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CLINICAL RESEARCH

Tibial Tubercle Osteotomy or Quadriceps Snip in Two-stage Revision for Prosthetic Knee Infection? A Randomized Prospective Study

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Abstract

Background Although 7% to 38% of revision total knee arthroplasties (RTKAs) are attributable to prosthetic knee infections, controversy exists regarding the best surgical approach while reducing the risk of extensor mechanism complications and the reinfection rate.

Questions/purposes We compared The Knee Society Score© (KSS), incidences of complications, maximum knee flexion, residual extension lag, and reinfection rate in patients with prosthetic knee infections treated with two-stage RTKAs using either the tibial tubercle osteotomy (TTO) or the quadriceps snip (QS) for exposure at the time of reimplantation.

Methods We prospectively followed 81 patients with chronic prosthetic knee infections treated between 1997 and 2004. Patients were randomized to receive a TTO or QS for exposure at the time of reimplantation. All patients had the same rehabilitation protocol. The minimum followup was 8 years (mean, 12 years; range, 8–15 years).

Results Patients in the TTO group had a higher mean KSS than the QS group (88 versus 70, respectively). Mean maximum knee flexion was greater in the TTO group (113° versus 94°); with a lower incidence of extension lag (45% versus 13%). We observed no differences in reinfection rate between groups.

Conclusions We found the TTO combined with an early rehabilitation protocol associated with superior KSS did not impair extensor mechanism function or increase the reinfection rate. We believe a two-stage RTKA with TTO is a reasonable approach for treating prosthetic knee infections.

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

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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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Introduction

Infection is a leading cause for revision total knee arthroplasty (RTKA) [11, 12]. Studies have shown that 6.6% to 38% of RTKAs are attributable to prosthetic knee infections [5, 11, 23, 24, 31, 41, 43, 55, 58, 76, 95, 96]. Although some [56, 63] prefer it, a two-stage procedure for chronic prosthetic knee infection requires temporary cement spacers to preserve limb length and reduce soft tissue retraction. Static spacers have been suggested [7, 15, 28, 30] to be more stable than mobile spacers when these knees have substantial bone loss. In either case subsequent exposure for reimplantation is more difficult owing to soft tissue shortening [2, 20, 29, 30, 33, 38, 49, 57, 89, 98], with an increased risk of extensor mechanism rupture, delayed wound healing, and reinfection [64, 79, 104].

Many exposures have been developed to preserve the integrity of the extensor mechanism in primary and revision procedures [13, 27, 62, 73, 79, 105]. In 1943, Coonse and Adams [20] described a proximal release of the extensor mechanism, called the VY quadricepsplasty. Although it provides a wide exposure, prolonged postoperative immobilization is required, with a high incidence of extension lag [83, 92] and avascular necrosis of the patella [60, 85]. Insall [52] modified this technique, extending the incision through the vastus lateralis to preserve the inferior lateral geniculate vessels, calling it the patellar turndown. Later, Garvin et al. [36] developed the quadriceps snip (QS) (Fig. 1), a 45°-angle cut in the vastus lateralis, and in a review of 16 patients, including 10 with RTKAs, rated 10 patients as having excellent results and six as having good results using the Hospital for Special Surgery scoring system, without extensor mechanism impairment and the ROM improved in all knees by an average of 30°. The tibial tubercle osteotomy (TTO) (Fig. 2) was described by Dolin [25, 26], and later by Whiteside [99] and Whiteside and Ohl [101]. Although TTO provides excellent exposure of the joint and allows lengthening and extensor realignment, it was associated with increased complication rates, including anterior knee pain, nonunion, tibial metaphyseal fracture, tubercle avulsion fracture, extension lag, and hardware-related pain, regardless whether screws or cerclage wires were used for fixation [6, 102]. The function and morbidity related to these exposures is unclear.

We therefore asked whether a TTO or QS would result in a superior Knee Society Score© (KSS) [53] in two-stage RTKAs for prosthetic knee infections, incidence of complications, postoperative maximum knee flexion, residual extension lag, and reinfection rates.

Patients and Methods

Ninety patients, treated between 1997 and 2004 for two-stage RTKAs for chronic prosthetic knee infections, were followed prospectively. A diagnosis of chronic prosthetic knee infection, at more than 6 weeks after TKA, [8, 40, 54, 71, 77, 93], defined by at least three of the following, was the inclusion criteria (Table 1): (1) unexplained pain with no radiographic evidence of implant malpositioning; (2) 10 mg/L or greater C-reactive protein (CRP) without preexisting inflammatory joint disease [4, 75, 86]; (3) 30 mm/hour or greater erythrocyte sedimentation rate

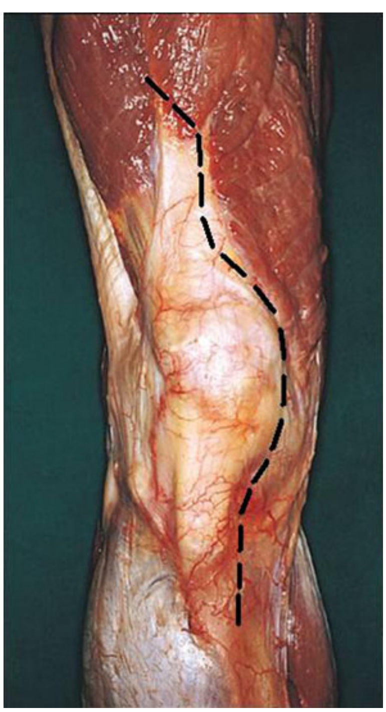

Fig. 1 The QS joint exposure is shown on this cadaveric specimen.

