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Tibial tubercle osteotomy in revision total knee arthroplasty: A systematic review

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Abstract

BACKGROUND

Tibial tubercle osteotomy (TTO) is a well-established surgical technique to deal with a stiff knee in revision total knee arthroplasty (RTKA). However, several reports have described potential osteotomy-related complications such as non-union, tibial tubercle migration and fragmentation, and metalware related pain.

AIM

To evaluate the literature and estimate the efficiency of TTO in RTKA in terms of osteotomy union, knee mobility and complications.

METHODS

MEDLINE, Scopus, and the Cochrane Central Register of Controlled Trials were investigated for completed studies until February 2020. The principle outcome of the study was the incidence of union of the osteotomy. Secondary outcomes were the knee range of motion as well as the TTO-related and overall procedure complication rate.

RESULTS

Fifteen clinical studies with a total of 593 TTOs were included. The TTO union rate was 98.1%. Proximal migration and anterior knee pain were the most common TTO-related complications accounting for 6.9% and 6.4% of all cases, respectively. However, only 2.2% of cases suffering from anterior knee pain needed hardware removal. Knee flexion was improved from 82.9° preoperatively to 100.1° postoperatively and total knee range of motion was increased from 73.4° before surgery to 97° after surgery. Stiffness requiring manipulation under anesthesia was recorded in 4.6% of cases. No major complications were reported.

CONCLUSION

The current systematic review supports the use of TTO in RTKA, as it is associated with high union rate, significant improvement in knee motion and low osteotomy-related complication risk that rarely leads to secondary tibial tubercle procedures.

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Key words: Tibial tubercle osteotomy; Knee flexion; Extension lag; Union; Revision total knee arthroplasty; Stiff knee

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Core tip: Tibial tubercle osteotomy (TTO) is a useful technique to deal with a stiff knee in revision total knee arthroplasty. However, several reports have described potential osteotomy-related complications such as non-union, tibial tubercle migration and fragmentation as well as metalware related pain. The purpose of the current systematic review was to evaluate the literature and estimate the efficacy of TTO in revision total knee arthroplasty in terms of osteotomy union, knee range of motion, and complication rate. TTO was found to result in high union rate, significant improvement in knee motion and low osteotomy-related complication risk that rarely leads to secondary tibial tubercle procedures.

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INTRODUCTION

Tibial tubercle osteotomy (TTO) is a useful and well-established technique to deal with a tight extensor mechanism and stiffness in revision total knee arthroplasty (RTKA). It provides excellent exposure and visualization of the knee joint as it allows unforceful eversion or lateral subluxation of the patella and unimpeded access to the lateral gutter and lateral component-bone interface^[1,2]. The osteotomized bone fragment should be of sufficient size to facilitate secure hardware fixation with wires and screws and provide an appropriate contact area for bone consolidation. Furthermore, preservation of the musculature sleeve is of primary importance for bone segment viability and stability and a good result can be achieved even after a previously performed TTO^[2].

The osteotomy can be safely extended into the intramedullary tibial canal to utilize removal of the tibial stem and retained cement^[3,4]. Although the intramedullary extension of the osteotomy may prolong union time due to the relatively small bone-to-bone contact area at the site of the TTO, good healing capacity has been reported^[2]. In addition, re-alignment of the extensor mechanism for optimal balance and simultaneous correction of patellar height by proximalization of the tibial tubercle can be safely applied at the time of osteotomy fixation^[2,3].

On the other hand, several reports have described potential osteotomy-related complications such as extensor lag, tibia fracture, nonunion, tibial tubercle migration, metalware irritation, and wire breakage. In the majority of cases, the aforementioned problems were largely attributed to surgical technique and adversely affected the functional outcome^[5,6].

The current review aims to investigate the literature and estimate the efficiency of TTO in RTKA in terms of osteotomy union rate, knee range of motion (ROM), and incidence of complications.

MATERIAL AND METHODS

The authors followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) recommendations^[7].

