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Tibial Tuberosity Advancement for Stabilization of the Canine Cranial Cruciate Ligament-Deficient Stifle Joint: Surgical Technique, Early Results, and Complications in 101 Dogs

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Objective—To describe the surgical technique, early results and complications of tibial tuberosity advancement (TTA) for treatment for cranial cruciate ligament (CrCL)-deficient stifle joints in dogs.
Study Design—Retrospective clinical study.
Animals—Dogs (n = 101) with CrCL-deficient stifles (114).
Methods—Medical records of 101 dogs that had TTA were reviewed. Complications were recorded and separated into either major or minor complications based on the need for additional surgery. In-hospital re-evaluation of limb function and time to radiographic healing were reviewed. Further follow-up was obtained by telephone interview of owners.
Results—Complications occurred in 31.5% of the dogs (12.3% major, 19.3% minor). Major complications included subsequent meniscal tear, tibial fracture, implant failure, infection, lick granuloma, incisional trauma, and medial patellar luxation; all major complications were treated with successful outcomes. All but 2 minor complications resolved. The mean time to documented radiographic healing was 11.3 weeks. Final in-hospital re-evaluation of limb function (mean, 13.5 weeks), was recorded for 93 dogs with lameness categorized as none (74.5%), mild (23.5%), moderate (2%), and severe (1%). All but 2 owners interviewed were satisfied with outcome and 83.1% reported a marked improvement or a return to pre-injury status.
Conclusions—TTA is a procedure comparable with alternate methods of CrCL repair with expected good to excellent functional outcome.
Clinical Relevance—TTA procedure can be successfully used to obtain the dynamic stability of a CrCL-deficient stifle joint in dogs.

INTRODUCTION

RUPTURE OF the cranial cruciate ligament (CrCL) leads to abnormal craniocaudal motion of the tibia and excessive internal rotation of the stifle joint, which leads to progressive osteoarthritis.[1–3] Restoration of function is obtained surgically by neutralizing the tibiofemoral shear forces in a CrCL-deficient stifle either statically or dynamically. Tibial plateau leveling osteotomy (TPLO) is reported to stabilize the stifle joint functionally during weight-bearing by neutralizing the cranial tibial thrust (CrTT).[4,5] This is achieved by radial osteotomy of the proximal tibia, allowing rotation of the tibial plateau along this arc to obtain reduction of the tibial plateau angle (TPA).[5–8]

Recently, a new technique, tibial tuberosity advancement (TTA), has been proposed to similarly stabilize the stifle joint during weight-bearing by neutralizing the CrTT.[9–11] This is achieved by frontal plane osteotomy of the tibial crest to advance the patellar tendon perpendic-

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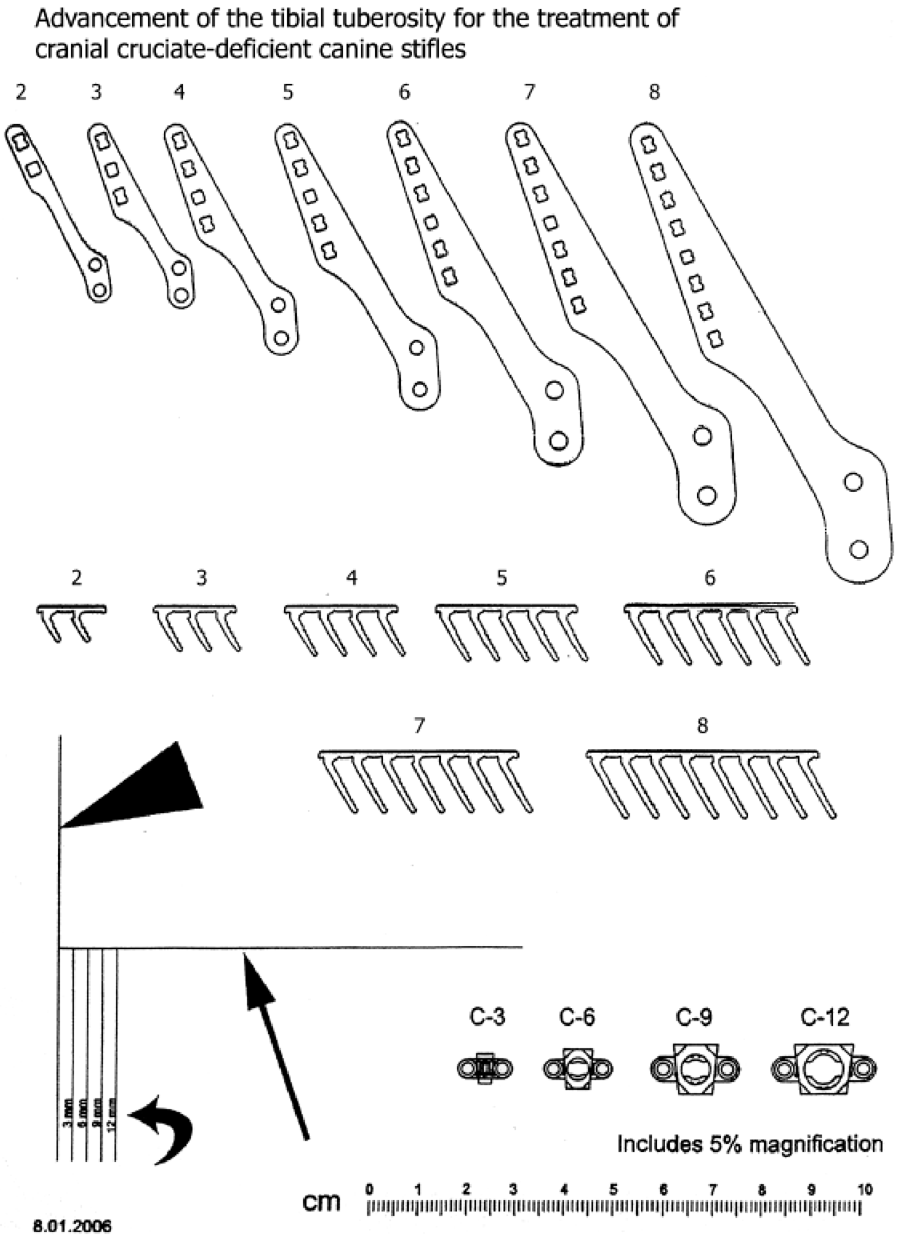

Fig 1. Transparency Guide (Kyon). Top: Plate sizes from 2-hole to 8-hole, which correspond to the size of the tibial crest (and forks of the identical number to match the plate). Bottom: Measuring guide to determine cage width; horizontal line aligns with the tibial plateau slope (arrow), vertical line aligns with the cranial margin of the patellar tendon (arrowhead), and distance determined by the overlay from the vertical line to the tibial tuberosity (curved arrow; compare with Fig 2). Cage widths correspond to the 3, 6, 9, and 12 mm vertical lines present.

ular to the tibial plateau.[9] TTA is also reported to functionally stabilize the stifle joint during weight-bearing by neutralizing CrTT.[12]

Our purpose was (1) to describe the surgical technique for TTA using a specially designed tension-band plate (Kyon; Zürich, Switzerland) and (2) to describe early results and complications in an initial series of 101 dogs.