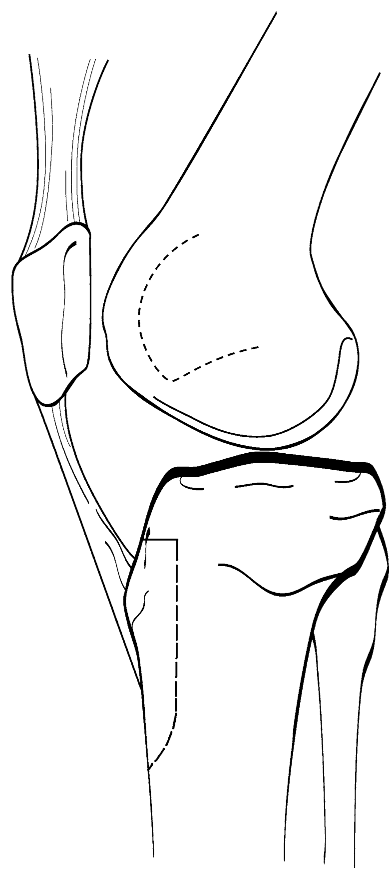

Fig. 2 A schematic drawing illustrates the TTO. The proximal step-cut and the distal tapered cut can be seen.

Table 1. Incidence of diagnostic criteria in quadriceps snip and tibial tubercle osteotomy groups

Diagnostic criteria	Quadriceps snip group (number of patients = 42)	Tibial tubercle osteotomy group (number of patients = 39)	p value
Unexplained pain and discomfort with no radiographic evidence of implant malpositioning	37 (88%)	39 (100%)	0.996
C-reactive protein of 10 mg/L or greater in patients without preexisting inflammatory joint disease [38–40]	42 (100%)	39 (100%)	0.991
Erythrocyte sedimentation rate of 30 mm/hour or greater in patients without preexisting inflammatory joint disease [38–40]	33 (79%)	31 (79%)	0.996
Radiographic evidence of implant loosening and/or periosteal bone formation and/or progressive nonfocal osteolysis without malpositioning of the implant [41]	12 (29%)	11 (28%)	0.997
A sinus tract or a fistula communicating with the prosthesis	13 (31%)	16 (41%)	0.994
Abnormal spots on leukocytes labeled with technetium-99 m scintigraphy (LeukoScan®) [42]	30 (71%)	27 (69%)	0.995
A positive culture of synovial fluid collected with a preoperative joint aspiration	8 (19%)	13 (33%)	0.987
Five or more polymorphonuclear cells in at least five fields of a high power field in periprosthetic tissue collected during the removal of the primary implant [43–45]	38 (90%)	39 (100%)	0.997
Positive synovial fluid cell count (> 2000 polymorphonuclear cells with > 64% polymorphonuclear cells in patients without preexisting inflammatory joint disease [39–45])	20 (48%)	17 (44%)	0.993
Patients with at least three diagnostic criteria	42 (100%)	39 (100%)	0.996

No significant differences were noted between the groups.

(ESR) without preexisting inflammatory joint disease [4, 75, 86]; (4) radiographic implant loosening and/or periosteal osteogenesis and/or progressive nonfocal osteolysis without implant malpositioning [90]; (5) sinus or fistula communicating with prosthesis; (6) abnormal leukocytes labeled technetium-99 m bone scan (LeukoScan®, Immunomedics GmbH, Darmstadt, Germany) [61]; (7) a positive culture of synovial fluid collected preoperatively; (8) five or more polymorphonuclear cells in at least five high-power fields in periprosthetic tissue samples, collected on removal of primary implant [9, 32, 91]; (9) a positive synovial fluid cell count (more than 2000 polymorphonuclear cells with greater than 64% polymorphonuclear leukocytes) without preexisting inflammatory joint disease [75, 91]. A high American Society of Anesthesiologists (ASA) score [59] excluded four patients. They were treated with antibiotics and pain management. Computer-generated randomization populated the QS or TTO groups. No differences in demographics, functions, or serology differences were noted between them before primary implant removal (Table 2). Of the 90 patients recruited, nine were unavailable for final evaluations: five in the QS group (four died of unrelated reasons, one was lost to followup); four in the TTO group (two died of unrelated reasons, two lost to followup). Forty-two patients in the QS group and 39 in the TTO group were available with final followups ranging from 8 to 15 years. The groups also had similar indications for primary TKA (Table 3).

The sample size to detect at least a 20-point difference (two-sided, $p = 0.05$) in the KSS between the two groups at final followup [87], with an assumed SD of ± 25, an effect size of 0.8, and power of 80% was 35 subjects per group. Forty-five patients were recruited per group to compensate for 15% to 20% dropout.

