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Tibial Tuberosity Transposition Stabilization Using a Cortical Screw Placed Adjacent to the Tuberosity in Dogs with Patellar Luxation

Barbro Filliquist[1] Sivert Viskjer[2] Susan M. Stover[1]

[1] Department of Surgical and Radiological Sciences, School of Veterinary Medicine, University of California, Davis, CA, United States
[2] Evidensia Strömsholm Referral Small Animal Hospital, Strömsholm, Sweden

Address for correspondence Barbro Filliquist, DVM, DACVS-SA, DECVS, Department of Surgical and Radiological Sciences, School of Veterinary Medicine, University of California, Davis, CA 95616, United States (e-mail: bfilliquist@ucdavis.edu).

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Abstract

Objectives The aim of this study was to describe a screw fixation method of the tibial tuberosity after transposition during surgical treatment of patellar luxation and to report complications and outcome of the procedure.

Materials and Methods Medical records (2010–2016) of dogs treated for patellar luxation with tibial tuberosity transposition stabilization using a cortical bone screw placed adjacent to the tuberosity were retrospectively reviewed. Radiographs acquired immediately after surgery were evaluated for fissures. Proximal tibial dimensions and tibial tuberosity segments were measured. Intraoperative and postoperative complications were recorded.

Results One-hundred and six dogs and 131 stifle surgeries were included. Implant complications associated with the screw occurred in 2/106 dogs (1.9%). Two dogs developed tibial tuberosity fracture and proximal displacement within 1 week of surgery and required stabilization with pin and tension band. Patellar reluxation rate following surgery was 6.9% (9/131 procedures). Presence of a fissure on postoperative radiographs increased the odds of tibial tuberosity fracture development ($p < 0.001$), while greater tibial tuberosity size ($p = 0.023$) and larger distal cortical attachment ($p = 0.018$) decreased the odds of fissure formation.

Clinical significance Tibial tuberosity transposition can be achieved with a cortical screw placed lateral or medial to the tibial tuberosity.

Keywords
- patellar luxation
- tibial tuberosity transposition
- complications
- tibial tuberosity size
- canine

Introduction

Patellar luxation is one of the most common orthopaedic diseases affecting the canine stifle.[1,2] Common surgical methods for elimination of patellar luxation include releasing incisions of the retinaculum and joint capsule, imbrication of the joint capsule, modification of the femoral trochlear groove, and tibial tuberosity transposition (TTT).[3–6] Tibial tuberosity transposition corrects the malalignment of the quadriceps mechanism by realigning the quadriceps muscle over the cranial aspect of the femur and has been shown to reduce the incidence of reluxation and major complications after patellar luxation surgery.[3] More complex cases may require a distal femoral osteotomy, which also corrects quadriceps mechanism malalignment.[7]

Transposition of the tibial tuberosity requires a complete or incomplete osteotomy of the tuberosity including the insertion of the patellar ligament. Techniques used to reattach the osteotomized tibial tuberosity segment include wire suture, single pin fixation, multiple pin fixation, tension band wire with one or two pins, lag screw with pin and tibial tuberosity advancement plate.[6,8–11] All of these techniques transfix the

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tuberosity to the tibia. Complications reported with these techniques include implant migration, implant failure, tibial tuberosity fracture or avulsion, soft tissue inflammation or irritation and soft tissue infection with a complication rate ranging from 8 to 24%.[6,10,12,13]

Our surgical group developed a novel stabilization method for the tibial crest after transposition that did not require the placement of an implant through the tibial crest. Following a partial osteotomy, leaving the distal portion of the cortex intact, a cortical screw is placed adjacent to the transposed tibial tuberosity. The screw head thus prevents the tibia tuberosity from sliding back toward its original position.

The objectives of this study were to describe the surgical technique, report the short-term complications and outcomes in a cohort of clinical cases and determine if dog age and weight, rehabilitation and tibial tuberosity attachment geometry affect the odds of developing a fissure or a fracture at the distal aspect of the tibial tuberosity, lameness and patellar reluxation.