Literature search

MEDLINE, Scopus, and the Cochrane Central Register of Controlled Trials were searched for entries from inception to February 2020. The search strategy for Medline was "(tibial tubercle osteotomy) AND (total knee)" and was adjusted to each database and no filters or language restrictions were used. The reference lists from the included articles were also manually screened for additional studies. Two authors (Kitridis D and Chalidis B) independently searched for studies and reviewed all titles and

abstracts. Subsequently, the full texts were screened for eligible studies that met all identified inclusion criteria.

Eligibility criteria

Clinical studies relevant to TTO in RTKA, which enrolled more than 10 patients over 18 years old, were included in the review. Trials with incomplete clinical data and articles reporting mixed results with primary total knee arthroplasty were excluded.

Data extraction

Two authors (Kitridis D and Chalidis B) performed the data extraction process from the selected articles in a blinded manner. Studies and patients' characteristics (*i.e.*, study type, year, country and size, as well as patients' demographics), kind of surgical interventions, clinical results and complications, and the follow-up observations were gathered and analyzed. Any disagreement was resolved by review from a third author (Givissis P).

When there were insufficient data, these were requested from the corresponding author of each article.

Quality assessment

Two investigators (Kitridis D and Chalidis B) independently performed the quality appraisal. Case series studies were assessed using the tool developed by Moga *et al*^[8], which consists of 18 entries; studies achieving a score of 13 or greater are considered of high quality, 7-12 of moderate, and 0-6 of low quality. Comparative trials were evaluated using the Coleman Methodology Score^[9], which relies to ten methodological criteria; a score of 100% is considered the optimal high quality score.

Outcomes

The main outcome of the review was the TTO union. Secondary outcomes were the improvement of ROM and the incidence of TTO-related and RTKA complications.

Statistical analysis

Pooled-data analysis was performed using weights according to each study's sample size. Categorical outcomes were expressed as percentages. The longest follow-up measurements of each study were used. Microsoft Excel version 16 and IBM Statistical Package for Social Sciences software version 24 were utilized for data analysis.

RESULTS

The literature search yielded 395 articles, of which 183 were duplicates and 139 were excluded from the titles and abstracts. Finally, 29 clinical studies did not fulfill the selection criteria and 15 clinical studies were considered for review (Figure 1).

Characteristics of the included studies

Ten retrospective case series studies^[1,2,4,6,10-15], three retrospective non-randomized comparative studies^[3,16,17], one prospective non-randomized comparative trial^[18], and one prospective randomized clinical trial^[19] enrolled 780 patients. Data were extracted from a total of 545 patients, who underwent 593 TTOs. Of them, 296 were performed in aseptic RTKAs and 297 in septic RTKAs. Of note, eight studies included two-stage revisions for infected RTKAs^[2-4,6,10,11,13,19]. All the cited articles were published from 1998 to 2019. Eight studies originated from Europe^[1,6,12-16,19], five from North America^[2,4,10,11,17], and two from Asia^[3,18]. Tables 1 and 2 present details about studies and surgical interventions, respectively.

Quality assessment

Ten studies were level IV evidence^[1,2,4,6,10-15], four were level III^[3,16-18], and one was level II^[19]. Nine case series were found to be of high quality^[2,4,6,10-15], and one of low quality^[1]. The effect of the particular low-quality study was evaluated as a potential confounding factor; the stratified analysis of outcomes was repeated after excluding the study, and no substantial differences were noted ($P = 0.83$). Therefore, the study was finally included in the review. The comparative trials were rated with a mean Coleman Methodology Score^[3,16-19] of 73.6% (range 54-92%).

Synthesis of the results

Eleven non-unions out of 593 TTOs were reported (union rate 98.1%, Figure 2). There were three intraoperative tibial tubercle (TT) fractures (0.5%), 10 proximal avulsion fractures (1.7%), and five metaphyseal tibial fractures (0.8%). Proximal migration of the TT was observed in 41 cases (6.9%). Anterior knee pain was reported in 38 cases