Informed consent was obtained from patients, who were blinded at the time of primary implant removal. The study was approved by the institutional review board. Antibiotics were discontinued at least 4 weeks before primary implant removal.

Similar surgical procedures were performed by the senior authors (MM, SZ, FI) including use of tourniquet, type of cement spacer, and implant (P.F.C.® Sigma® TC3 Revision Knee System; DePuy®, Warsaw, IN, USA). The joint was exposed with a standard medial parapatellar arthrotomy through the previous skin incision, expanded for sinus excision. The components were removed in the same sequence. Scarred and necrotic tissue was débrided. We collected six tissue samples for microbiologic cultures:

Table 2. Demographics, laboratory, and clinical and functional results before primary implant removal

Variable	Quadriceps snip group (n = 42 patients)				Tibial tubercle osteotomy group (n = 39 patients)				p value
Sex (M/F)	9/33				11/28				0.653
Age* (years)	74 ± 8				72 ± 6				0.679
	(62–84)				(61–87)				
Limb (right/left)	19/23				28/11				0.087
BMI* (kg/m^2)	29 ± 4				28 ± 5				0.919
	(22–43)				(22–44)				
Comorbidities	4 ± 3				3 ± 2				0.312
	(0–9)				(1–9)				
Interval from TKA to prosthetic knee infection* (months)	14 ± 12				16 ± 9				0.603
	(12–36)				(11–36)				
ESR* (mm/hour)	62 ± 36				58 ± 26				0.749
	(37–125)				(33–108)				
CRP* (mg/L)	52.7 ± 34.6				64.1 ± 24.9				0.791
	(10.2–180.5)				(10.7–130.4)				
Maximum knee flexion*	60° ± 7°				57° ± 11°				0.935
	(10°–85°)				(15°–105°)				
Extension lag	None		28 patients		None		27 patients		0.887
	< 15°		7 patients		< 15°		7 patients		
	> 15°		7 patients		> 15°		5 patients		
The Knee Society Score©*	14 ± 9				11 ± 9				0.914
	(0–53)				(0–49)				
	< 60	60–69	70–79	80–100	< 60	60–69	70–79	80–100	
	42 patients	0	0	0	39 patients	0	0	0	

No significant differences were noted between the groups; * values are expressed as mean ± SD with range in parentheses; ESR = erythrocyte sedimentation rate; CRP = C-reactive protein.

Table 3. Indications for primary TKA in both groups

Group	Primary osteoarthritis	Rheumatoid arthritis	Posttraumatic arthritis	p value
Quadriceps snip group	37	3	2	0.986
Tibial tubercle osteotomy group	33	4	2	0.969
Total	70	7	4	0.978

No significant differences were found between the groups.

one from the suprapatellar pouch, one from each gutter, and one from each bone-implant interface. Additional samples were collected to determine the number of polymorphonuclear cells in the periprosthetic tissue. In 77 cases (38 in the QS group; 39 in the TTO group) five or more cells were found in at least five high power fields [9, 32, 91] (Table 1). Prophylactic antibiotic therapy with 2 g intravenous cefazolin was started just after tissue sampling and another gram was administered every 8 hours on the first postoperative day. A vancomycin-loaded (2 g per 20 g cement) static cement spacer (Simplex™ T, Stryker®, Kalamazoo, MI, USA) with tobramycin was molded intraoperatively.

At discharge, patients were prescribed intravenous antibiotics by an infectious disease specialist (EZ) based on microbiologic cultures (Table 4) and antibiograms. Patients with negative cultures received empiric antibiotic therapy (levofloxacin, 500 mg/day plus rifampicin, 600 mg/day, and teicoplanin, 800 mg/day) for 4 weeks. Laboratory tests (blood cell count, CRP, and ESR) were obtained at 7, 15, 30, and 60 days after surgery. Kidney and liver functions were monitored at 3-day intervals.

A standard postoperative protocol was followed (Table 5). At 60 days, all patients with no clinical signs of infection, normal ESR and CRP underwent LeukoScan® imaging. Patients with negative LeukoScan® imaging were offered RTKA.

Second-stage surgeries were performed according to the general principles described by Bourne and Crawford [10], under spinal anesthesia and sedation, through the original skin incision, with a tourniquet and on intravenous antibiotic prophylaxis of 2 g cefazolin. A medial parapatellar arthrotomy was performed with excision of scar tissue from

Table 4. Results of microbiologic cultures for synovial fluid and tissue samples

Group	Negative	MSSE	MRSE	MSSA	MRSA	Pneumococcus	Escherichia coli	Cocci	Multi	Total
Quadriceps snip	13	11	7	4	1	3	0	0	3	42
Tibial tubercle osteotomy	23	7	2	2	0	1	1	2	1	39
Total	36	18	9	6	1	4	1	2	4	81

MSSE = Methicillin-sensitive Staphylococcus epidermidis; MRSE = Methicillin-resistant Staphylococcus epidermidis; MSSA = Methicillin-sensitive Staphylococcus aureus; MRSA = Methicillin-resistant Staphylococcus aureus; Multi = cultures with multibacterial growth.