MATERIALS AND METHODS

Inclusion Criteria

Medical records of 101 dogs with CrCL injuries that had the TTA procedure were reviewed. Dogs were admitted to Alameda East Veterinary Hospital (July 2003 to September 2004) and Cummings School of Veterinary Medicine at Tufts

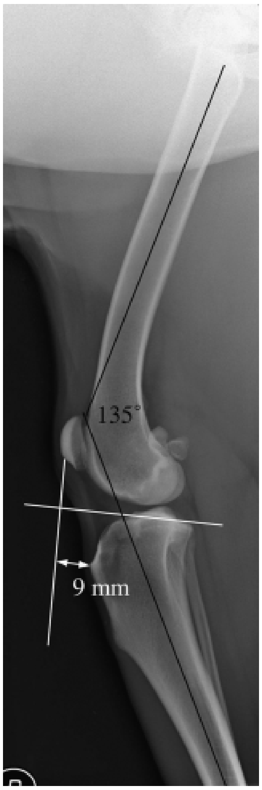

Fig 2. Pre-operative, true lateral radiographic projection; the stifle joint is at 135° extension (the femoral and tibial axes are determined by the diaphyses). For simplicity, only 2 lines are drawn (identical to the transparency guide; compare with Fig 1): horizontal line along the tibial plateau slope, and vertical line along the cranial margin of the patellar tendon. The distance to advance the cage in this example is 9 mm.

University (January 2004 to September 2004) and represent the first series of cases operated using TTA at each institution. Age, gender, weight, and breed were recorded. Complications (intra- and post-operative), treatment, and outcome were recorded.

Post-operative complications were defined as any unexpected developments that occurred after surgery. Major complications were defined as those complications requiring subsequent surgical intervention; minor complications were defined as those not requiring additional surgical treatment.

Surgical Planning (Guerrero TG, Tepic S, Baviera B, et al: Advancement of the tibial tuberosity for the treatment of cranial cruciate deficient canine stifle [video]. The First Instructional Course for Tibial Tuberosity Advancement (TTA) for Cranial Cruciate Deficient Stifle in Dogs. Denver, CO, 2004).

Standard craniocaudal and lateral radiographic projections of the affected stifle joint were obtained pre-operatively to assess the joint. The lateral projection was centered on the stifle joint (perfect positioning confirmed by superimposition of both femoral condyles) at a stifle joint angle of 135°, using the long axes of the femur and tibia (the entire femur was included to determine the appropriate femoral long axis). The joint was positioned so that there was no cranial tibial translocation. A standardized TTA transparency (Kyon) was used to determine the amount of TTA required to position the patellar tendon perpendicular to the tibial plateau in a standing position (135° stifle joint extension) and the size of the plate to cover the entire extent of the tibial crest (Fig 1). These measurements were obtained from the lateral radiographic projection (Fig 2). Alignment of the plate guide helped to determine holes (for the fork) and the final plate position along the tibial crest; in some cases it was necessary to align the proximal end of the plate slightly caudally (Fig 3).

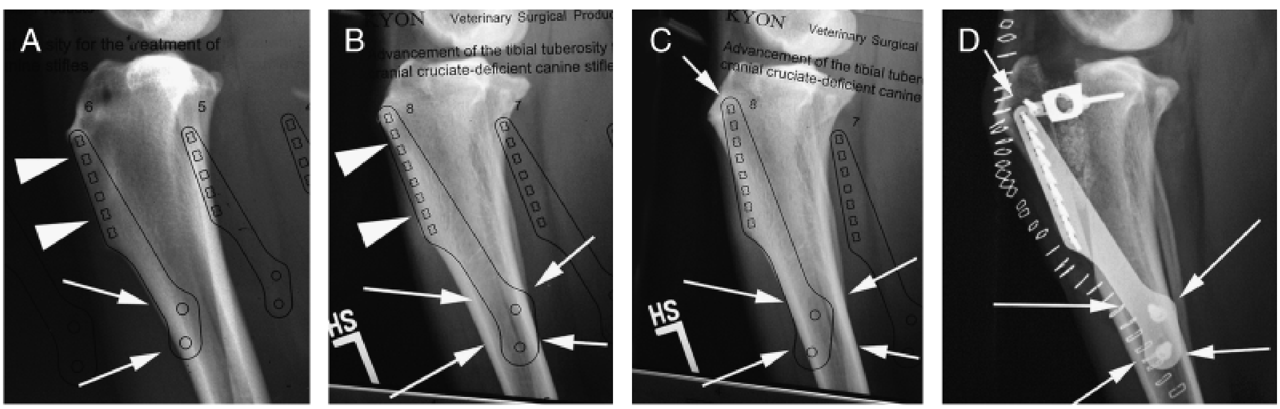

Fig 3. (A) In most dogs, the plate can be aligned parallel to the rostral border of the tibial crest (arrowheads), which results in a slightly cranial location of the distal end of the plate (arrows); (B) In some dogs, the tibial crest is not as prominent distally; therefore, aligning the template (and plate) parallel to the tibial crest (arrowheads) will result in the distal plate aligning with the central tibial axis before the advancement (arrows); (C) Aligning the template (and plate) so that the proximal aspect is more caudally positioned (short arrow) will result in the distal plate aligning slightly cranial to the tibial long axis (arrows); this is the desired position; (D) Post-operative radiograph showing the plate position (compare with C; short arrow); after advancement of the tibial tuberosity, the distal plate position moves caudally (arrows) and now rests once again along the tibial long axis.