Materials and Methods

Medical records of dogs treated for patellar luxation with TTT at the Evidensia Strömsholm Referral Veterinary Hospital between January 2010 and December 2016 were reviewed. Dogs were included if surgical stabilization of the TTT was performed with a screw placed adjacent to the transposed tibial tuberosity and at least one follow-up orthopaedic examination was performed. Cases were excluded if medical records were incomplete or if preoperative imaging and immediately postoperative imaging were not available. Preoperative imaging consisted of a craniocaudal radiographic and a lateral radiographic view of the affected limb or computed tomography of the pelvic limb from hip to tarsus. Data retrieved included signalment, body weight, direction and grade of patellar luxation,[14] additional surgical procedures performed, complications, follow-up orthopaedic examination and recurrence of patellar luxation. Major complications were those that needed additional surgical intervention, while minor complications were those that resolved without surgery.[12]

Surgical Technique

An incomplete tibial tuberosity osteotomy was created using an oscillating saw with the most craniodistal part of the tuberosity left attached (►Fig. 1A). The goal was a cortical attachment width of ~3 to 5 mm. The proximal aspect of the tuberosity was transposed to the intended new position and held in place temporarily with a Kirschner wire measuring

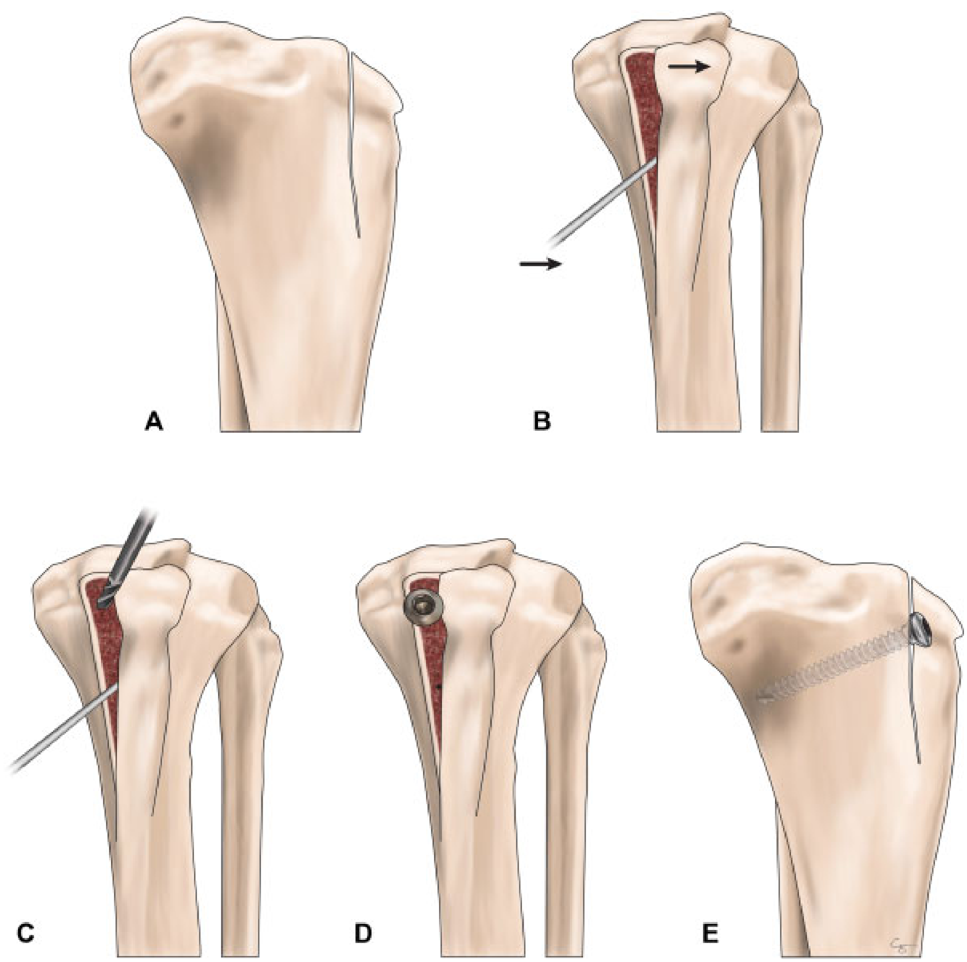

Fig. 1 Illustration of the tibial tuberosity transposition procedure. (**A**) Development of a partial osteotomy; (**B**) transposition and placement of temporary pin; (**C**) drilling for screw placement; (**D**) screw position in craniocaudal orientation; (**E**) screw position in lateral orientation.