Table 5. Postoperative care and rehabilitation protocol

Stage	Parameter	Postoperative			Rehabilitation				
		Day 1	Day 2	Day 3	Day 15	Day 30	Day 60	Day 90	Day 180
1	Physiotherapy	Two 30-minute sessions	Two 30-minute sessions						
	Exercises	Passive hip and ankle ROM	30% weightbearing						
	Wound		Drain removal		Suture removal				
	Orthotic		Extension brace, crutches						
	Clinical examination				Signs of infection				
	Radiology						Radiograph, LeukoScan® imaging		
	Laboratory test						ESR, CRP		
2	Physiotherapy	Two 30-minute sessions	Two 30-minute sessions	Two 30-minute sessions					
	Exercises	Passive hip and ankle ROM	Passive CPM 0° to 30°	30% weightbearing	Active extension	Closed kinetic strengthening	Open kinetic strengthening, resisted weight training		
	Wound		Drain removal		Suture removal				
	Orthotic	Extensor brace		Extension brace, crutches	Discontinue brace				
	Clinical examination					ROM, extension lag, complications, reinfection rate, KSS			
	Radiology					AP, lateral radiographs - limb alignment, complications			
	Laboratory test					ESR, CRP			

KSS = The Knee Society Score©; ESR = erythrocyte sedimentation rate; CRP = C-reactive protein; CPM = continuous passive motion.

the suprapatellar pouch and the gutters. The cement spacer was removed. Pulsatile lavage (Inter-pulse lavage system, Stryker, Newbury, UK) of the joint cavity was performed with 1000 mL sterile 0.9% normal saline solution, with no antibiotic or antiseptic. A drain was left in each gutter (for 48 hours) and the skin was closed with a Proximate® Px Skin Stapler (Ethicon, Johnson & Johnson Medical spa; New Brunswick, NJ, USA).

In the QS group, (n = 42) (Fig. 1), the rectus tendon was divided proximally and laterally at a 45°-angle at the apical end of the standard incision [36, 104] (Fig. 1). The patella was everted with knee flexion. After lateral release and excision of additional scar tissue, the knee was gently flexed to its limit and the position maintained for 1 minute to stretch the envelope. After implantation of the final components, the rectus tendon was repaired with a modified Mason-Allen knot [37], using a nonabsorbable suture (Ethibond No. 2, Ethicon, Somerville, MA, USA). Tension in the repaired quadriceps mechanism and patellar tracking were verified by cycling the knee through ROM according to the no-thumb technique to exclude patellar clunk [1, 35, 74]. A lateral release was required in 20 patients.

In the TTO group, (n = 39), the skin incision was extended on the proximal anteromedial tibial shaft for 10 cm. An 8- to 10-cm osteotomy of the tibial tubercle was made using an oscillating saw (Fig. 2) with an initial mediolateral cut just scoring the inner side of the lateral cortex, to be completed with osteotomes [94]. Before the saw cut, a step-cut was done at the proximal end of the osteotomy to prevent proximal migration [69, 87]. The distal end of the osteotomy was tapered to reduce anterior cortical stress risers [87] (Fig. 2). The lateral periosteal hinge and muscle attachments were left intact to preserve blood supply. The osteotomy was elevated laterally, rather than proximally [99]. During closure, two wires were passed from the lateral edge of the tibial tubercle into the medial tibial cortex (Fig. 3). A third wire was passed proximally through the lateral edge of the osteotomized tibial tubercle to impact it under the transverse step-cut osteotomy and prevent proximal migration. Lateral drill holes were placed proximal to the medial drill holes, angling 45° to the shaft, pulling the osteotomy distally [94]. After placement of the stem, the three wires were tightened onto the medial shaft of the tibia (Fig. 4), compressing the osteotomy to the cortical bone, to resist lateral dislocation during flexion. The no-thumb technique was used to check patellar tracking and exclude patellar clunk [1, 35, 74]. A lateral release was performed in 23 patients. Severe patella baja was corrected in 19 patients by freeing the patellar tendon insertion from the proximal end of the tubercle which was removed using a rongeur, reducing the tibial tubercle proximally (Fig. 5). No adjunctive fixation was required in either group.

The same rehabilitation protocol was used in both groups (Table 5).

Postoperative followups were performed by one of four observers (MLP, GMMM, GR, IH) not associated with the surgery (Table 5). Major procedure-related complications were defined as nonunion of the osteotomized fragment [69, 99, 103], progressive proximal displacement or migration of the osteotomized fragment greater than 5 mm [16, 19, 44, 69, 99, 103], avulsion fracture of the osteotomized fragment [16, 19], and fracture of the tibial metaphysis [88, 99].

Four independent observers with no clinical and surgical contact with the patients (MLP, GMMM, GR, IH) examined all postoperative radiographs. The lateral radiograph was used to assess healing (presence of bridging callus [16, 34, 47, 70]) of the osteotomy fragment and proximal displacement (greater than 5-mm gap between the distal end of the fragment and the tibia) [16]. The integrity of the wires and progressive radiolucencies between the prosthesis and the host bone also were assessed [90]. Interobserver correlation coefficient was 0.87.

