CASE REPORT

Intraoperative use of a transarticular circular fixator construct to facilitate reduction and stabilisation of a proximal tibial physeal fracture in a dog

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Case report A 4-month-old female intact American Pit Bull Terrier was presented for right pelvic limb lameness 1 day after the dog had been hit by an all-terrain vehicle. Orthogonal radiographs of the right stifle revealed a Salter-Harris type IV fracture through the proximal tibial physis extending caudodistally through the proximal tibial metaphysis. The distal tibia was markedly displaced cranially, laterally and proximally, resulting in complete overriding of the fracture segments. An open approach was made in order to facilitate direct reduction, but the fracture could not be sufficiently distracted and the epiphyseal segment remained fixed caudal to the remainder of the tibia. Concerns regarding possible iatrogenic trauma to the epiphysis prompted the use of a transarticular circular fixator construct to distract the fracture segments to facilitate reduction. Distraction that facilitated reduction was performed using three TrueLok Rapid Quick Adjust Struts that were positioned between the two ring components. The struts also allowed for multiplanar adjustment of alignment, which allowed the fracture to be maintained in anatomic reduction as divergent interfragmentary Kirschner wires were placed. Radiographic union was confirmed 19 days after surgery.

Conclusion/Clinical significance Transient intraoperative application of a circular construct incorporating the TrueLok components facilitated accurate fracture reduction without inflicting further iatrogenic trauma to the epiphysis, after traditional direct reduction techniques proved ineffective, and afforded a successful clinical outcome in the dog reported here.

Keywords dogs; orthopaedics; Quick Adjust Strut; Salter-Harris fracture; surgery; transarticular fixator reduction

Abbreviations mMPTA, mechanical medial proximal tibial angle; RQAS, Rapid Quick Adjust Strut; TPA, tibial plateau angle

FRactures of the proximal tibia are relatively uncommon in dogs and account for 3–7% of all physeal fractures.1–3 Tibial tuberosity avulsion and physeal fractures constitute the most common proximal tibial fractures.4,5 Tibial tuberosity avulsion can occur independently6 or in association with proximal epiphyseal fractures.7–9 Previous retrospective studies have discussed management options for proximal tibial physeal fractures.6–9 Minimally or mildly displaced fractures that can be reduced in a closed fashion can be successfully managed conservatively with coaptation.6 Mildly or moderately displaced fractures that maintain some contact between the tibial epiphysis and metaphysis, which can be reduced closed or by means of open reduction, are typically stabilised with divergent interfragmentary Kirschner wires.7,8 One case series reported successful outcomes for severely displaced proximal physeal fractures by means of divergent interfragmentary Kirschner wires or plate stabilisation augmented with transarticular external fixator application for the first 3 weeks following surgery.9 Although specific details regarding reduction of these fractures were not discussed, difficulty obtaining reduction necessitating extensive soft tissue dissection was proposed as a cause of postoperative complications in one dog.9

The emerging trend towards minimally invasive fracture repair has placed an emphasis on indirect fracture reduction techniques.10–12 In human trauma patients with complex tibial fractures, a temporary external fixator is often placed in order to maintain limb length and provide transient stability until definitive surgical intervention can be implemented at a later, more appropriate time.13–15 Several reports have described the transient use of external fixators to perform indirect fracture reduction in dogs.16–19 Recent studies have described the intraoperative use of a two-ring circular external fixator construct to distract the major fracture segments while allowing adequate access to perform minimally invasive percutaneous osteosynthesis to stabilise antebrachial and crural fractures in dogs.16,18,19 Adjustment of the position of the rings on the articulating threaded connection rods was used to facilitate distraction, while alterations in rotational alignment were performed by adjusting the position of the attachment of the fixation wires about the circumference of the ring.18,19