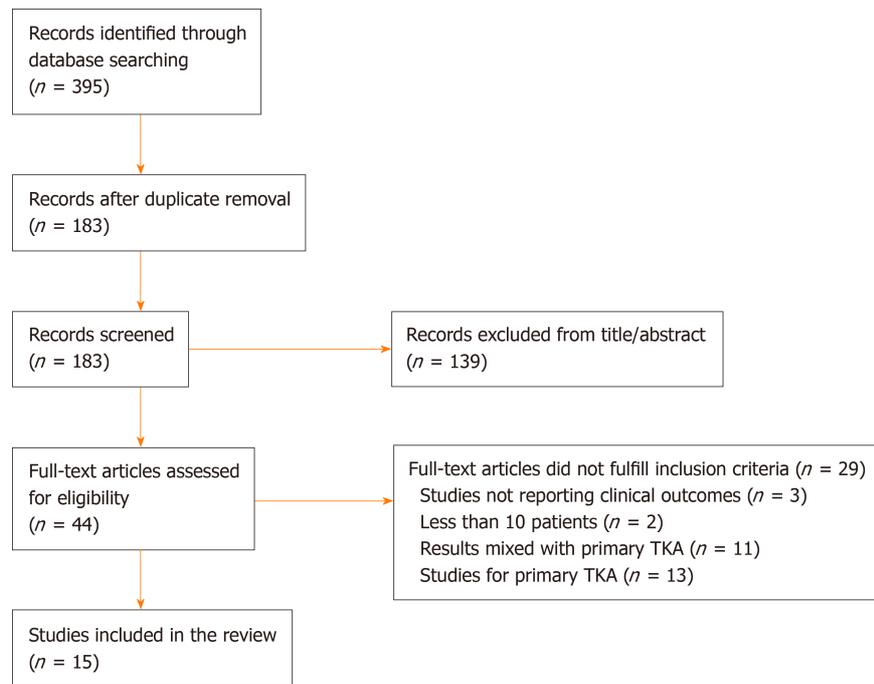


Figure 1 Flow chart diagram for inclusion and exclusion article process. TKA: Total knee arthroplasty.

(6.4%), 13 of which required hardware removal (2.2%). All TTO-related complications are reported in [Table 3](#).

Total ROM improved from 73.4° preoperatively to 97° postoperatively and knee flexion increased from 82.9° before surgery to 100.1° after surgery. Data in detail are reported in [Table 4](#).

Stiffness requiring manipulation under anesthesia was evident in 27 cases (4.6%). From all RTKAs that performed due to periprosthetic joint infection via TTO, 29 knees (9.8%) showed recurrence of infection. None of the studies reported any major complications. Specifically, all non-TTO related complications are documented in [Table 5](#).

DISCUSSION

The present systematic review advocates the use of TTO in RTKA. Knee flexion and ROM were improved from 82.9° and 73.4° preoperatively to 100.1° and 97° postoperatively, respectively. Furthermore, TTO permits early rehabilitation and restoration of quadriceps excursion and strength minimizing the incidence of extension lag^[4]. Bruni *et al*^[19] compared the utilization of TTO and Rectus Snip techniques at the time of reimplantation during two-stage RTKA for prosthetic joint infection. Patients in the TTO group had a higher mean Knee Society Score than the Rectus Snip group (88 *vs* 70, respectively). Mean maximum knee flexion was greater in the TTO group (113° *vs* 94°) with a lower incidence of extension lag (45% *vs* 13%). However, the risk of joint arthrofibrosis and stiffness even after utilization of TTO isn't insignificant. We found that 4.6% of cases underwent postoperative closed manipulation under anesthesia to improve knee ROM.

Non-union of osteotomy is rare as 98.1% of bone healing was obtained. Even in case of tibial tubercle distalization or/and medialization for achieving proper tension and tracking of the patella and the extensor mechanism, excellent healing capacity should be expected^[2,16]. Similarly, repeat osteotomy as well as intramedullary extension of osteotomy was associated with high union rates. Chalidis and Ries noticed that the median union time for the primary TTO was 15 wk (range 6 to 47 wk) and for the repeat TTO was 21 wk (range 7 to 27 wk)^[2]. In addition, intramedullary TTO had a longer healing time (median 21 wk, range 7 to 38 wk) when compared to extramedullary osteotomy (median 12 wk, range 6 to 47 wk).