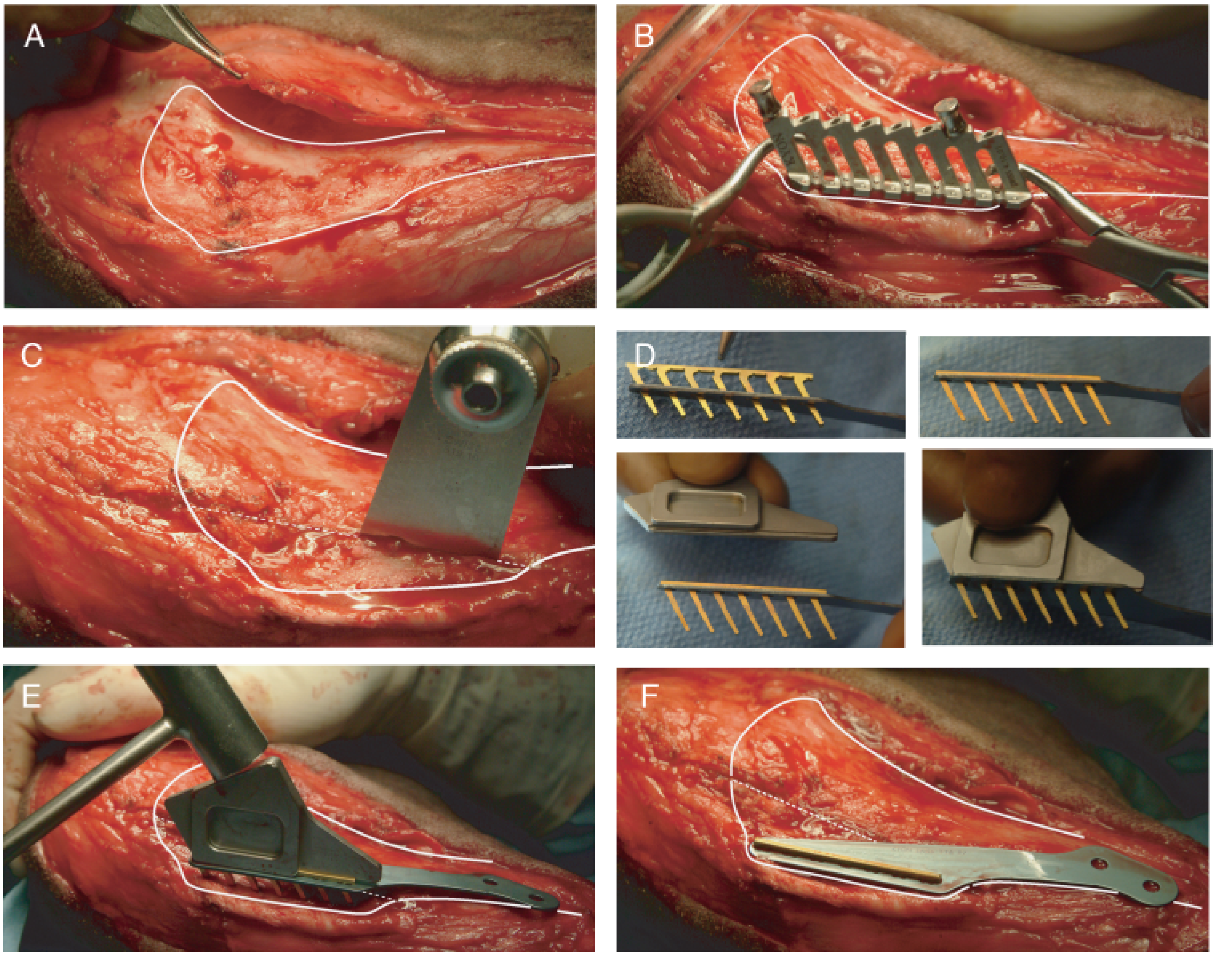

Fig 4. Sequential intra-operative photographs demonstrating key points in the surgical technique (7-hole plate, 12 mm cage); the dog is in dorsal recumbency, and the right hind limb is rotated onto the surface of a Mayo stand to align the tibia parallel to the floor (for orientation all photographs show the outline of the medial tibial surface). (A) Approach to the medial tibial surface; the caudal belly of the sartorius muscle and the aponeurosis of the gracilis, semi-membranosus, and semi-tendinosus muscle insertions have been incised and elevated (thumb forceps). The incision originates a few millimeters caudal and parallel to the tibial crest and is extended distally to the tibial diaphysis; rostrally, the periosteum is reflected to expose the cranial bone margin along the entire tibial crest; the elevated periosteum allows a point of attachment for re-suturing the aponeurosis of the elevated musculature with wound closure. (B) An 8-hole drill guide (Kyon) is placed parallel to the cranial margin of the tibial crest, with the first hole positioned at the level of the patellar tendon insertion into the tibial tuberosity; in this example, a 7-hole plate is to be applied (the most proximal and distal holes, #1 and #7, are drilled and alignment pins are placed to maintain the guide position before drilling all remaining holes, #3–6). (C) An osteotomy is performed parallel to the frontal plane extending from the distal extent of the tibial crest to a point immediately cranial to the medial meniscus (and cranial to the long digital extensor tendon). A bicortical osteotomy is performed distally, and extended only through the medial cortex proximally. (D) The appropriate size plate and fork are assembled. Note that the central peg of the fork has a notch to match the smaller square central hole of the plate to snap both pieces together. A fork inserter (Kyon) is secured to the base of the fork (and plate combination) to facilitate its application into the tibial crest. (E and F) A small mallet is used to seat the plate/fork combination into the tibial crest (note the cranial position of the distal plate in relation to the tibial long axis); after the plate is seated, the bicortical osteotomy in the tibial crest is completed.

Surgical Technique (Guerrero TG, Tepic S, Baviera B, et al: Advancement of the tibial tuberosity for the treatment of cranial cruciate deficient canine stifle [video]. The First Instructional Course for Tibial Tuberosity Advancement (TTA) for Cranial Cruciate Deficient Stifle in Dogs. Denver, CO, 2004).

Surgery was performed with the dog positioned in dorsal recumbency. The affected limb was aseptically prepared and draped to provide full access to the limb from mid thigh to the hock. All dogs were administered perioperative cefazolin (22 mg/kg).