Table 1 Screw size selection recommended based on patient size

Patient size (kg)	Screw size (mm)
< 2 kg	1.5
2–5	2.0
6–15	2.7
>15	3.5

1.2 to 2.0 mm, depending on bone size. The Kirschner wire was inserted through the osteotomy adjacent to the transposed tibial tuberosity approximately equidistant from the proximal and distal aspects of the osteotomy without exiting the caudal tibial cortex (►**Fig. 1B**). A drill hole was created through the tibia adjacent to the osteotomy and directed caudally to exit the trans-cortex. The hole was located at the level of the insertion of the patellar ligament on the tibial tuberosity (►**Fig. 1C**). Depth was measured and a non-self-tapping cortical screw was placed and seated such that the tightened screw head rested on the osteotomized tibial cortex and prevented the tibial tuberosity from sliding back to its original position and the temporary Kirschner wire was removed (►**Fig. 1D** and **E**). The diameter of the screw ranged from 1.5 to 3.5 mm, based on dog size (►**Table 1**). Block recession trochleoplasty, imbrication, release, or some combination of these procedures were performed at the discretion of the surgeon. In a subset of dogs, a Kirschner wire was placed through the tibial tuberosity in addition to the screw. The dogs were discharged with written instructions for activity restriction and gradual increase in leash walk activity over the following 6 weeks. Physical rehabilitation using underwater treadmill was recommended starting after 2 weeks.

Postoperative Evaluation

Postoperative radiographs were reviewed by a single observer (BF) and evaluated for the absence or presence of fissures (incomplete or complete). An incomplete fissure was defined as a fissure extending from the distal aspect of the osteotomy towards the intact cortex, while a complete fissure was a fissure extending distally from the osteotomy through the cranial tibial cortex. The proximodistal osteotomy length, the size of the distal tibial tuberosity cortical attachment, proximal tibial width and width of the tibia at the distal end of the osteotomy were measured on the lateral projection radiograph using a commercially available programme (Horos; The Horos Project, horosproject.org) (►**Fig. 2**). Ratios of the width of the distal cortical attachment to the proximal tibial width (C/E, F/E), the width of the tibia at the distal end of the osteotomy to the proximal tibial width (C + D/E) and the width of the distal cortical attachment to the osteotomy length (C/A, F/A) were calculated. Ratios were used for analysis instead of exact numerical values as the shape and size of the tibial tuberosity and the width of the proximal tibia in the craniocaudal orientation vary between dogs, the radiographs were not always in perfect lateral position and the radiographic measurements were not calibrated to a measurement standard. At