Proximal migration of TT and anterior knee pain were the most common complications of TTO with an incidence of 6.9% and 6.4%, respectively. Proximal step-cut osteotomy might prevent superior displacement of the osteotomized tibial

Table 1 Summary of studies characteristics

Ref.	n	TTOs	Mean age (yr)	Males/ Females	Mean follow-up (mo)	Outcome measures
Barrack <i>et al</i> ^[17] , 1998	15	15	NR	NR	30 (24-48)	ROM, KSS, Subjective satisfaction and function questionnaires
Bruni <i>et al</i> ^[19] , 2013	39	39	72 ± 6	11/28	144 ± 24	ROM, VAS, KSS, Complications
Chalidis <i>et al</i> ^[2] , 2009	74	87	60 (29-89)	35/39	49 (6-108)	ROM, Complications
Choi <i>et al</i> ^[10] , 2012 (1)	36	51	67 (38-87)	20/16	57 (7-126)	ROM, KSS, Complications
Choi <i>et al</i> ^[11] , 2012 (2)	13	26	60 (38-85)	9/4	56 (15-126)	ROM, KSS, Complications
Chun <i>et al</i> ^[18] , 2019	31	31	73.8 ± 7.5	5/26	62.4 (36-210)	ROM, KSS, HSS, Complications
Hocking <i>et al</i> ^[1] , 2007	52	52	NR	NR	NR	ROM, KSS, Complications
Le Moulec <i>et al</i> ^[12] , 2014	63	63	72 ± 11.3	29/36	27.8 ± 10.7	ROM, IKS, Patellar height, Complications
Mendes <i>et al</i> ^[4] , 2004	64	67	65.6 (35-93)	25/39	30 (5-60)	ROM, KSS, Complications
Punwar <i>et al</i> ^[6] , 2016	38	42	66 (33-92)	24/14	6-24	OKS, ROM, Walking status, Complications
Segur <i>et al</i> ^[13] , 2014	26	26	73 (64-88)	12/14	40.8 (28.8- 3.2)	KSS, WOMAC, ROM, Complications
Sun <i>et al</i> ^[3] , 2014	21	21	70.1 ± 7.7	6/15	48.1 ± 17.2	ROM, KSS, HSS, Complications
Van den Broek <i>et al</i> ^[14] , 2006	37	37	54.2 (37-78)	NR	28.4 (12-46)	ROM, KSS, VAS for satisfaction, Complications
Vandeputte <i>et al</i> ^[16] , 2017	13	13	53.6 (34-71)	5/8	24	ROM, KSS, Complications
Zonnenberg <i>et al</i> ^[15] , 2014	23	23	69.6 (43-84)	7/16	16.1 (1-43)	KSS, ROM, SF-36, Complications

TTO: Tibial tubercle osteotomy; NR: Not reported; ROM: Range of motion; KSS: Knee society score; VAS: Visual analogue scale; HSS: Hospital for special surgery score; OKS: Oxford knee score; WOMAC: Western Ontario and McMaster universities osteoarthritis index; IKS: International knee society score; SF-36: 36-item short form health survey.

fragment, although this was not necessarily associated with extensor mechanism dysfunction^[2,14]. Anterior knee pain was mainly related to metalware prominence and irritation and it was apparent regardless the type of fixation with wires and screws^[10,11]. However, we found that only 2.2% of cases required hardware removal. Suture repair may reduce even further the incidence of anterior knee pain but the technique relies on the integrity of the lateral periosteal sleeve and therefore risks migration of TTO^[15,20].

Recurrence of periprosthetic knee joint infection was identified in 9.8% of RTKA cases. The overall risk appears to be a complex and multifactorial issue involving patient and surgical factors. Tibial tubercle osteotomy should be considered a safe extensile procedure as so far there is no evidence that the technique may adversely affect the possibility of reinfection. When TTO was compared to rectus snip regarding re-infections after two-stage revisions in infected RTKA, Bruni *et al*^[19] reported that the results were similar in both groups (7% in the snip group and 5% in the TTO group, $P = 0.84$). Furthermore, Sun *et al*^[3] in another comparative study found that the incidence of reinfection in two-stage RTKAs was 4.8% in the TTO group and 7.4% in the snip group. Nevertheless, this difference failed to reach statistical significance ($P = 0.71$).