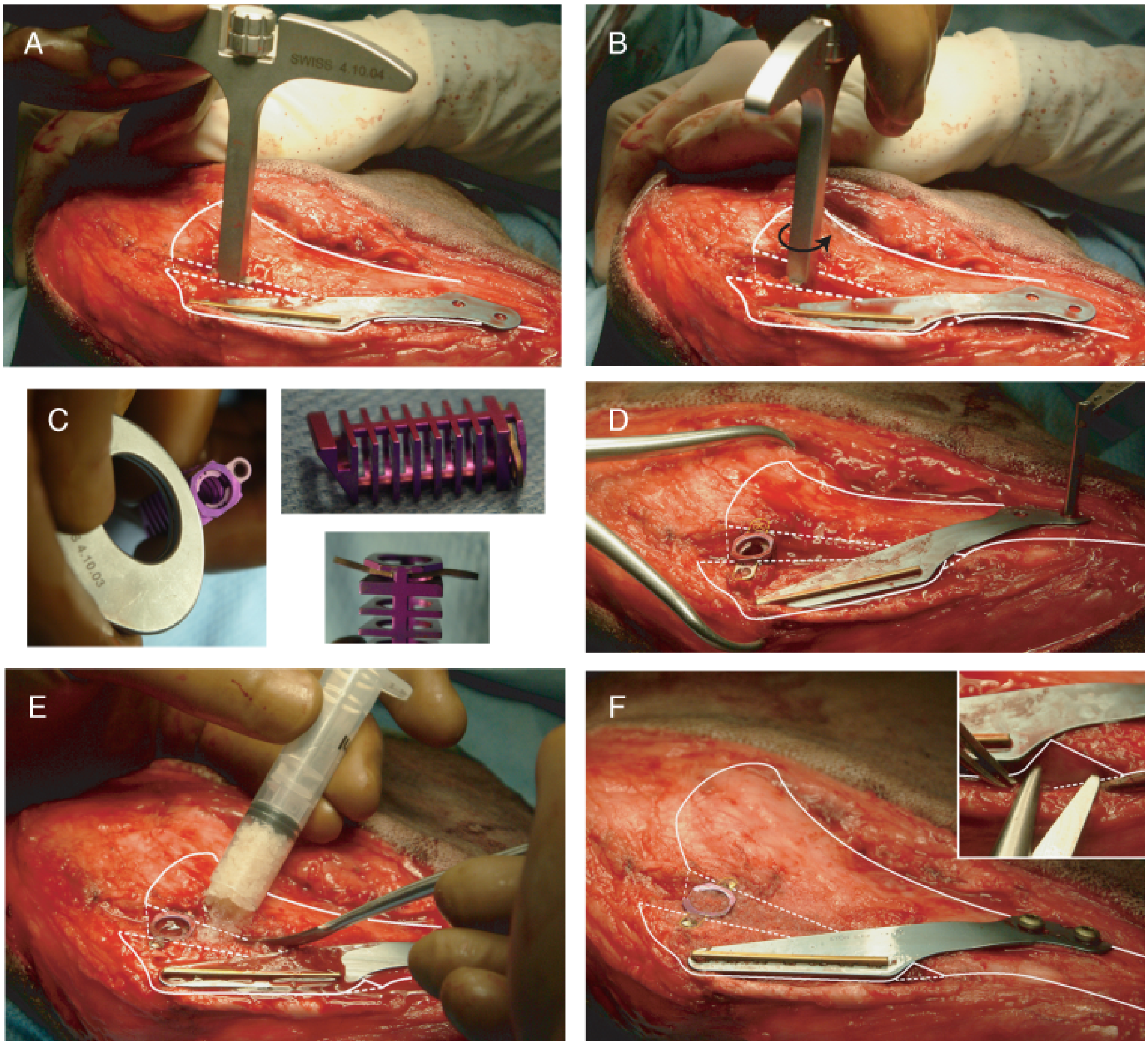

Fig 5. **Sequential intra-operative photographs demonstrating key points in the surgical technique—continued. (A & B) A T-handle with a 12 mm spreader attached distally (Kyon) is inserted into the osteotomy gap and then rotated 90°; the spreader assures a gap of sufficient width to place the 12 mm cage. (C) The appropriate length 12 mm cage is prepared for insertion; the ears are bent to match the corresponding contour of the tibia (the bottom right photo shows the most dorsal (wider) cage surface with the caudal ear bent slightly up and rotated slightly counterclockwise, and the cranial ear bent slightly down and also rotated slightly clockwise. (D) The cage has been secured with a 2.4 mm screw in the caudal ear (directed caudodistally) and the distal drill-hole in the plate is about to be placed (to accept a 3.5 mm screw); note that bone contact is obtained at the distal extent of the tibial crest and there is a slight shift proximally; also note the now central position of the plate along the tibial long axis after the tibial tuberosity has been advanced. (E) An allograft, fine corticocancellous bone chips with Demineralized Bone Matrix powder (Fine Mix Osteo-Allograft™, Veterinary Transplant Services) is placed within the osteotomy gap distal to the cage and also into the cage. (F) Completed appearance of the tibial tuberosity advancement. Inset: again notice the slight proximal displacement of the tibial crest so as to ensure a center of rotation of the patellar tendon's attachment to the tibial tuberosity based at the patella.**

Exploration of the stifle joint before surgical stabilization was completed either by arthrotomy or arthroscopy to evaluate the stifle joint (degree of damage to the cruciate ligaments and menisci, and to evaluate the presence of degenerative joint disease). Remnants of the torn CrCL were debrided and any meniscal tears were treated by partial or complete meniscectomy. Initially, all intact menisci were left in situ; however, in later cases a medial meniscal release was performed, either mid-substance during arthroscopy or by transection of the caudal meniscotibial ligament during arthrotomy.

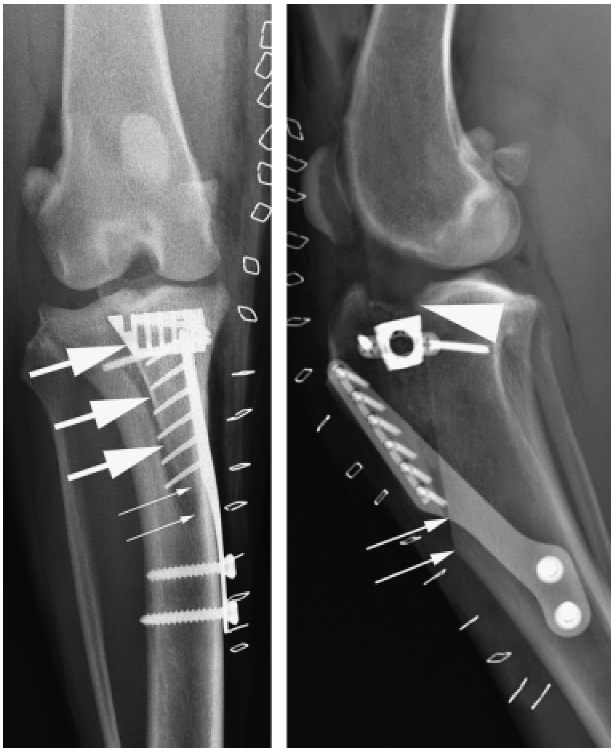

Fig 6. Craniocaudal and lateral post-operative radiographs of a completed tibial tuberosity advancement immediately post-operatively. The slight proximal shift of the tibial crest can be seen (small arrows). Notice in this case that the plate has been placed parallel to the cranial tibial margin of the tibial crest. The lateral border of the osteotomized tibial crest can also be seen; notice that the lateral margin of the cage follows the contour of the bone at this level (large arrows). The cage is placed 2–3 mm below the proximal extent of the tibia (arrowhead). Also notice that the caudal extent of the osteotomy at the level of the tibial joint surface: immediately cranial to the medial meniscus (this position is also cranial to the long digital extensor tendon laterally).

Exposure of the craniomedial aspect of the tibial crest was performed by incising the insertion of the caudal belly of the sartorius muscle and the aponeurosis of the gracilis, semimembranosus, and semitendinosus muscle insertions (Fig 4A). This incision was made a few millimeters caudal and parallel to the tibial crest and extended distally to the tibial diaphysis. The periosteum of the tibial crest was reflected cranially to expose the cranial bone margin of the entire tibial crest. An 8-hole drill guide (Kyon) was positioned parallel to the cranial margin of the tibial crest, with the first hole aligned with the level of the patellar tendon insertion into the tibial tuberosity (Fig 4B). The number of 2.0-mm holes drilled corresponded to the plate size determined during pre-operative planning. Before drilling these holes, plate orientation was checked so that the distal end was slightly forward of the central tibial axis to ensure that after subsequent advancement/rotation of the tibial tuberosity, the distal screw-holes in the plate would overlay the central tibia. Sometimes, it was necessary to align the proximal end of the plate slightly caudally (Fig 3).

The planned osteotomy, perpendicular to the sagittal plane of the tibia, was oriented from a point immediately cranial to the medial meniscus (and cranial to the long digital extensor tendon) to the distal extent of the tibial crest. A bicortical osteotomy was begun distally, and extended only through the medial cortex for approximately one-half of the total distance proximally (Fig 4C). A TTA tension-band plate was contoured to match the shape of the tibial crest and proximal tibia. The plate was bent with a slight caudal rotation and distomedial bend; all bending/twisting was performed in the area between the fork and screw-holes. A fork designed to fit within the tension-band plate, of the corresponding size, was locked into the plate (Fig 4D). The plate/fork combination was then secured into the tibial crest (which required impaction of the fork with a mallet into the pre-drilled holes in the bone; Fig 4E and F). The remainder of the osteotomy was completed. The tibial crest, with attached plate, was moved cranially using a spacer attached to a T-handle (Kyon) that corresponded to the selected cage width (Fig 5A and B). A cage was placed into the osteotomy site at the proximal extent of the osteotomy ($\sim$ 2–3 mm from the proximal tibial bone margin) and secured at its caudal margin to the tibia with a 2.4 mm screw directed caudodistally; the "ears" of the cage (screw-holes) were contoured to match the corresponding tibial surfaces (Fig 5C and D). The plate was then secured distally to the tibia with the appropriately sized screws (2.7 mm or 3.5 mm); the entire tibial crest was allowed to shift a few millimeters proximally to ensure that the patella position was unaltered (arc of rotation of the patellar tendon's attachment to the tibial tuberosity centered at the patella). Finally, the cranial cage screw was secured into the tibial tuberosity directed cranioproximally. The limb was evaluated to confirm the absence of CrTT. A bone graft was placed into the osteotomy (Fig 5 E and F). Sources of bone graft material included either autograft retrieved from the dog at surgery (proximal tibia or distal femur) or commercially available frozen allograft (Demineralized Bone Matrix [DBM] powder or Fine Mix Osteo-Allograft™ [corticocancellous chips sieved to $<$2.5 mm and DBM]; Veterinary Transplant Services, Kent, WA). The quantity of graft used was sufficient to fill the entire osteotomy gap, including the cage (generally 2–5 mL depending on the size of the dog).