We recently acquired a fixator component from an external skeletal fixation system used in human patients that was developed to facilitate the indirect reduction of appendicular long bone fractures. The component is known as a TrueLok Rapid Quick Adjust Strut (RQAS) (Orthofix TrueLok Ring Fixation System, medium length Rapid Quick Adjust Strut, Verona, Italy) and combines a double-layer tubular strut with a telescopic linear distractor rod and lockable universal hinges positioned at both ends of the rod (Figure 1). Two or more of these struts can be used to articulate the two ring components to create a highly adjustable fixator construct. The inner and outer RQAS tubes allow rapid elongation or collapse of the

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component to match the placement of the rings and allow manual distraction or compression of the construct. Tightening of the side locking bolt and clamp washer maintains the strut at the desired length. The threaded telescoping linear distractor rod confers a second method for performing linear distraction or compression by rotation of the plastic drive bushing that extrudes (clockwise rotation) or retracts (counter clockwise rotation) the linear distractor rod. A complete rotation of the drive bushing results in 1 mm of linear translation of the rod and this latter feature is particularly advantageous for overcoming tension in the regional soft tissues. The universal joints on either end of the RQAS allow for multiplanar angular and rotational adjustments and can be rapidly locked or loosened by adjusting the rapid nuts that secure the ring components to the universal hinge joints. The rapid nuts allow easy finger tightening of the universal locking joints. Once finger tightened, the universal joints provide relative stability while still permitting minor adjustments in alignment. A hex wrench can then be used to further tighten the rapid nuts, locking the universal joint in the desired position. This case report describes the intraoperative application of a transarticular rapid distraction circular fixator construct to facilitate reduction and stabilisation of severely displaced Salter-Harris type IV proximal tibial physeal fracture in a dog.

**Case report**

A 4-month-old female intact American Pit Bull Terrier was presented for right pelvic limb lameness 1 day after being hit by an all-terrain vehicle. Physical examination did not reveal abnormalities on cardiotoracic auscultation or abdominal palpation. Orthopaedic assessment revealed a non-weight-bearing lameness in the right pelvic limb. The right stifle was circumferentially swollen and manipulation of the stifle elicited a pain response. In addition, there was visible varus deviation of the limb distal to the stifle.

Orthogonal radiographs of the right stifle revealed a Salter-Harris type IV fracture through the proximal tibial physal extending caudodistally through the proximal tibial metaphysis. The distal tibia was markedly displaced cranially, laterally and proximally, resulting in complete overriding of the fracture segments. Fractures of the tibial tuberosity and the lateral aspect of the proximal tibial epiphysis were also present. There were concurrent fractures of the proximal fibula: one fracture traversed through the proximal fibular physis, with the distal fibular segment being displaced caudal and lateral, and a second incomplete, slightly oblique fracture involved the proximal diaphysis. The soft tissues surrounding the right stifle were markedly thickened (Figure 2). Radiographs of the left crus were also obtained: the tibial plateau angle (TPA)20 of the left tibia was 28°/C14 while the mechanical medial proximal tibial angle (mMPTA)21 was 92°/C14.

The following day the dog was anaesthetised for surgical reduction and stabilisation of the fracture. The dog was premedicated with 0.3 mg/kg intramuscular methadone (Methadone Hydrochloride USP, Mylan Institutional LLC, IL, USA), followed by induction with 0.3 mg/kg intravenous midazolam (Midazolam Hydrochloride Injection USP, West-Ward Pharmaceutical, NJ, USA) and 5.4 mg/kg propofol (PropoFlo™, Abbott Laboratories, IL, USA). SevoFlurane (Petrem™ Pira- mal Critical Care Inc., NY, USA) was administered at 3–4% to maintain the anaesthetic plane. Intravenous cefazolin (22 mg/kg; Cefazolin for Injection, Hospira Inc., IL, USA) was administered at the time of induction and repeated every 90 min during the procedure.

Attempted manual closed reduction was unrewarding because the fracture could not be distracted sufficiently to achieve reduction. A craniomedial approach to the proximal tibia was made to perform a
direct open reduction. A medial arthrotomy was performed to allow direct visual assessment of the epiphyseal fracture segment. Minor medial-to-lateral movement of the fracture segments was achieved following the arthrotomy; however, the fracture could not be sufficiently distracted and the epiphyseal segment remained fixed caudal to the tibia. A Freer periosteal elevator was used in an attempt to lever the caudomedially displaced epiphyseal segment into reduction; however, this manoeuvre was also unsuccessful. In the process, the tibial tuberosity became grossly unstable from the remainder of the proximal tibial epiphysis.