Pain at the osteotomy site [106], delayed wound healing, and superficial skin necrosis [44, 88] not requiring surgical management were considered minor complications. Infection was considered to have recurred if at any evaluation patients had at least two of the following: (1) unexplained pain and discomfort with no implant malpositioning observed on radiographs; (2) CRP of 10 mg/L or greater without preexisting inflammatory joint disease [4, 75, 86]; (3) ESR of 30 mm/hour or greater without preexisting inflammatory joint disease [4, 75, 86];

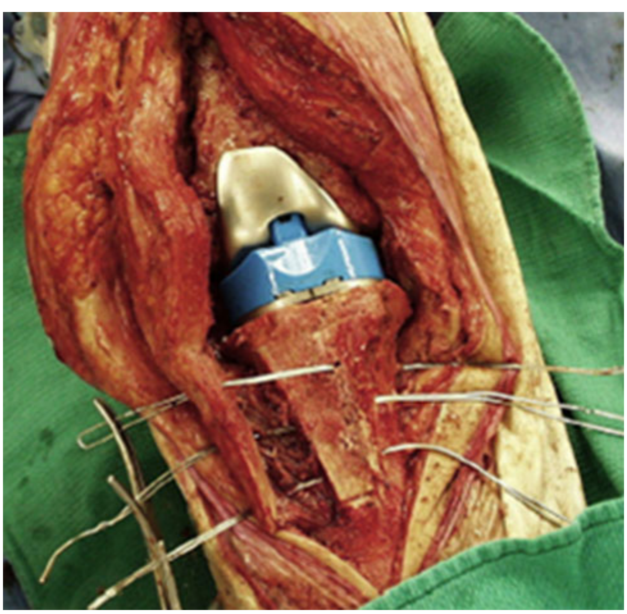

Fig. 3 This intraoperative photograph shows placement of cerclage wires through the osteotomized tibial tubercle.

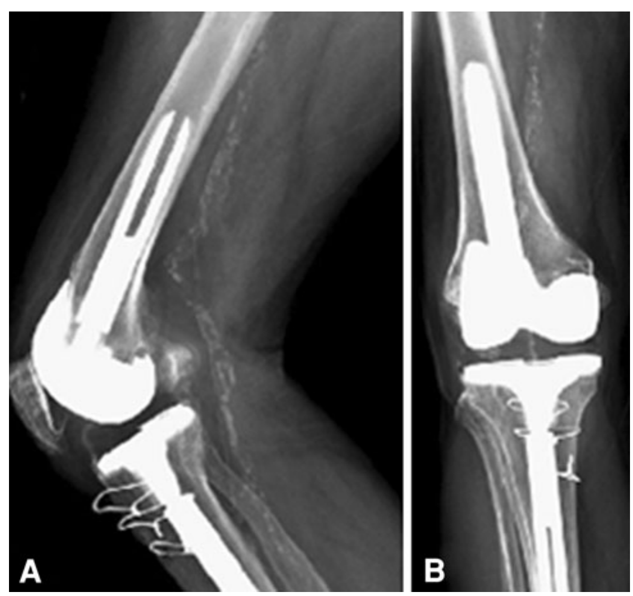

Fig. 4A–B (**A**) Lateral and (**B**) AP view radiographs of the knee show the cerclage knots medially and healing of the osteotomy at the 6-month followup.

Fig. 5 This radiograph shows the proximally repositioned tibial tubercle used to treat patella baja. The patient, a 53-year-old man, previously had a Schatzker Type 4 tibial plateau fracture. He was treated at an outside institution with open reduction and internal fixation. He had severe posttraumatic knee arthritis develop and 5 years after the fracture, was treated with one-stage hardware removal and TKA. A prosthetic knee infection was diagnosed 6 months after the TKA and he was referred to our institute where he was treated with a two-stage RTKA. Despite the distal gap at the osteotomy site the patient did not have pain at the osteotomy site at final followup.

(4) radiographic evidence of implant loosening, periosteal bone formation, and/or progressive nonfocal osteolysis without malpositioning [90]; or (5) a sinus tract or fistula communicating with the prosthesis.

Continuous variables (age, BMI, number of comorbidities, interval from TKA to prosthetic knee infection and from prosthetic knee infection to RTKA, ESR, C-reactive protein, number of débridement and cement spacer exchange procedures performed before RTKA, maximum knee flexion, KSS, followup time) were expressed as an arithmetic mean ± SD with minimum and maximum ranges. The Mann-Whitney U test also was used to compare difference in the KSS between the groups at final followup and to compare continuous variables between them (age, BMI, number of comorbidities, interval from TKA to prosthetic knee infection and from prosthetic knee infection to RTKA, ESR, CRP, number of débridement and cement spacer exchange procedures performed before RTKA, maximum knee flexion, followup time). Demographic differences were evaluated using the independent t-test and Fisher's exact test. Fisher's exact test and chi-square tests were used to check nominal variables (reinfection, major complications, stiffness requiring manipulation under anesthesia, and extension lag) between groups. Statistical analysis was performed using SPSS 16 (SPSS Inc, IBM, Armonk, NY, USA).