Closure of the surgical site was initially achieved by apposition of the aponeurosis of the medial thigh muscles to the periosteum of the tibial crest to cover the implants. This began at the level of the tibial tuberosity with the stifle joint in full flexion. Occasionally, it was necessary to transect the distal crural fascia of the semitendinosus muscle (attachment to the medial surface of the tibia) and/or incise further proximally along the cranial border of the caudal sartorius muscle to further mobilize these structures. The remaining wound was closed in layers. Post-operative radiographs were obtained to evaluate the osteotomy and plate/cage position (Fig 6). A modified Robert Jones bandage was applied for the first 24–48 hours post-operatively in most dogs at the surgeon's discretion, and removed before hospital discharge.

Table 1. Major Complications (Defined as Subsequent Surgical Intervention) After Tibial Tuberosity Advancement in 114 Stifle Joints in 101 Dogs

Complication	Number	Additional Details	Treatment	Outcome
Subsequent meniscal tear	7*	Mean 24.5 weeks post-operative (range, 13–31 weeks)	Stifle joint re-exploration; partial meniscectomy	Resolution of lameness
Implant failure	1	Multiple forks fractured, loss of fixation to tibial crest (3 weeks post-operative)	Implant removal and replacement	Healed within 6 weeks and resolution of lameness
Tibial fracture	2	Stress fracture though either proximal or distal screw of plate (in both cases osteotomy extended to level of screws)	Open reduction internal fixation using a dynamic compression plate	Healed fracture within 8–12 weeks
Lick granuloma	2	Began within 4–7 weeks post-operative; unsuccessful with E-collar	Excised with primary closure	Healed without future problems
Septic arthritis	1	5 weeks post-operative	Open joint flush with joint culture and antibiotic susceptibility testing (*Staphylococcus* sp); 30 days doxycycline	Infection resolved
Chronic poor performance	1*	#1: Lameness at 16 weeks post-operative #2: lameness at 43 weeks post-operative	#1: meniscal tear with debridement #2: medial patella luxation, (hypermobile patella and rotational joint instability); lateral suture stabilization	Resolution of lameness on both occasions

*1 dog with a subsequent meniscal tear is included in both complication categories.

Follow-Up

In-hospital evaluations were performed post-operatively at the respective institutions, or by the referring veterinarian, until fracture healing was radiographically evident. All dogs were assessed for lameness as well as any other complications. Limb function was categorized as: no lameness, mild lameness (weight-bearing lame), moderate lameness (weight-bearing lame with intermittent non-weight bearing), severe lameness (non-weight-bearing lameness with brief intermittent weight bearing) and non-weight-bearing lameness. All post-operative complications were recorded. Further longer-term follow-up was obtained by telephone interview of owners who were asked to rate their dog's performance after surgery and to comment on whether or not they would again consider TTA to treat CrCL injuries in their pets.

RESULTS

Signalment

TTA for CrCL repair was performed in 101 dogs (50 spayed [49.5%] and 3 intact females [3%] and 48 castrated males [47.5%]). The mean age was 5.9 years (range, 1–13 years) and the mean body weight was 36.7 kg (range, 14.5–83.0 kg). There were 33 Labrador Retrievers (32.7%), 17 mixed breeds (16.8%), 11 German Shepherd Dogs (10.9%), 4 Golden Retrievers (3.9%), 4 Boxers (3.9%), 4 Rottweilers (3.9%), 3 Newfoundland Dogs (2.9%), 3 Australian Shepherd Dogs (2.9%), 3 Cocker Spaniels (2.9%), 2 Border Collies (1.9%), 2 Springer Spaniels (1.9%), 2 Chesapeake Bay Retrievers (1.9%), and 1 each (1.0%) of the following breeds: Alaskan Malamute, Australian Cattle Dog, Bulldog, Chow chow, Collie, Elkhound, Giant Schnauzer, Great Dane, Great Pyrenees, Mastiff, Samoyed, Chinese Shar-Pei, and Siberian Husky.

Surgical Findings

TTA was performed in 114 stifle joints (56 [49.1%] right, 58 [50.9%] left). Thirteen dogs (12.8%) had bilateral TTA, with the second procedure performed at varying intervals after the first. Seventy-four joints were evaluated by arthroscopy and 40 by arthrotomy. Forty-six joints (40.3%) had a medial meniscal tear (bucket-handle or caudal pole) at initial surgery that was debrided by partial meniscectomy. Initially, intact menisci were left in situ; however, later in the study, meniscal release (either caudal meniscotibial ligament or mid-substance) was performed in 22 stifle joints.

Autograft was used in the first 17 dogs (adjacent proximal tibia in 8 dogs and adjacent distal femur in 9 dogs), and the other 97 had an allograft (DMB matrix powder in the first 20 joints, then Fine Mix in the next 77). Use of the Fine Mix graft was made primarily because of convenience compared with additional autograft procurement, and its improved handling characteristics compared with DBM.

Table 2. Minor Complications (Defined as No Further Surgical Intervention) After Tibial Tuberosity Advancement in 114 Stifle Joints in 101 Dogs

Complication	Number	Additional Details	Treatment	Outcome
Non-displaced tibial tuberosity chip fracture	4	Incidental finding; no clinical signs	None	
Suspect subsequent meniscal tear	3	Audible clicking; lameness in 1 dog	None; no clinical signs in 2 dogs, owner declined treatment in 1 dog	Unchanged: 2 dogs remained asymptomatic, 1 dog with persistent lameness
Implant failure	3	Incidental finding; fracture of 1–2 forks within tibial crest in 2 cases, lucency around cage in 1 case; no clinical signs	None	
Poor mineralization within osteotomy gap	3	Incidental finding; no change in appearance followed ~ 6+ months; no clinical signs	None	
Post-operative stifle joint and distal limb swelling	3	All within first 24–72 hours post-operative	Robert Jones bandage in 1 for 48 hours; no treatment in 2	Resolved within an additional 48–72 hours
Superficial skin infection	2	Suture reaction/local skin infection	Removed exposed subcutaneous sutures; Oral antibiotics	Resolved
Incisional dehiscence	1	Opening of distal 2 cm	Oral antibiotics	Healed by second intention
Incisional trauma	1	Self trauma (removed staples)	None	
Chronic poor performance	1	Severe lameness at first in-hospital re-evaluation 12 weeks post-operative; Full joint range of motion without pain	Aggressive physiotherapy {Did not return for further in-hospital evaluation}	Long-term telephone follow-up of moderate lameness only after heavy activity
Intra-operative tibial fracture (non-displaced)	1	Fracture occurred during distal plate re-positioning	Type Ia (4-pin) SK™ ESF applied immediately intra-operatively	Healed, ESF removed at 6 weeks post-operative