The main limitation of the current study was the fact that it was not feasible to conduct a meta-analysis with direct comparisons between interventions. This occurred because the majority of the included studies did not include a control group.

Table 2 Surgery parameters

Ref.	TTO length (cm)	Fixation	Approach	Oscillating saw or osteotome
Barrack <i>et al</i> ^[17] , 1998	10	Wires	Medial parapatellar	Saw
Bruni <i>et al</i> ^[19] , 2013	8-10	Wires	Medial parapatellar	Both
Chalidis <i>et al</i> ^[2] , 2009	10.6 (7.9-15.3)	Wires (<i>n</i> = 16) Screws (<i>n</i> = 9) Wires and screws (<i>n</i> = 59)	Medial parapatellar	Both
Choi <i>et al</i> ^[10] , 2012 (1)	8	Wires (<i>n</i> = 49) Screws (<i>n</i> = 2)	Medial parapatellar	Both
Choi <i>et al</i> ^[11] , 2012 (2)	8	Wires (<i>n</i> = 25) Screws (<i>n</i> = 1)	Medial parapatellar	Both
Chun <i>et al</i> ^[18] , 2019	10	Screws	Medial parapatellar	Both
Hocking <i>et al</i> ^[1] , 2007	5-8	Wires	Medial parapatellar	Both
Le Moulec <i>et al</i> ^[12] , 2014	7.7 ± 1.6	Wires	Medial parapatellar	Both
Mendes <i>et al</i> ^[4] , 2004	8-10	Wires (<i>n</i> = 66) Wires and screw (<i>n</i> = 1)	Midvastus (<i>n</i> = 40) Medial parapatellar (<i>n</i> = 19) Subvastus (<i>n</i> = 40) Not noted (<i>n</i> = 4)	Saw
Punwar <i>et al</i> ^[6] , 2016	7	Screws	Medial parapatellar	Both
Segur <i>et al</i> ^[13] , 2014	10	Wires (<i>n</i> = 25) Nonabsorbable sutures (<i>n</i> = 1)	Medial parapatellar	Saw
Sun <i>et al</i> ^[3] , 2014	6-8	Screws	Medial parapatellar	Saw
van den Broek <i>et al</i> ^[14] , 2006	6-8	Screws (<i>n</i> = 36) Wires (<i>n</i> = 1)	Medial parapatellar	Both
Vandeputte <i>et al</i> ^[16] , 2017	6-8	Wires or screws	Medial parapatellar	Saw
Zonnenberg <i>et al</i> ^[15] , 2014	4-8	Absorbable sutures	Medial parapatellar	Osteotome

Moreover, the case series studies were of low level of evidence. Another limitation was that the study by Zonnenberg *et al*^[15] had a borderline moderate quality Coleman methodology score of 54%, and the study by Hocking *et al*^[1] was of low quality according to the Moga score. After accounting for the risk of bias introduced in the review by the latter study with a stratified analysis, no significant changes of the results were noted compared to the primary analysis. Therefore, both studies were included to increase the sample size and improve the power of the review. Also, 13 out of 15 studies were retrospective, which might create data collection or patient selection bias. All these reflect the need for high-quality trials comparing different interventions.

CONCLUSION

In conclusion, TTO shows great clinical safety and efficacy in RTKA. Non-union is rare, and the most reported TTO-related complications are proximal migration and anterior knee pain. However, in the vast majority of cases they aren't associated with secondary procedures of osteotomy refixation or metalware removal.