Results

Both groups showed clinical improvement; patients in the QS group had a lower ($p = 0.017$) mean KSS with respect to patients in the TTO group at the last followup: 70 ± 41 versus 88 ± 43, respectively (Table 6).

The incidence of general complications was similar in the two groups. Two patients in the QS group had pulmonary embolism and three (two in the QS group and one in the TTO group) had deep venous thrombosis (Table 6). All complications resolved with medical treatment. All patients with a TTO had radiographic evidence of callus formation on the lateral view (Fig. 5). No patients had symptomatic proximal migration or avulsion fracture of the fragment, metaphyseal tibial fractures, or breakage of the fixation wires (Table 7). Eleven patients reported pain on the tibial tubercle at the 6 months observation; eight underwent hardware removal and were free of pain 1 year after surgery. The remaining three patients declined hardware removal and continued to experience mild to moderate pain over the fixation wires. The remaining 28 patients in the TTO group were free of pain at the TTO site at the 6-month followup and remained free of pain at last observation. Three patients in the QS group (7%) and three in the TTO group (8%) underwent manipulation for persistent knee stiffness after the second followup 2 months after surgery (Table 6). All six patients gained greater than 90° ROM with no complications related to the procedure.

Mean postoperative maximum knee flexion was greater ($p = 0.003$) for the TTO group than the QS group (113° versus 94°, respectively). A greater percentage ($p = 0.005$) of patients in the QS group had a residual extension lag: 45% versus 13% (Table 6).

We observed no differences in the reinfection rate between the two groups at last followup (Table 4), and no patient had rupture of the extensor mechanism. Three patients (7%) in the QS group and two (5%) in the TTO group had recurrences of infection; they were treated with joint débridement and positioning of new antibiotic-loaded bone cement spacers. In all cases, the same surgical exposure that was used for the reimplantation procedure was used for prosthesis removal. After the infections resolved, two patients in the QS group and two in the TTO group underwent new reimplantations and remained free of infection at their last followup. The remaining patient in the QS group required three additional surgical débridements and antibiotic-loaded bone cement spacer exchange. This patient had

Table 6. Clinical and radiographic results at final followup

Variable	QS group (n = 42 patients)				TTO group (n = 39 patients)				p value
Followup* (years)	12 ± 2				12 ± 2				0.966
	(8–15)				(9–15)				
Interval from prosthetic knee infection to RTKA* (months)	6.8 ± 2.1				7.1 ± 2.7				0.246
	(4.2–8.8)				(4.9–9.1)				
	< 2	2–4	4–6	> 6	< 2	2–4	4–6	> 6	
	1	6	11	24	0	10	5	24	
Open débridement and antibiotic-loaded bone cement spacer exchange procedures performed before RTKA*	2 ± 1				2 ± 1				0.908
	(1–4)				(1–4)				
Reinfections	3				2				0.838
	(7%)				(5%)				
General medical complications	4				1				0.407
	Pulmonary embolism		Deep vein thrombosis		Pulmonary embolism		Deep vein thrombosis		
	2		2		0		1		
Stiffness requiring manipulation under anesthesia	3				3				0.982
	(7.1%)				(7.7%)				
Maximum knee flexion*	94° ± 15.3°				113° ± 15.1°				0.003
	(60°–105°)				(65°–115°)				
Extension lag	None		23		None		34		0.005
	< 15°		17		< 15°		5		
	> 15°		2		> 15°		0		
The Knee Society Score©*	70 ± 41				88 ± 43				0.017
	(46–80)				(52–96)				
	Poor	Fair	Good	Excellent	Poor	Fair	Good	Excellent	
	(< 60)	(60–69)	(70–79)	(80–100)	(< 60)	(60–69)	(70–79)	(80–100)	
	2	13	17	10	8	5	10	16	

* Values are expressed as mean ± SD with ranges in parentheses; RTKA = revision total knee arthroplasty.

delayed wound healing requiring a gastrocnemius flap, and he finally underwent a knee arthrodesis with a press-fit intramedullary nail [51]. The patient remained free of infection at the last observation (Table 6) (Fig. 5).

Discussion

Although 25% of all RTKAs performed are for infection [11] and the two-stage RTKA is the accepted standard for a prosthetic knee infection [56, 63], controversy exists regarding which surgical exposure provides superior clinical results with the lowest risk of extensor mechanism disruption and reinfection [79, 104]. One previous prospective study [6] of QS and TTO in patients who had RTKA found similar KSS clinical scores for both groups, better ROM in the QS group, and less extension lag in the TTO group; the authors reported no prosthetic knee infections. We therefore compared function, complications, and reinfection rates in chronic prosthetic knee infections treated with a two-stage RTKA using either a TTO or a QS.