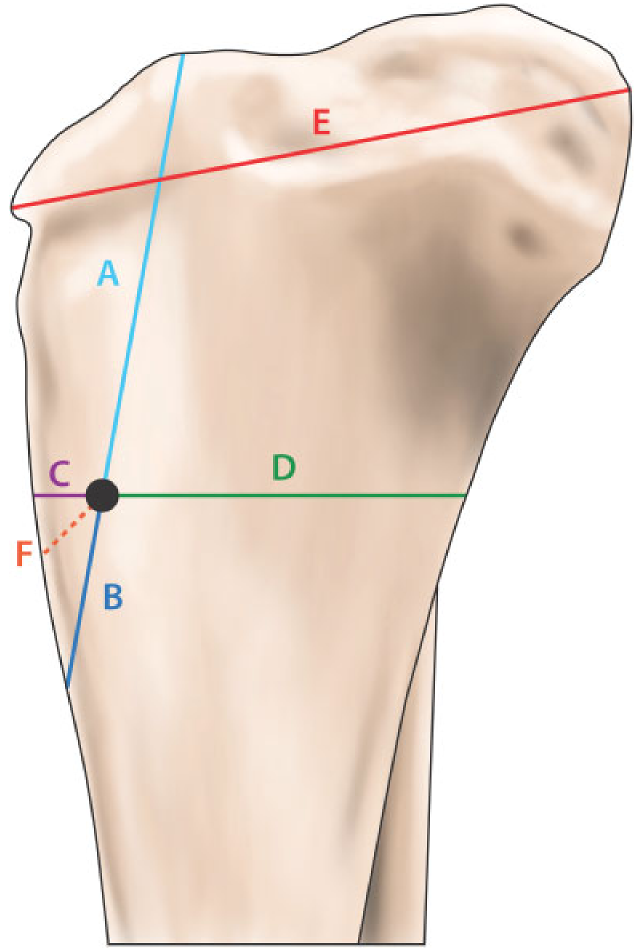

Fig. 2 Illustration of the canine proximal tibia in the mediolateral view. (**A**) Proximodistal length of osteotomy; (**B**) remaining attachment of the tibial tuberosity as a direct continuation of the osteotomy; (**C**) width of the distal cortical tibial tuberosity attachment at the end of the osteotomy; (**D**) width of the tibia measured from the osteotomy to the caudal tibial cortex; (**E**) width of the proximal tibia; (**F**) width of the distal tibial tuberosity attachment as measured at a 45-degree angle from lines B and C.

the time of re-examination, lameness was assessed subjectively by the attending veterinarian and categorized into four categories: 1 = no lameness noted; 2 = mild intermittent or continuous lameness; 3 = moderate weight bearing lameness; 4 = severe lameness.[4]

Statistical Analysis

Complications and outcomes are described as percentages of the number of dogs in the study. Univariate regression procedures were used to evaluate the effect of continuous variables (age, weight, size of the distal cortical attachment, tibial osteotomy length and size and shape ratios of the tibial tuberosity) on binary or ordinal categorical outcomes (e.g. presence of a fissure [none, present]; presence of a fracture [none, present]; rehabilitation [no, yes]). Multivariate stepwise and backward logistic regression procedures were performed to aid in assessing potential confounding of the independent variables. Contingency tables and Fisher's exact tests were used to examine relationships between the frequency distributions of categorical variables (e.g. fissure

Table 2 Summary of signalment and type of patellar luxation

Signalment			Number of cases				
			Total ($n = 106$)	MPL ($n = 100$)	LPL ($n = 6$)	Unilateral ($n = 32$)	Bilateral ($n = 74$)
Sex	Female	Intact	46 (43%)	44	2	15	31
		Spayed	2 (2%)	2	0	0	2
	Male	Intact	41 (39%)	38	3	10	31
		Castrated	17 (16%)	16	1	7	10

Abbreviations: LPL, lateral patellar luxation; MPL, medial patellar luxation.

[none, present], rehabilitation [no, yes], patellar reluxation [no, yes], lameness at recheck examination [none, mild, moderate, severe], presence of a pin [no, yes], post-op tibial tuberosity fracture [no, yes]). All data were entered into and maintained in a computer spreadsheet programme (Excel 2015; Microsoft, Redmond, Washington, United States). Mean and median values were calculated using an Internet statistical calculator (https://www.calculators.org/math/standard-deviation.php). Statistical software was used for analyses (SAS Statistical Software, Version 9.4, SAS Institute Inc., Cary, North Carolina, United States). Data were reported as statistically significant if $p < 0.05$.

Results

Three hundred and forty dogs underwent patellar surgery with TTT during the 7-year time interval. Two hundred and thirty-four dogs were excluded due to lack of postoperative radiographs ($n = 135$) or stabilization of the transposed tibial tuberosity using pins or pin and tension band technique ($n = 99$). One-hundred and six dogs met the inclusion criteria; 25 underwent bilateral staged surgery for a total of 131 TTT procedures. One-hundred and five dogs underwent surgery for the first time, while one dog had previously undergone block recession trochleoplasty and soft tissue augmentation surgery for patellar luxation at 5 months of age.

