3)	0.9±0.25 (0.5 to 1.3)	0.7005 (–0.170 to 0.115)
KSS pain	95.18±5 (84 to 99)	95.5±3.53 (88 to 100)	0.8189 (–3.11 to 2.48)	97±3 (88 to 100)	94±4 (84 to 100)	0.0195 (0.48 to 5.17)	95±5 (84 to 100)	96±3 (90 to 100)	0.4394 (–1.58 to 3.55)
KSS function	96.2±7 (80 to 100)	96±6 (96 to 80)	0.9587 (–4.18 to 4.40)	98±5 (80 to 100)	94±6 (80 to 100)	0.0200 (0.72 to 7.92)	96±6 (80 to 100)	96±6 (80 to 100)	0.6666 (–4.79 to 3.10)

Δ, change in quadriceps strength from pre-to-post-op. F/E, flexion/extension; KSS, Knee Society Scores; SV, subvastus; MV, midvastus.

CI: –6.676 to –1.370). Furthermore, patients with BMI >30 kg/m^2 had significantly higher post-operative F/E ratio compared to patients ≤30 kg/m^2 (P=0.0168, 95% CI: –0.306 to –0.032).

The presence of concomitant back pathology, contralateral knee or hip pathology, or incision type did not influence post-operative quadriceps or hamstring muscle strength. However, patients who had contralateral hip or knee pathology demonstrated a higher post-operative F/E ratio, KSS function, and KSS pain scores (*Table 2*).

Discussion

Restoration of quadriceps and hamstring muscle strength following TKA is an important predictor of functional improvement and ultimately satisfaction following TKA (6). Previously, literature has demonstrated that restoration of strength can take as long as 2 years post-operatively to improve, thus presenting substantial disability to perform tasks of daily living (7-12). A single-radius design prosthesis offers several theoretical advantages in restoring post-operative quadriceps and hamstring muscle strength, however, there is a paucity of data investigating the influence of patient characteristics on muscle strength in the setting of a SR TKA. We demonstrated that patients who underwent TKA utilizing a SR, CR prosthesis had a 37% and 26% increase in quadriceps and hamstring muscle strength, had excellent ROM and KSS (95 to 96 points), while maintaining an appropriate F/E ratio. In addition, we found that patients who had a BMI of >30 kg/m^2 had significantly higher gains in muscle strength from before to after surgery.

This study has several limitations. The relatively small sample size and sub-groups makes our results hard to extrapolate to the general public. Furthermore, only pre-to post-operative quadriceps and hamstring muscle strengths were evaluated with no comparison to an age-matched cohort or contralateral knee. Nevertheless, we were able to demonstrate excellent strength and functional outcomes in patients who received cruciate-retaining SR total knee arthroplasties.

Gómez-Barrena *et al.* evaluated isokinetic strength at 60 degrees/second in a case-control of 30 single radius (SR-Scorpio Stryker Orthopaedics, Mahwah, New Jersey) and 30 multi radius (MR-NexGen Simmer, Warsaw, Indiana) design TKA, demonstrating lower F/E ratio, increased extension peak torque (77 *vs.* 69), and decreased flexion peak torque (40 *vs.* 49) in the SR cohort. Furthermore, patients with SR design required fewer physical therapy session and were able to remove one crutches at a mean 1.5 weeks sooner (22). Biomechanical studies investigating the single-radius design have concluded that a more posterior flexion-extension access acts to lengthen the quadriceps moment arm and making the quadriceps more efficient (16,20). Alterations in movement mechanics as a compensatory effect of quadriceps and hamstring weakness decreased during sit-to-stand, stair climbing, or walking in patients post-operatively (10). Mahoney *et al.* performed a case-control study of independent rise from chair in 83 MR and 101 SR knees. At 1 year post-operatively 89% of patients within the SR group could independently rise from a chair compared to 74% of the multi-radius group (20). Furthermore, Wang *et al.* demonstrated that MR TKA design was associated with a higher degree of compensatory changes requiring a greater activation of the quadriceps and hamstring muscles during sit-to-stand movements (18). Similarly, Colwell *et al.* investigated 94 knees utilizing the Scorpio non-restrictive geometry-CR knee prosthesis, demonstrating at 1-year post-operatively 67% of knees had improved flexion and a mean flexion of 116.9 degrees (23). Conversely, Hall *et al.* compared 50 patients with Scorpio-PS and 50 patients with Press Fit Condylar Sigma design (Johnson & Johnson PFC; DePuy, Johnson & Johnson, Warsaw, Ind) demonstrating no difference in mean maximum flexion, with both cohorts at 106 (24). Nevertheless, most studies, including the present one, have demonstrated excellent outcomes with the use of SR, CR total knee arthroplasty design.

In conclusion, the use of a SR, CR total knee arthroplasty system provides significant improvements post-operatively in quadriceps and hamstring strength regardless of gender, age, contralateral knee pathology, back pathology, or incision type. Obese patients should be counseled that muscle weakness may persist post-operatively and appropriate pre-operative counseling on weight management is appropriate. Further comparative investigation on the impact of implant design on hamstring and quadriceps muscle strength is warranted. However, SR, CR total knee arthroplasty system demonstrated excellent results in terms of muscle strength and ROM improvements.

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None.

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

Ethical Statement: The study was approved by Institutional Review Board of Bonutti Clinic.

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