In-Hospital Re-Evaluation

In-hospital evaluation and radiographic assessment of healing occurred in 93 dogs (102 stifle joints) from 3 to 63 weeks post-operatively with the mean time for final in-hospital re-evaluation of limb function being 13.5 weeks post-operatively. Outcome was: no lameness, 67 dogs (76 joints, 74.5%); mild lameness, 23 dogs (24 joints, 23.5%); moderate lameness, 2 dogs (2 joints, 2.0%); and severe lameness, 1 dog (1 joint, 1%). The mean time to complete healing was 11.3 weeks (range, 4–63 weeks); 10 healed within 4–6 weeks, 31 in 6–8 weeks, 37 in 8–12 weeks, and 15 had healing at some point >12 weeks. Thus, 44.1% were healed within 8 weeks and 83.9% within 12 weeks; however, in 7 of the remaining cases that healed >12 weeks, the first radiographic follow-up was obtained between 16 and 63 weeks (mean, 34.6 weeks; median, 40 weeks). The mean time to complete radiographic healing, eliminating these latter cases, was 9.4 weeks (range, 4–20 weeks). No difference in healing was observed between autograft or allograft use to fill the osteotomy gap.

Complications

Post-operative complications were reported for 36 (31.5%) of the 114 stifle joints. Of these, 14 (12.3%) were classified as major complications (Table 1) and 22 (19.3%) as minor complications (Table 2).

Major complications (Table 1). There were 7 documented meniscal tears, 2 tibial fractures, 2 lick granulomas, and 1 each of implant failure, septic arthritis, and medial patellar luxation. Meniscal tears were documented further during exploratory surgery and partial meniscectomy was performed. The 2 tibial fractures were stabilized with plate fixation. The 2 lick granulomas were originally treated with Elizabethan collars to prevent licking, but were unsuccessful and the granulomas were surgically excised. The infection was treated by joint exploration and debridement and based on bacterial culture and susceptibility testing antibiotic therapy was administered for 4 weeks. Medial patellar luxation occurred after a second surgical exploration of the joint to address a subsequent meniscal tear. During this third surgical procedure, the joint had excessive rotational instability and a hypermobile patella. Lateral retinacular stabilization was performed to restabilize the joint. All major complications were corrected and resulted in successful outcomes.

Minor complications (Table 2). There were 4 non-displaced tibial tuberosity chip fractures (small non-displaced avulsion fracture fragments observed at the proximal end of the tibial tuberosity), 3 implant failures (1 or 2 prongs of the forks fractured, but without any displacement in 2 stifle joints; radiolucency around a

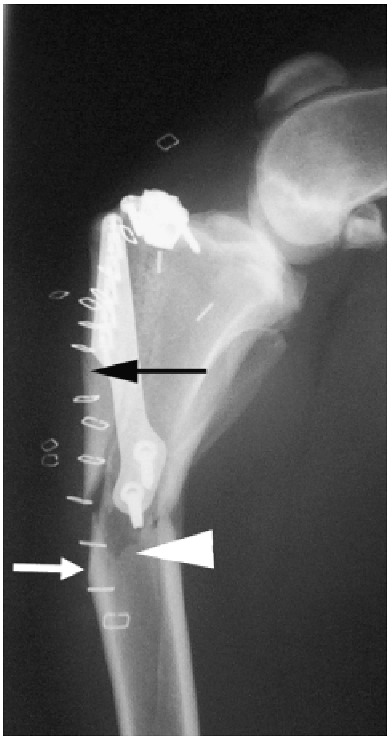

Fig 7. Lateral radiograph of a tibial fracture 2.5 weeks post-operatively. A number of technical failures are evident: The osteotomy cut is too far cranial and the cage is located too far proximally. The key error, however, is the distal extent of the tibial osteotomy (white arrow), which extends distal to the distal screw attachment of the plate (arrowhead); a stress-riser is created that pre-disposes to a fracture at this location. The plate should be sufficiently large, and the osteotomy cut should end sufficiently proximal, at the distal tibial crest (black arrow), to ensure an intact tibial cortex at the level of screw insertion of the plate.

portion of the cage in 1 stifle joint), 3 with audible clicking with ambulation, 3 with post-operative swelling, 3 with poor graft mineralization, 2 with superficial incisional infections, and 1 each of chronic poor performance, partial incisional dehiscence (<2 cm), non-displaced intra-operative tibial fracture, and self-inflicted incisional trauma (<2 cm). No treatment was performed in the 4 cases of tibial tuberosity chip fractures, the 3 dogs with implant failure, and the 3 dogs with poor graft mineralization (followed for 6 months without any observable change to the area), all of which were incidental findings. No treatment was performed in the 3 dogs with audible clicking because of the absence of any clinical dysfunction in 2 dogs, and was declined in the other dog. We presumed that these were meniscal tears, which occurred after TTA.

Post-operative joint swelling resolved in the 3 dogs within 72 hours; this occurred without treatment in 2 dogs, and application of a Robert Jones bandage in 1 dog. The 2 infections and the incisional dehiscence were treated with antibiotics. In the dog with the non-displaced intra-operative tibial fracture, the tibia was supplemented with a 4-pin Type I external skeletal fixator for the first 6 weeks post-operatively. The patient-induced incisional trauma was treated with an Elizabethan collar only. In the dog with the chronic poor performance, the first in-hospital re-evaluation was at 12 weeks, at which time the dog was minimally weight bearing with marked quadriceps muscle atrophy. The stifle joint had full range of motion and no palpable instability present. Aggressive physical therapy was recommended. This dog was lost to further in-hospital follow-up; however, with subsequent long-term telephone follow-up (at 1 year) the dog was reported to be generally sound, but moderately lame only after heavy activity. All minor complications were successfully resolved, except 1 dog with the audible clicking, which had a persistent lameness, and the dog with chronic poor performance, which was not examined again.

Telephone (Owner) Follow-Up

Follow-up for 91 (90.1%) owners was obtained by telephone survey 3–15 months post-operatively (mean, 8.4 months) and revealed that most owners were satisfied with the outcome. All contacted owners indicated that their dog improved after TTA. Seven (6.9%) owners indicated that their dog improved only slightly, 38 (37.6%) indicated marked improvement, whereas 46 (45.5%) stated that their dog returned to the pre-injury status. Of these 91 owners, only 2 (2.2%) indicated that they were displeased with the surgical procedure and would most likely pursue alternative treatment for a cruciate ligament injury should their pet require similar surgery in the future. One owner was displeased because of the poor long-term outcome, although the last in-hospital evaluation at 8 months post-operatively indicated that the dog was not lame. The other owner was unhappy because of complications that occurred post-operatively, which included a subsequent meniscal tear and medial patellar luxation. The remaining 89 owners (97.8%) indicated that they would choose TTA again without hesitation.