There were 34 different breed categories represented with mixed breed ($n = 30$), Chihuahuas ($n = 19$), Yorkshire Terriers ($n = 9$) and French Bulldogs ($n = 8$) being the most common breeds. Age ranged from 6 to 105 months (median, 25 months; mean ± standard deviation [SD], 33 ± 23 months). Weight ranged from 1.5 to 32.4 kg (median, 4.6 kg; mean ± SD, 7.5 ± 6.8 kg) with 10 dogs weighing more than 15 kg. The sex, grade and type of patellar luxation, leg affected and type of additional surgical techniques performed are summarized in ►**Tables 2** and **3**. One-hundred and six surgical procedures had a single cortical screw placed to stabilize the transposed tibial tuberosity and one procedure had two screws placed adjacent to each other in the proximodistal direction. In dogs with a single cortical screw, the implant complication rate leading to implant removal was 1.9% (2/106 dogs). These two dogs had lameness at the re-examination with no evidence of infection, patellar luxation or implant migration. The lameness resolved following screw removal. Twenty-four surgical procedures had a Kirschner wire placed through the tibial tuberosity in addition to the screw. Placement of a Kirschner wire did not affect fracture development postoperatively ($p = 0.176$) and as such, this subset of dogs was included in the statistical analysis. One dog required removal of the pin due to pin migration and development of infection. The screw was removed 1 week following pin removal.

Postoperative radiographs review showed an incomplete osteotomy of the tibial tuberosity performed with no evidence of fissure distally in 115 limbs. Eleven limbs had incomplete fissures detected postoperatively and 5 had complete fissures. Of the limbs with incomplete fissures, four had a pin placed through the tibial tuberosity at the time of surgery in addition to the screw, while seven had only a screw in place. Of the limbs with complete fissures, three cases had a pin placed through the tibial tuberosity in addition to the screw, while two limbs had only a screw in place. Larger tibial tuberosity attachment width relative to osteotomy length (F/A, $p < 0.001$ and C/A, $p = 0.004$) and to proximal tibial width (F/E, $p < 0.001$ and C/E, $p = 0.018$), along with a greater tibial tuberosity width at the distal end of the osteotomy relative to proximal tibial width (C + D/E, $p = 0.023$), decreased the odds of fissure formation (►**Table 4**). Fissure formation was not associated with weight ($p = 0.098$) or age of the dog ($p = 0.57$).

Table 3 Summary of grade of patellar luxation and the type of surgery performed in addition to tibial tuberosity transposition

Grade patellar luxation ($n = 131$)	1	2	3	4
	2 (1.5%)	77 (59%)	50 (38%)	2 (1.5%)
Type of surgery performed ($n = 131$)	Block recession Imbrication	Block recession Imbrication Release	Imbrication Release	Imbrication
	96 (73%)	29 (22%)	3[a] (2%)	4 (3%)

Note: The type of surgery performed is independent of the type of patellar luxation present.
[a]Two cases underwent patellar groove replacement.

Table 4 Ratios (mean ± SD, [range]) of distal tibial tuberosity attachment dimensions relative to osteotomy and proximal tibial dimensions

	F/A	C/A	F/E	C/E	C + D/E
	Mean ± SD (range)	Mean ± SD (range)	Mean ± SD (range)	Mean ± SD (range)	Mean ± SD (range)
No Fissure ($n = 114$[a])	0.25 ± 0.10 (0.02–0.66)	0.23 ± 0.08 (0.05–0.48)	0.14 ± 0.05 (0.01–0.29)	0.13 ± 0.04 (0.05–0.25)	0.62 ± 0.08 (0.42–0.75)
Fissure ($n = 16$[a])	0.13 ± 0.12 (0–0.39)	0.13 ± 0.11 (0–0.39)	0.08 ± 0.07 (0–0.19)	0.08 ± 0.07 (0–0.19)	0.54 ± 0.08 (0.44–0.70)
p-value	<0.001	0.004	<0.001	0.018	0.023

Abbreviations: C/A, distal tibial attachment relative to the length of the osteotomy; C/E, distal tibial attachment relative to the width of the proximal tibia; C + D/E, width of the tibial tuberosity at the distal end of the osteotomy relative to the proximal tibial width; F/A, distal tibial attachment at a 45° relative to the length of osteotomy; F/E, distal tibial attachment at a 45° relative to the width of the proximal tibia; SD, standard deviation.
[a]Only 130 stifles were included in the analysis as one dog's osteotomy could not be measured on postoperative radiograph.