Concerns regarding possible iatrogenic trauma to the epiphysis prompted the application of the transarticular external fixator to distract the fracture segments and facilitate reduction. The construct used 84-mm rings consisting of a proximal stretch ring and a distal complete ring (Circular External Skeletal Fixation System, IMEX Veterinary, Inc., TX, USA). A 1.6-mm Kirschner wire was placed from lateral-to-medial through the distal femoral metaphysis, perpendicular to the anatomic longitudinal axis of the femur. The stretch ring was attached to this wire. A second wire was placed from lateral-to-medial through the distal tibial diaphysis, perpendicular to the tibial anatomic axis. The complete ring was attached to this wire. Both wires were placed in the mediolateral plane. The rings were articulated using three RQAS (Figure 3), with one strut placed cranio lateral, the second strut caudolateral and a third strut caudomedial. Wire placement, as well as subsequent fracture reduction and implant placement, were assessed using intraoperative fluoroscopy (Fluoroscan InSight Mini-C-arm: Hologic, Diagnostic Health Care Systems, NC, USA).

Elongation of the fixator was performed by applying manual distraction to the rings with the side locking bolts loosened. Once manual distraction became limited by soft tissue constraints, the side locking bolts on each of the RQAS were tightened. Further distraction was achieved by rotating the plastic drive bushing on each of the RQAS until there was sufficient separation of the fracture segments to allow reduction of the fracture (Figure 4). The rapid nuts were loosened on the universal joints; securing each of the RQAS allowed for multiplanar adjustment of the relative position of the two rings.

Bone-holding forceps were applied to the cranial aspect of the proximal tibial diaphysis in order to apply caudal followed by lateral pressure in order to further reduce the fracture. The rapid nuts on each of the RQAS were tightened. The fracture was maintained in reduction while a 1.1-mm interfragmentary Kirschner wire was placed from the cranio medial proximal margin of the epiphysis and directed caudolaterally into the metaphysis (Figure 5). This wire was advanced until the tip of the wire emerged from the caudolateral metaphyseal cortex. A second, divergent 1.6-mm interfragmentary Kirschner wire was placed from the caudomedial proximal margin of the tibial epiphysis and advanced in a craniolateral direction.

**Figure 3.** Intraoperative photograph after application of the transarticular fixator, prior to applying distraction. The proximal stretch ring is attached to a single 1.6-mm Kirschner wire placed through the distal femoral diaphysis. The distal full ring is attached to a second 1.6-mm Kirschner wire placed through the distal tibial diaphysis.

**Figure 4.** Craniocaudal (A, C, E) and lateral (B, D, F) intraoperative images of the fracture demonstrating progressive distraction using the TrueLok Rapid Quick Adjust Struts and initial Kirschner wire placement after reduction. (C, D) The construct has been distracted to relieve impingement. The distal surface of the epiphysis is positioned proximal to the tibial metaphysis. (E, F) Bone forceps applied to the tibial diaphysis to achieve and maintain fracture reduction and the initial Kirschner wire has been placed.
Attempts to place a Kirschner wire from the lateral aspect of the epiphysis were unsuccessful; however, a third divergent Kirschner wire was placed from the medial tibial metaphysis and directed in a cranial, proximal and lateral direction. The wire was advanced through the epiphysis until the trocar emerged from the joint capsule. The point of the wire was trimmed and the wire was retracted until the tip of the wire was no longer palpable in the joint using a Freer periosteal elevator. The Kirschner wires were trimmed and the fixator and associated fixation wires were removed. The avulsed tibial tuberosity was manually reduced and stabilised with two 1.1-mm Kirschner wires and a 0.64-mm figure-of-eight tension band wire.