DISCUSSION

TTA is based on a mechanical model analysis of the human knee that characterizes the joint forces acting on the knee in a weight-bearing position.[13] Based on this model, there is a resultant joint force approximately parallel to the patellar tendon with either an anterior or posterior tibiofemoral shear force present based upon

Fig 8. Immediate post-operative lateral radiograph, and 3-week post-operative lateral and craniocaudal radiograph illustrating implant failure. A number of technical failures are evident in the post-operative radiograph; the osteotomy cut is too far cranial and oriented obliquely (arrows outline the medial extent of the cut—aligning with the medial aspect of the cage). The forks of the plate can be observed secured only in the medial tibial cortex. In addition, the cage is too small for this dog (6 mm cage in a dog with an 8-hole plate). In the follow-up radiographs, the forks have fractured and the tibial crest is no longer secured; the tibial crest has rotated caudally (and the cranial ear of the cage has fractured).

the knee flexion angle, and a crossover point of neutral tibiofemoral shear that is dependent upon the patellar tendon angle (PTA—angle between the patellar tendon and tibial plateau slope).[13] Similar assumptions have been made in the dog.[9–11] The point at which there is a crossover, or neutral tibiofemoral shear force, was proposed to be at a PTA of 90° during the fully extended weight-bearing position of the gait.[9–11] Therefore, the basis of the TTA is to move the tibial tuberosity sufficiently far cranially to maintain a PTA $\leq 90°$ during weight bearing so as to obtain a neutral or caudally directed tibiofemoral shear force during ambulation, thereby stabilizing the joint.[9–11] The effect of advancing the tibial tuberosity has been validated in an in vitro experimental study.[12] The TTA surgical technique has been used with success clinically at the University of Zürich, where it was developed.[9] Furthermore, this technique is currently being used clinically by >250 surgeons, >9000 cases, in the United States and Europe (personal communication, 2007—Slobodan Tepic: Kyon); however, there are no current reports that describe the details of the surgical technique, and there is little information available regarding complications.[14,15]

TTA is a relatively simple method to alter the effective insertion point of the patellar tendon, thus altering stifle joint function. The surgical dissection is limited to the medial tibial surface, with an osteotomy similar to that performed for tibial tuberosity transposition for correction of patellar luxation, albeit with osteotomy of a much larger bone fragment. This procedure, therefore, does not involve any major circumferential surgical dissection of the tibia (although currently there are some surgeons performing a more limited dissection with, for example, the TPLO). The specially designed tension-band plate is a thin, pure titanium implant. This implant provides adequate neutralization of the distractive forces, similar to a tension-band wire, and as an implant of commercially pure titanium, has excellent biocompatibility.[16–18]

In-Hospital Re-Evaluation

The in-hospital follow-up (93 dogs) revealed generally good results. Most dogs (84%) had radiographic healing within 12 weeks with either no lameness or mild lameness in 97% of the dogs. These results may be overly optimistic based upon retrospective evaluation of medical records where specific criteria to assess lameness were not established at the time of the in-hospital assessment. Furthermore, the mean follow-up time (13.5 weeks) was short.

The mean time to complete radiographic healing was ~ 11 weeks. Radiographic follow-up was not available for all dogs, nor was it available at consistent intervals, and so the actual time to final radiographic healing may have been shorter. For those dogs where radiographic follow-up was available, healing was complete in $\sim 50\%$

at 6–8 weeks and in >80% at 8–12 weeks. Almost 50% of the remaining cases did not have their first follow-up radiographs until >12 weeks post-operatively (mean, 34 weeks). It may be reasonably assumed that many of these dogs had probably healed before this time frame. If these cases are excluded, the final time to radiographic healing decreases to a mean of 9.4 weeks (range, 4–20 weeks).

Complications

Complications are frequently reported as either major or minor depending upon their perceived clinical importance. Because this is a subjective assessment, we chose to adopt a more objective measure, namely whether or not further surgery was required. This classification, however, produced some anomalies; some problems would more likely be classified in the opposite area based upon their severity or perceived clinical importance, or lack thereof, regardless of whether or not further surgery was performed. For example, the 2 lick granulomas could be considered minor issues despite ultimate use of surgery for resolution. Similarly, the 3 dogs with audible clicks in the joint most likely represented meniscal tears, and therefore could be considered major complications. Also, the 1 dog with continued poor performance could also be considered a major complication despite their owner's reluctance to pursue further treatment, although no diagnosis was obtained. Finally, the 1 intra-operative fracture could be considered a major complication even though no further surgery was required. Based upon these further more subjective and perhaps clinically relevant assessments, we believe it reasonable to state that there were 17 (14.9%) "major" complications and 19 (16.7%) "minor" complications. Moreover, some of the listed minor complications were incidental findings: the 4 non-displaced tibial tuberosity chip fractures at the proximal extent of the tibial tuberosity, 3 implant failures, and 3 poor graft mineralization. If the latter were eliminated, then the minor complication rate could be <8%.

Overall complications occurred in ~31% of the stifle joints operated, which is similar to that reported for TPLO (18.8–28%).[19–21] In 1 TPLO study, complications were classified as major and minor complications, yielding 12.6% major and 21.7% minor complications,[19] which is similar to our findings with TTA. Review of the other 2 TPLO studies shows a comparable rate of complications that can be similarly grouped.[20,21]

Like any surgical procedure, there are nuances that must be learned to avoid intra- and post-operative errors that may result in complications. As noted previously, all cases reported represent our first TTA cases. Some of the major complications seemingly resulted from technical mistakes during the initial learning curve associated with TTA. The 3 tibial fractures (1 occurred intra-operatively) and 1 implant failure (Figs 7 and 8) resulted from poor pre-operative planning or surgical execution resulting in incorrect size or position of the osteotomy cut and/or incorrect plate positioning. The result of these errors was fracture of the tibia, or tibial crest, because of the increased stress-risers thus created. Because these complications occurred within the first 10 cases (at the respective institutions), we believe that they were technical failures related to surgeon inexperience. Attention to detail of the surgical technique cannot be over-emphasized and could eliminate these issues.

Most of the other major complications were meniscal injuries. The number of meniscal tears identified at the original surgical procedure appears to be consistent with previous reports.[22–25] The number of apparent subsequent meniscal injuries, on the other hand, was a concern despite these evidently accounting for <10% of the cases. This frequency of occurrence could be viewed as an acceptable number of subsequent injuries regardless of the surgical procedure.

Meniscal tears discovered during convalescence could have been missed lesions at initial surgery. Because the overall number of meniscal tears observed at initial surgery was consistent with that expected from past clinical and reported experience, we did not believe that we had overlooked some; however, this could have occurred. Subsequent meniscal tears from later trauma, secondary to altered forces within the CrCL-deficient stifle joint, could have occurred. The latter possibility has been the rationale for the meniscal release recommended with TPLO (Seminar titled Tibial Plateau Leveling Osteotomy for Cranial Cruciate Ligament Repair; Slocum Enterprises Inc, Eugene, OR).[6] It had been proposed that TTA, because of unaltered tibial plateau position, might spare the caudal portion of the joint and obviate the need to perform meniscal release.[7,8]

Ten subsequent meniscal tears were assumed to occur (7 documented), with an apparent frequency of 8.8% (10/114 joints). However, the number of meniscal injuries reported actually under-represents the number of possible subsequent injuries because 46 joints had an existing meniscal tear and partial meniscectomy was performed. Thus, the corrected frequency of subsequent meniscal tears is seemingly 14.7% (10/68). Nevertheless, both institutions were concerned with the apparently high number of subsequent meniscal tears observed and began performing medial meniscal release of the intact meniscus (22 joints). Therefore, a more accurate representation of frequency of subsequent meniscal tears is 21.7% (10/46 joints). Based on this high frequency, an argument can be made to support meniscal release, especially because no further meniscal injuries were identified after this procedure was instituted, either as a result of a lack of initial identification (missed lesion) or further (subsequent) trauma. Conjecture that performing a meniscal release in all cases could have eliminated all subsequent meniscal tears is an attractive proposition. If this were the case, the major complication rate could have been $\sim 6\%$ (including those cases that were early technical failures). Such data extrapolation, however attractive, cannot be validated without further follow-up, including operating additional cases, but may be a point to contemplate. This question, however, remains open to debate and is controversial because of the inherent function of the meniscus within the joint, and the ensuing argument of the value of eliminating a crucial stabilizer to the joint.[26–28] The effect of meniscal release, and its possible detrimental long-term effects in a large population of dogs, needs to be evaluated.