Table 3 Tibial tubercle osteotomy-related complications

Ref.	n	Non-unions	TT fractures	Proximal avulsion fractures	Metaphyseal tibial fractures	Proximal migration	Anterior knee pain
Barrack <i>et al</i> ^[17] , 1998	15	-	-	-	-	-	3
Bruni <i>et al</i> ^[19] , 2013	39	-	-	-	-	-	11
Chalidis <i>et al</i> ^[2] , 2009	74	-	-	3	2	2	5
Choi <i>et al</i> ^[10] , 2012 (1)	36	-	-	2	1	5	-
Choi <i>et al</i> ^[11] , 2012 (2)	13	-	-	-	-	3	-
Chun <i>et al</i> ^[18] , 2019	31	-	-	-	-	-	-
Hocking <i>et al</i> ^[1] , 2007	52	-	1	1	-	10	-
Le Moulec <i>et al</i> ^[12] , 2014	63	4	-	-	-	4	-
Mendes <i>et al</i> ^[4] , 2004	64	2	-	-	1	13	11
Punwar <i>et al</i> ^[6] , 2016	38	-	-	-	1	2	-
Segur <i>et al</i> ^[13] , 2014	26	2	1	-	-	-	-
Sun <i>et al</i> ^[3] , 2014	21	-	-	2	-	-	5
van den Broek <i>et al</i> ^[14] , 2006	37	-	-	1	-	2	3
Vandeputte <i>et al</i> ^[16] , 2017	13	-	-	-	-	-	-
Zonnenberg <i>et al</i> ^[15] , 2014	23	3	1	-	-	-	-

TT: Tibial tubercle.

Table 4 Mean range of motion, flexion, extension lag and flexion contracture values

Ref.	n	Total ROM (°)		Flexion (°)		Extension lag	Flexion contracture
		Preop	Postop	Preop	Postop		
Barrack <i>et al</i> ^[17] , 1998	15	73	81			1.5°	
Bruni <i>et al</i> ^[19] , 2013	39			57	113	5 cases < 15°	
Chalidis <i>et al</i> ^[2] , 2009	74	60	95	80	95	2.5°	2.5°
Choi <i>et al</i> ^[10] , 2012 (1)	36	40	92				
Choi <i>et al</i> ^[11] , 2012 (2)	13	60	94	68	95		1°
Chun <i>et al</i> ^[18] , 2019	31	101	109		109		4°
Hocking <i>et al</i> ^[1] , 2007	52				91	3 cases	
Le Moulec <i>et al</i> ^[12] , 2014	63	87.8	103.7			15 cases	10 cases
Mendes <i>et al</i> ^[4] , 2004	64			101	107	3 cases < 15°	
Punwar <i>et al</i> ^[6] , 2016	38			85	95		15 cases
Segur <i>et al</i> ^[13] , 2014	26			90	95	1 case < 5°	
Sun <i>et al</i> ^[3] , 2014	21		94.1		101.7		3.8°
van den Broek <i>et al</i> ^[14] , 2006	37	81	93			1 case	
Vandeputte <i>et al</i> ^[16] , 2017	13						
Zonnenberg <i>et al</i> ^[15] , 2014	23	87.9	95.3				

Table 5 Non-tibial tubercle osteotomy related complications

Ref.	Complications
Barrack <i>et al</i> ^[17] , 1998	None reported
Bruni <i>et al</i> ^[19] , 2013	MUA for stiffness (<i>n</i> = 3) Reinfections (<i>n</i> = 2) DVT (<i>n</i> = 1)
Chalidis <i>et al</i> ^[2] , 2009	MUA for stiffness (<i>n</i> = 10) Skin necrosis (<i>n</i> = 1) Reinfections (<i>n</i> = 6)
Choi <i>et al</i> ^[10] , 2012 (1)	MUA for stiffness (<i>n</i> = 2) Spacer subluxation (<i>n</i> = 1) Reinfections (<i>n</i> = 10)
Choi <i>et al</i> ^[11] , 2012 (2)	MUA for stiffness (<i>n</i> = 2) Spacer subluxation (<i>n</i> = 1) Reinfections (<i>n</i> = 4)
Chun <i>et al</i> ^[18] , 2019	Skin necrosis (<i>n</i> = 2)
Hocking <i>et al</i> ^[1] , 2007	MUA for stiffness (<i>n</i> = 4)
Le Moulec <i>et al</i> ^[12] , 2014	None reported
Mendes <i>et al</i> ^[4] , 2004	MUA for stiffness (<i>n</i> = 9) Pain not associated to TTO (<i>n</i> = 2) Reinfection (<i>n</i> = 1) Delayed wound healing (<i>n</i> = 5) Transient peroneal nerve palsy (<i>n</i> = 3)
Punwar <i>et al</i> ^[6] , 2016	Reinfections (<i>n</i> = 2)
Segur <i>et al</i> ^[13] , 2014	Reinfections (<i>n</i> = 3)
Sun <i>et al</i> ^[3] , 2014	Reinfection (<i>n</i> =1)
van den Broek <i>et al</i> ^[14] , 2006	None reported
Vandeputte <i>et al</i> ^[16] , 2017	None reported
Zonnenberg <i>et al</i> ^[15] , 2014	MUA for stiffness (<i>n</i> = 1) Fractures of tibial plateau (<i>n</i> = 5) Patellar pain resolved with patellar resurfacing (<i>n</i> = 1) Wound leakage resolved conservatively (<i>n</i> = 5)