Postoperative radiographs confirmed anatomic fracture reduction and appropriate implant placement (Figure 6). The position of the displaced lateral epiphyseal fracture fragment was unchanged. The immediate postoperative TPA for the right tibia was 28° and mMPTA was 93°.

Postoperatively, the dog was placed in a modified Robert Jones soft padded bandage incorporating a thermoplastic lateral splint (Vetlite: Runlite SA, Allard International, Belgium) to provide supplementary stability and to reduce stiffness motion. Initial pain management was achieved by administrating 0.05 mg/kg methadone every 4 h and a single dose of 2 mg/kg carprofen (Carprofen Sterile Injectable Solution, Putney Inc., ME, USA). The day following surgery, 25 mg tramadol (Tramadol: Amneal Pharmaceutical of New York, NY, USA) and 25 mg carprofen (Rimadyl: Pfizer Inc., IL, USA) were administered orally every 8–12 h and once daily, respectively, for 1 week. The dog was discharged 2 days after surgery and returned 3 days later to have the splint changed. Although the splint had slipped distal to the stifle, the dog was ambulating well on the limb. A lateral coaptation splint was reapplied that extended proximal to the stifle.

The dog was presented 13 days after surgery for recheck examination and follow-up radiography. Upon presentation the dog was ambulating well in the splint, which had again slipped distally and no longer immobilised the stifle as intended. The radiographs revealed that there had been no loss of reduction or fixation. The TPA of the right tibia was measured to be 29° and the mMPTA was 94°. Moderate periosteal reaction was present along the cranial, medial and caudal aspects of the mid and proximal tibial diaphysis and proximal tibial metaphysis. This was thought to be the result of periosteal trauma from the injury and the manipulations during reduction, in addition to callus formation along the fracture sites. The splint was not reapplied and the owners were instructed to confine the dog to a small area in the house and the dog was to be kept on a leash at all times when walked outside until the next recheck 1 week later for probable implant removal.

The dog returned 19 days after surgery for removal of the tension band fixation implants stabilising the tibial tuberosity. The dog was ambulating well and placing substantial weight on the right pelvic limb. Palpation and manipulation of the stifle revealed mild periarticular swelling, but no discomfort upon manipulation of the joint. Radiographs obtained at that time revealed progressive remodeling of the periosteal reaction, which had become smoother and well-defined, with stable implants. The proximal tibial and fibular fracture lines were more ill-defined, with progressive closure of the proximal tibial and fibular physes. The TPA of the right tibia was measured to be 28° and the mMPTA was 95°. The pin and tension band implants were removed with fluoroscopic guidance, but the three Kirschner wires stabilising the tibial epiphysis were left in place.

The dog was re-evaluated 47 days postoperatively and the owner reported that the dog had minimal lameness and had resumed...
normal activities (Figure 7). Orthopaedic examination revealed that the dog had subtle intermittent right pelvic limb lameness. This gait abnormality was most noticeable when the dog first rose from being recumbent. The limb was not angulated, and the right stifle was not painful on palpation and had a full pain-free range of motion. Radiographs taken at that time revealed complete healing of the tibial and fibular fracture sites, with closure of the proximal tibial physis, and progressive closure and remodeling of the tibial tuberosity. The periosteal reaction was smoother and more well-defined, consistent with the healing process (Figure 8). The TPA of the right tibia was measured to be 28° and the mMPTA was 92°. Despite multiple attempts to contact the owner and the primary care veterinarian, further information regarding the dog’s progress has been unobtainable.