Our study has several limitations. First, the equal rate of recurrent infection between groups could be a Type II error. To the best of our knowledge, in 1997 when the current study was designed, no prospective comparative study on reinfection rates in patients treated with a two-stage RTKA for a prosthetic knee infection was reported in literature. The a priori power analysis was based on the question whether a TTO or QS would result in a superior KSS [53] of at least 20 points in two-stage RTKAs for prosthetic knee infections. Two-stage RTKAs for prosthetic knee infections have reported rates of infection control between 80% and 96% [17, 39, 42, 45, 46, 50, 64, 68, 84, 100]. If a mean reinfection rate is 10% and a

Table 7. Comparison of complications from the literature and our study

Study	Level/type of study	Complications related to the procedure									
		Major					Minor				
		Nonunions	Avulsion fracture	Proximal migration/ displaced cement	Extensor mechanism ruptures	Metaphyseal tibial fractures	Extension lag: Preoperative	Extension lag: Final followup	TTO-related pain	Stiffness requiring MUA/ arthrolysis	Skin necrosis/ delayed wound healing
Young et al. [103]	IV/Retrospective study	1	NR	9	2 patellar fractures	0	4	6	NR	4	NR
van den Broek et al. [94]	IV/Retrospective study	0	NR	2	0	0	NR	0	3	NR	NR
Tabutin et al. [88]	IV/Retrospective study	0	NR	0	NR	2	NR	NR	NR	1	0
Ries & Richman [80]	IV/Retrospective study	NR	1	1	NR	NR	NR	All < 5°	4	NR	0
Choi et al. [19]	IV/Retrospective study	0	1	3	NR	NR	All > 5°	All < 5°	0	NR	0
Chalidis & Ries [16]	IV/Retrospective study	0	3	2	NR	NR	All > 5°	All < 5°	5	10	1
Ritter et al. [81]	IV/Case series	NR	NR	1	NR	2	NR	NR	NR	NR	NR
Mendes et al. [69]	IV/Retrospective study	2	0	13 (22%)	0	2 (3%)	5	3 (4.5%)	11 (16%)	9 (13%)	5 (7%)
Hirschmann et al. [48]	II/Prospective comparative study with no randomization	0	0	0	0	1	NR	0	0	1	0
		NR	0	0	0	NR	NR	0	NR	0	0
Choi et al. [18]	IV/Retrospective study	1	2 (4%)	5 (10%)	0	1 (2%)	0	0	0	2 (4%)	0
Arredondo et al. [3]	IV/Case series	0	0	0	0	1	NR	NR	NR	NR	NR
Maruyama [67]	IV/Case series	0	0	0	0	0	NR	NR	0	0	0
Whiteside [99]	IV/Retrospective study	0	2 (1.5%)	0	0	2 (1.5%)	NR	2 (1.5%)	3 (2.2%)	1 (0.7%)	0
Current study	I/Prospective randomized comparative study	0	NR	NR	0	NR	14	19 (45%)	NR	3 (7%)	1
		NR	0	0	0	0	12	5 (13%)	11	3 (8%)	0

TTO = tibial tubercle osteotomy; MUA = manipulation under anesthesia; NR = not recorded.

Table 8. Comparison of demographics of our patients with those in the literature

Study	Level/type of study	Demographics						
		Number of patients	Followup (years)	Age of patients (years)	Male/female	Number of patients who dropped out of study	Number of prosthetic knee infections (%)	TTO fixation
Young et al. [103]	IV/Retrospective study	41	8.4 (± 2.86; 2–13.4)	65 (34–80)	19/23	5	14 (34%)	3 wires
van den Broek et al. [94]	IV/Retrospective study	37	28.4 (12–46)	64.2 (37–78)	NR	2	9 (24%)	3 screws
Tabutin et al. [88]	IV/Retrospective study	20	54 (8–195)	71 (42–90)	10/10	NR	3 (15%)	Initially 2 metallic screws; since 1995 resorbable screws in polylactic acid with number not reported
Ries & Richman [80]	IV/Retrospective study	29	18 (6–48)	65 (24–93)	9/20	1	NR	3–4 screws
Choi et al. [19]	IV/Retrospective study	13	56 (15–126)	60 (38–85)	9/4	0	13 (100%)	3–5 wires
Chalidis & Ries [16]	IV/Retrospective study	74	49 (6–108)	60 (29–89)	35/39	0	38 (51%)	Screws and/or wires; number of screws and wires not reported but variable
Ritter et al. [81]	IV/Case series	9	NR	NR	NR	NR	NR	2 wires
Mendes et al. [69]	IV/Retrospective study	67	30 (5–60)	65.6 (35–93)	25/39	6	10 (15%)	3–6 wires
Hirschmann et al. [48]	II/Prospective comparative study with no randomization	76 TTO 77 MPA	25 ± 3 26 ± 5	72 ± 8 67 ± 7	33/43 22/45	3	0	2 screws NR
Choi et al. [18]	IV/Retrospective study	36	57 (7–126)	67 (38–87)	20/16	0	36 (100%)	3–5 wires
Arredondo et al. [3]	IV/Case series	1	NR	67	0/1	NR	NR	3 wires
Maruyama [67]	IV/Case series	3	2.6	74 (72–76)	0/3	0	0	NR
Whiteside [99]	IV/Retrospective study	136	2	NR	NR	NR	24 (18%)	2–3 wires
Current study	I/Prospective randomized comparative study	42 QS 39 TTO	8 ± 2 (8–15)	74 ± 8 (62–84) 72 ± 6 (61–87)	9/33 11/28	9	81 (100%)	 3 wires

QS = quadriceps snip; TTO = tibial tubercle osteotomy; MPA = medial parapatellar approach; NR = not reported.

difference of 5% would be clinically meaningful, 450 patients per group would reach a power of at least 80% with a CI of 95%. Considering the 0.7% to 2% incidence of prosthetic knee infections [65, 66, 72, 78, 82], this would be unrealistic. Second, a comparison of all the surgical exposures described [97, 104], was not performed for same reason. Third, different fixation techniques of the tibial tubercle [6, 26, 94, 99, 101, 102, 106] were not performed, however, cadaveric studies have shown no differences in failure rate [14, 21, 22]. The current study can be compared with published studies on the basis of patient demographics (Table 8), clinical results (Table 9), and complications (Table 7).