The 4 cases of proximal tibial tuberosity chip fractures were unexplained; however, these were only observed in the initial cases. Our assumption is that there could have been some iatrogenic damage to this region during surgical dissection, perhaps some over-zealous exposure to the area of attachment of the patellar tendon when elevating the periosteum to expose the bone. Regardless, this complication was eliminated with additional experience. No clinical signs were associated with this finding, and no treatment was required.

The 3 incidental implant failures, which also occurred during the initial cases, were thought to be technical failures resulting from inexperience with TTA. In these 3 cases, there was incorrect plate positioning as the distal end of the plate was secured along the tibial axis without obtaining bone contact at the distal end of the osteotomized tibial tuberosity. In these instances, the initial proximal plate position was secured without recognizing that the distal plate position was already overlaying the tibia (Fig 3). After advancement of the tibial tuberosity, the distal plate position would have been caudal to the tibial shaft with rotation/advancement of the tuberosity. The distal plate was still secured mid-tibia, which resulted in a gap between the bone fragments. We surmise that the fixation was thus somewhat unstable, resulting in implant failure (forks) and resorption observed around the cage. Despite the uncomplicated healing observed, these observations highlight the limits of the fixation device, and the necessity to obtain a second (distal) point of contact (in addition to the proximal contact with the cage) of the bone to ensure load sharing with the implant. Appropriate pre-operative planning will avoid this problem (Fig 3). Another alternative to address this issue, should it be recognized after the fact, would be to contour the plate around the caudal tibial margin. Although this requires increased surgical dissection, it will make certain bone contact is obtained distally, and thus protect the implants.

Three infections were observed, yielding a frequency of 2.6%, which is comparable with that reported for a clean surgical procedure.[29,30]

Poor mineralization within the osteotomy gap (3 dogs) was not believed to be of clinical importance because there were no associated clinical signs, lameness, or palpable discomfort. Furthermore, the region was palpated as a firm, unyielding texture, which was consistent with bone. Finally, the radiographic appearance did not change upon repeated evaluations up to 6 months post-operatively. In all 3 dogs, a commercially available allograft was used (2 DBM powder, 1 Fine Mix Osteo-Allograft™); 2 cases occurred sequentially at 1 institution, and the other at the other institution. Tracking of these allografts, using the transplant records, was performed with the manufacturer; all allografts were from different donors. Furthermore, these allografts are always manufactured from 2 animals, primarily for the economic advantage related to small sample size, and with the further advantage of homogenization of osteoinductive factors (personal communication, 2007—Helen Newman-Gage: VTS, Kent, WA). It is speculated that the poorer mineralization in 2 cases could have been associated with the lesser osteoinductive capacity of the DBM powder used alone compared with the Fine Mix Osteo-Allograft™.

Some form of irritation was noted in 3 dogs (lick granuloma, self-trauma). A multiplicity of reasons could explain this occurrence, from surgical irritation to infection to a reaction to the implants themselves, but none were definitively identified. It is our opinion that the reaction was because of the suture material (Polysorb™; United States Surgical Corporation, Norwalk, CT) based upon its superficial association with the original skin incision (as determined at the time of surgical excision and lack of histologic association with any of the deeper tissues), and only partial implant removal of the plate and fork only (the cage was not removed); however, this cannot be definitively stated, and is only speculation.

Post-operative swelling was probably related to the dissection required with the surgical approach, and occurred in 3 dogs and resolved within 72 hours; in 1 dog, a bandage was applied. The importance of this problem appears minimal based on the rapid resolution over a short time frame, and the absence of treatment in 2 cases. Post-operative swelling appears to be a greater problem with TPLO.[19,21] The observed difference may reflect disparity in the aggressiveness of the surgical dissection (TPLO > TTA) between techniques.

In the dog with medial patellar luxation, it could be hypothesized that the position of the tibial tuberosity was altered, thus misaligning the quadriceps mechanism. Patellar luxation did not occur, however, until after a second surgical procedure to perform a meniscectomy. At meniscectomy, there was no palpable or radiographic evidence of a patellar luxation. Similarly, at the time of patellar luxation, before the third surgical procedure, there was no radiographic evidence of mediolateral tibial tuberosity transposition. Furthermore, the observation of increased rotational instability in the stifle joint appeared to be the primary abnormality present. Because this problem occurred after the subsequent partial meniscectomy, the absence of a portion of the meniscus, or another possible injury to this or related structures at the time of the second surgery, or shortly thereafter, could have resulted in the instability we observed.

Telephone (Owner) Follow-Up

TTA resulted in a functional outcome without lameness in a relatively short time based on in-hospital reevaluation. These results appeared to be supported by the longer-term evaluation obtained from owner interview by telephone. Most owners were pleased with their dog's function with the dog either returning to pre-injury status or showing marked improvement after surgery. Furthermore, a number of owners had previous experience with either another dog, or the current dog, with CrCL injury treated by an alternate method (e.g. lateral suture, fibular head transposition, over-the-top intra-articular graft, TPLO), and offered [unsolicited] that the recovery from the TTA was much faster and easier compared with those techniques. These latter comments obviously are quite subjective interpretations by the owners, which may be affected by bias toward the most recently performed procedure. Regardless, both the in-hospital evaluations (albeit relatively short term) and the owner evaluations appear to indicate that the TTA is at least comparable with alternate methods of CrCL repair relative to an expected good to excellent function and outcome. We did not, however, attempt to make any functional assessments comparing any of the many available surgical techniques, but only to report on the individual efficacy of TTA, and report on the early complications associated with this surgical technique.

The limitations of this study include those inherent to a retrospective study as well as the absence of concrete measures of post-operative performance. Despite these limitations, sufficient data for an overall assessment of the dogs' function could be obtained. The complications were based upon an objective measure, of whether or not additional surgery was necessary, which allowed us to better assess the owner interpretation of their dog's outcome. No owner reported any surgical procedures other than those we provided. Regardless, the short-term in-hospital follow-up we obtained, confined to the point of radiographic healing only, remains an obvious limitation to any further evaluation of long-term function. Longer-term objective clinical studies are warranted to assess the continued clinical viability of the TTA, e.g., force plate and kinematic gait analysis, stifle joint range of motion, muscle mass, and long-term radiographic and functional evaluation.

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