Discussion

Proximal tibial physeal fractures occur infrequently in dogs.1,4 This rarity of occurrence is reflected by the relatively small number of case series published regarding the management of proximal tibial physeal fractures.2,7-9 Although minimally displaced fractures maybe adequately managed with closed reduction and coaptation,5,8 surgical reduction and stabilisation has been advocated for more markedly displaced fractures.8,9 Open reduction can be performed via either a craniolateral or craniomedial approach;5,22 the latter was used in the dog described here. The fracture can often be reduced by applying traction to the distal tibial segment as the metaphysis is forced laterally;5 however, we could not obtain reduction with this technique. We attempted to lever the epiphysis onto the proximal tibial metaphysis using a Freer periosteal elevator, as has been previously recommended,5,9 but it proved unsuccessful and the complete avulsion of the tibial tuberosity was ascribed to our attempts at obtaining direct reduction of the fracture. The difficulty encountered in reducing this particular fracture was ascribed to the marked displacement, with overriding of the fracture segments in a region of the limb with a proportionally large muscle mass that is inherently resistant to distraction. These factors combined to create an environment that made direct reduction of the fragile epiphyseal segment exceedingly difficult.

Transient intraoperative application of a simple two-ring circular fixator construct has been used to facilitate minimally invasive plate osteosynthesis of distal limb fractures in dogs.16-19 Our experience with this technique prompted us to apply a transarticular fixator to facilitate distraction of the fracture segments without direct manipulation of the epiphysis. The construct used three RQAS struts that facilitated rapid distraction of the fracture segments as well as providing sufficient stability during and after fracture reduction. Each strut acted as an independent linear distraction unit. Loosening of the side locking bolts on each RQAS allowed for rapid initial distraction of the fixator and the secured bone segments while manual traction was applied to the rings. Soft tissue constraints, however, prohibited us from obtaining sufficient distraction to allow fracture reduction. The side locking bolts were tightened and subsequent
progressive distraction was achieved by clockwise rotation of the RQAS nylon drive bushings that extruded the threaded rods from within the struts. This process afforded independent but symmetrical distraction and allowed for slight over-distraction of the fracture, relieving the impingement that had previously impeded reduction of the fracture. The universal joints located at either end of each RQAS allowed for adjustment of the frame in multiple planes. Once alignment adjustments were made, the universal joints were locked; the slight over-distraction was reversed by loosening the side bolts on the RQAS components in order to decrease the distance between the rings and bring the fracture segments into direct apposition. Although this was our first application of the RQAS, we suspect these devices could be useful for performing minimally invasive percutaneous osteosynthesis applications for antebrachial and crural fractures, and possibly mid to distal femoral fractures. The RQAS are available in small, medium and large lengths. The medium struts were used in the dog reported here.

Care must be taken when manipulating any physeal fracture to avoid causing iatrogenic fragmentation of the fragile epiphysis. The epiphysis was already fragmented pre-operatively in the dog reported here and application of the transarticular fixator allowed us to use the intact bone columns proximal and distal to the fracture to indirectly reduce the fracture. Once the fracture was anatomically reduced, we were able to place divergent Kirschner wires and tension fixation as previously described.

Abnormalities in the TPA can occur secondary to malunion of proximal tibial physeal fractures or eccentric closure of the proximal tibial physis and high TPAs can precipitate cranial cruciate ligament failure. Postoperatively the TPA and mMPTA of the operated limb matched that of the contralateral tibia, substantiating that the fracture had been anatomically reduced. The TPA remained essentially unchanged on subsequent radiographs as the fracture healed without loss of reduction and the entire proximal tibial physis closed. Asymmetrical growth from the proximal tibial growth plate can also cause varus or valgus deformity after fracture repair. The mMPTA was monitored during the postoperative convalescent period and did not change as the fracture healed. The final radiographs revealed that the fracture had healed with symmetrical closure of the proximal tibial physis. Although we do not have further radiographic follow-up of the dog, changes in the right tibial TPA or mMPTA are unlikely.

Use of the TrueLok components facilitated accurate fracture reduction without inflicting further iatrogenic trauma to the epiphysis when the traditional techniques proved ineffective and afforded a successful clinical outcome in the dog reported here. Although not used in the case reported here this construct could prove advantageous for performing closed reductions and percutaneous fracture stabilisation. Further analysis of the use of this transarticular modality for reducing surgical time, mitigating iatrogenic trauma or for use in physeal fractures in other anatomic locations warrants additional investigation.

Conflicts of interest and sources of funding

The authors declare no conflict of interest for the work presented here.

References


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