MUA: Manipulation under anesthesia; DVT: Deep vein thrombosis; TTO: Tibial tubercle osteotomy.

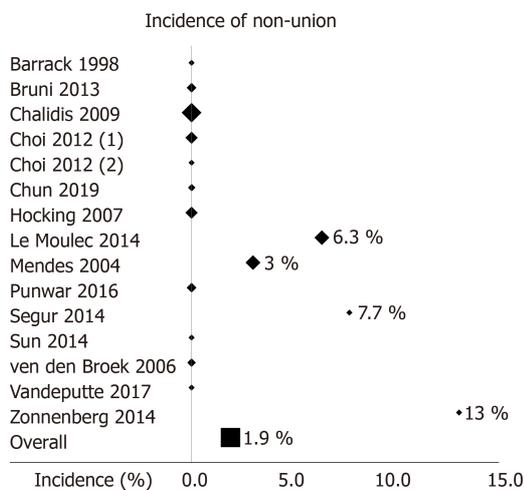


Figure 2 Forest plot of the incidence of non-union of the tibial tubercle osteotomy. The markers are weighted according to the number of the cases of each study.

ARTICLE HIGHLIGHTS

Research background

Tibial tubercle osteotomy (TTO) is a useful technique to deal with a stiff knee in revision total knee arthroplasty (RTKA). It provides excellent exposure and visualization of the knee joint as it allows unforceful eversion or lateral subluxation of the patella. Complications such as non-union, tibial tubercle migration and fragmentation, and metalware related pain have been reported.

Research motivation

Although TTO is widely utilized in RTKA, several reports have reported potential osteotomy-related complications. There is currently a lack of synthesis of the evidence about TTO in RTKA.

Research objectives

The present review aims to evaluate the available literature and estimate the efficiency of TTO in RTKA in terms of osteotomy union, knee mobility, and complications.

Research methods

Medline, Scopus, and the Cochrane Central Register of Controlled Trials were systematically screened for studies from inception to February 2020. The main outcome was the incidence of union of the osteotomy. Secondary outcomes were the knee range of motion as well as the TTO-related and overall procedure complication rate. The systematic review was conducted following the PRISMA recommendations.

Research results

Fifteen clinical studies were included in the systematic review. Eleven non-unions out of 593 TTOs were reported (union rate 98.1%). Proximal migration of the TT was observed in 41 cases (6.9%). Anterior knee pain was reported in 38 cases (6.4%), 13 of which required hardware removal (2.2%). Total knee range of motion improved from 73.4° preoperatively to 97° postoperatively and knee flexion increased from 82.9° before surgery to 100.1° after surgery. Stiffness requiring manipulation under anesthesia was evident in 27 cases (4.6%).

Research conclusions

TTO shows great clinical safety and efficacy in RTKA. Non-union is rare, and the most reported TTO-related complications are proximal migration and anterior knee pain. However, in the vast majority of cases they aren't associated with secondary procedures.

Research perspectives

Further clinical studies are encouraged to determine the optimal extensile approach in RTKA. High quality randomized studies comparing different techniques using standardized protocols will need to be performed.

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