Four dogs were diagnosed with tibial tuberosity avulsion fracture after surgery. Two of the dogs developed tibial tuberosity fracture-separation within 1 week of the initial surgery and were treated with pin and tension band placement. Both cases had incomplete fissures detected on postoperative radiographs and one of the cases had a pin placed in addition to the screw at the time of initial surgery. The remaining two dogs had tibial tuberosity fracture and proximal displacement of the tuberosity diagnosed with radiographs at the time of re-evaluation 42 and 43 days, respectively, following surgery. One dog had an incomplete fissure and one dog had a complete fissure detected on postoperative radiographs. The dog with the complete fissure had a pin placed in addition to the screw at the initial surgery. Both dogs were ambulatory without lameness at the time of re-evaluation and the patellae were stable. The presence of fissure postoperatively significantly increased the odds for fracture postoperatively ($p < 0.001$).

Follow-up time ranged from 4 to 32 weeks (median, 7 weeks) for the 131 surgical events. Thirty-eight dogs (29%) had a lateral projection radiograph acquired at the time of the first or a follow-up re-evaluation. The 38 dogs had intact screws without signs of migration of the implant and no lysis. Lameness scores were as follows: Grade 1($n = 100$ dogs), grade 2 ($n = 25$), grade 3 ($n = 6$), grade 4 ($n = 0$). The odds for lameness at the time of re-evaluation increased as the ratio of the distal cortical attachment to the width of the proximal aspect of the tibia decreased (C/E and F/E) (i.e. smaller distal cortical attachment, $p = 0.029$). Ninety-four (72%) surgical procedures underwent rehabilitation, consisting of walking on underwater treadmill and balance training, at a rehabilitation centre following surgery. Postoperative rehabilitation did not influence the presence of lameness ($p = 0.889$) and patella reluxation ($p = 0.280$) at the time of re-examination.

Ten stifles (7.6%) required one or two surgical interventions following the initial surgery for a total of 12/131 (9.2%) revision surgeries (►**Table 5**). Patellar reluxation rate following surgery was 6.9% (9/131 procedures) and the odds for reluxation decreased with increasing age at the time of surgery ($p = 0.02$). Five stifles (3.8%) had grade 2 or higher patellar luxation at re-examination and underwent additional surgery.

Discussion

The findings of our study show that the described TTT technique using a cortical screw adjacent to the tibial tuberosity was clinically successful and had a low complication rate.

In this study, the screw-related complication rate leading to implant removal was 1.9% which is less than previous reports of 7.7 to 24.6%[5,10,15] in patients with pins placed. In one study[10] with 137 stifles undergoing surgery for medial patellar luxation, 24.6% had implant migration and 13.8% had implant failure of the 65 stifles evaluated radiographically after surgery. There was no screw migration or breakage noted on re-examination radiographs in the current study but only 38 cases had follow-up radiographs. The screw was not palpable at the time of the re-examination in any of the cases and there were no reports of skin or subcutaneous tissue irritation during the postoperative period. The low incidence of implant-related complications in the current study can be due to several reasons. Cortical screws are less

Table 5 Causes for additional surgical intervention

	Cause for reoperation			
Additional surgeries (12)	Patella luxation	Tibial tuberosity fracture	Implant removal	
			Screw	Pins
1	5	2	2	1
2	n/a	n/a	1	1[a]

[a]One case underwent removal of pin and tension band following surgical stabilization of a tibial tuberosity fracture.

prone to migration compared with pins that lack threads. The implants used in the current study may be exposed to lower shear forces compared with other fixation methods as the screw is placed adjacent to the tibial tuberosity exiting the trans-cortex and because the distal attachment shares the load. Implants penetrating a completely transected tibial tuberosity have to resist the tensile forces from the quadriceps muscle during stance and extension of the stifle. Finally, because of its adjacent position, the screw is largely protected by the tibial tuberosity and has better soft tissue coverage compared with pins placed cranially through the tibial tuberosity.