Our patients in the TTO group had superior KSS, although 11 patients in the TTO group required hardware removal because of painful cerclage wires.

In contrast to previous reports [3, 6, 16, 69, 94, 99, 106], we observed no complications related to the TTO. We identified no extensor mechanism ruptures with either QS or TTO. Probably the most proximal cerclage wire through the tubercle fragment provides additional resistance against proximal migration of the fragment, while the two more distal cerclage wires reduce the stress riser effect of additional holes drilled through the tubercle.

A two-stage RTKA for a prosthetic knee infection requires an interim antibiotic-loaded bone cement spacer to

Table 9. Comparison of clinical outcomes

Study	Level/type of study	Clinical results						
		ROM		The Knee Society Score©		Survivorship	VAS score	Reinfections
		Preoperative	Final followup	Preoperative	Final followup			
Young et al. [103]	IV/Retrospective study	8°–74°	4°–91°	73 ± 37	124 ± 42	79% at 8 years	NR	NR
van den Broek et al. [94]	IV/Retrospective study	81° (20°–125°)	93° (30°–125°)	72 (9–133)	125 (13–200)	NR	70.7 (21–100)	NR
Tabutin et al. [88]	IV/Retrospective study	73° ± 4.9°	88° ± 21.1°	57.5 ± 22.4	84 ± 11.6	NR	NR	NR
Ries & Richman [80]	IV/Retrospective study	12°–95°	3°–104°	NR	NR	NR	NR	NR
Choi et al. [19]	IV/Retrospective study	60° (30°–90°)	94° (70°–120°)	39	78	92%	NR	4 (31%)
Chalidis & Ries [16]	IV/Retrospective study	60°	95°	NR	NR	NR	NR	NR
Ritter et al. [81]	IV/Case series	NR	NR	NR	NR	NR	NR	NR
Mendes et al. [69]	IV/Retrospective study	101°	107°	56	86 (82 in prosthetic knee infections) (87% rated as good or excellent results with The Knee Society Score©)	90% prosthetic knee infections	NR	1 (10%)
Hirschmann et al. [48]	II/Prospective comparative study with no randomization	112° ± 15°	118° ± 10°	50 ± 15	93 ± 11	96% at 2 years	9.1 ± 1.6	NR
		115° ± 15°	114° ± 10°	40 ± 15	88 ± 13	99% at 2 years	8.5 ± 2.2	NR
Choi et al. [18]	IV/Retrospective study	40° (10°–90°)	92° (50°–140°)	47	82	NR	NR	10 (28%)
Arredondo et al. [3]	IV/Case series	10°–60°	10°–95°	NR	NR	NR	NR	NR
Maruyama [67]	IV/Case series	NR	NR	NR	NR	NR	NR	NR
Whiteside [99]	IV/Retrospective study	NR	93.7° (15°–140°)	NR	NR	NR	NR	0
Current study	I/Prospective randomized comparative study	60° ± 7° (10°–85°)	94° ± 15.3° (60°–105°)	14 ± 9 (0–53)	70 ± 41 (46–80)	NR	75 ± 49 (10–100)	3 (7%)
		57° ± 11° (15°–105°)	113° ± 15.1° (65°–115°)	11 ± 9 (0–59)	88 ± 43 (52–96)	NR	82 ± 37 (10–100)	2 (5%)

NR = not reported.

be held in situ until the infection is resolved, with a potential for joint stiffness and extensor mechanism dysfunction. There were no differences in the manipulation rate between groups and patients who underwent manipulation gained a mean maximum knee flexion of 93° ± 14° (range, 88°–100°) without complications. Furthermore, the TTO group showed lower residual extension lags and higher knee flexion compared with the QS group with the same postoperative rehabilitation. Our findings suggest that TTO with early rehabilitation does not impair extensor mechanism function.

The reinfection rates of the two groups were similar. The two patients in the TTO group who had reinfections underwent new two-stage RTKAs with repeat TTOs and remained free of infection at last followup with no radiographic evidence of nonunion, a result consistent with previous reports [16, 69, 99]. Our study confirmed that repeat TTO in a RTKA does not impair bone healing potential [19, 99].

Our data suggest that TTO provides a superior KSS than QS in two-stage RTKAs in prosthetic knee infections, with comparable complications. The findings confirm those reported by Mendes et al. [69] that TTO is an efficacious alternative for surgical exposure in two-stage RTKAs for prosthetic knee infections regarding clinical results, healing potential of the osteotomized fragment, and complication rates.

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