The documented rate of tibia tuberosity avulsion fracture in the current study was 3% (4/131). This is comparable to other reported rates of 0.7 to 4%.[6,12,16] The presence of fissure postoperatively increased the odds of tibial tuberosity fracture through the distal attachment: 25% of the cases with fissures subsequently developed a fracture at a later time. Once a fissure has formed, the pull of the quadriceps on the tibial tuberosity will lead to cycling of the remaining cortical attachment and the fissure can easily continue to propagate and lead to failure. Only two of the four cases were presented with acute increase in clinical signs and needed surgery to stabilize the fracture. In this study, placement of a pin in addition to the screw did not prevent tibial tuberosity fracture. The reason for placement of pin in addition to the screw was not documented in every case. Because of the high percentage of patients with fissure subsequently having a fracture, we recommend using pin and tension band instead of the screw method to stabilize the tibial tuberosity if a fissure is noted.

Larger size of the tibial tuberosity and a wider distal cortical attachment relative to tibial size had a decreased odds of fissure formation in the current study. A larger distal attachment provides greater strength to resist quadriceps muscle loads and to withstand forces acted upon it during transposition. It is important to gradually translate the tibial tuberosity as slow loading allows for greater displacement. Age and weight did not influence the rate of fissure formation in our study. The geometry of tibial tuberosity has not been evaluated in patients with patella luxation previously but its role in stifle mechanics has been investigated. Inauen and colleagues[17] found that a smaller tibial tuberosity craniocaudal width increased the odds of cranial cruciate ligament rupture at a younger age.

Thirty-one dogs had residual lameness at re-examination in our study but 25 dogs had only mild lameness (grade 1). The median follow-up period was 7 weeks and it is possible that some of these dogs continued to improve after the re-examination. Interestingly, dogs with a smaller cortical attachment had increased odds of lameness at recheck. A larger cortical attachment may be more stable and thus contribute to less inflammation and pain. This could also be an indication of complications related to the osteotomy site such as progressive fissuring. Two of the dogs with moderate lameness (grade 3) at re-examination had concurrent orthopaedic disease (ipsilateral stifle osteochondrosis and ipsilateral cranial cruciate ligament rupture respectively) but no patellar reluxation. One of these dogs had re-examination radiographs confirming a healed osteotomy.

Limitations of the current study reflect its retrospective nature where data reported relied on the accuracy of the medical record entries and involved several veterinarians. Additional follow-up examinations beyond the median time of 7 weeks would have been preferred at other time points during the recovery. It is possible that the reluxation rate would have been higher with a longer follow-up period. Cook and colleagues[18] published guidelines with regard to time frames for data collection in clinical studies but in this retrospective study, we could not adhere to these guidelines. The goal of this study was to report a novel TTT technique and we expect that complications with the technique would decrease over time as the tibia tuberosity heals in the new position. Another limitation of our study is that the experience level varied among veterinarians. As our overall complication and reluxation rates were comparable to other studies, we do not believe that this compromised our study, but it may have affected the lameness scoring and patellar reluxation rate.

The quality of the postoperative radiographs was not standardized, and true lateral radiographs were not always available for measurement. This may have affected the results with regard to size of distal tibial tuberosity attachment and shape of tibial tuberosity, especially as the medial and lateral condyle of the tibia was not always superimposed. It is generally accepted that follow-up radiographs should be acquired when surgical implants have been placed. At our hospital, radiographs were unfortunately not taken regularly at re-examination following patellar luxation surgery if the dogs were doing well. It is possible that additional tibial tuberosity fractures would have been diagnosed if radiographs were taken at the re-examination; however, it would be considered a minor complication if the patient was clinically doing well.

In summary, TTT can successfully be performed by placing a cortical screw adjacent to the transposed tibial tuberosity. This technique has a low perioperative and postoperative complication rate.

Author Contribution

Barbro Filliquist contributed to conception of study, study design, acquisition of data and data analysis and interpretation. Sivert Viskjer contributed to conception of study, study design and acquisition of data. Dr Susan M. Stover contributed to study design and data analysis and interpretation. All authors drafted, revised and approved the submitted manuscript.

Conflict of Interest

None declared.

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