Tibial tuberosity transposition advancement for treatment of concomitant cranial cruciate ligament rupture and medial patellar luxation in four feline stifles

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Case Series

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Abstract

Case series summary Three cats (four stifles) were diagnosed with varying grades of medial patellar luxation and stifle instability in cranial tibial thrust. Radiographs showed periarticular osteophytosis, intra-articular mineralization and opacification encroachment of the infrapatellar fat pad. Stifle exploration revealed either partial (n = 2) or complete (n = 2) cranial cruciate ligament tear and medial meniscal injury in all cases. Medial meniscectomy, partial parasagittal patellectomy, femoral trochleoplasty and tibial tuberosity transposition advancement using a 6 mm cage, two-fork plate and 4 mm spacer were performed in four stifles. Screws (2.0 mm) and washers were used in the cranial cage ears rather than conventional 2.4 mm screws. By the 2-week recheck, lameness was minimal and stifles were stable. Radiographic follow-up at 8 weeks showed appropriate progression of osseous union in all cases. One cat experienced a major complication, suffering tibial fracture following a lapse in exercise restriction, and revision surgery was performed successfully with subsequent osseus union of the osteotomy site. At the mid-term follow-up, all cats had a return to previous level of function, as assessed by both owner questionnaire and clinical evaluation.

Relevance and novel information Tibial tuberosity transposition and advancement has been shown to be successful in dogs for the treatment of concomitant medial patellar luxation and cranial cruciate ligament rupture. To date, there have been no reports of tibial tuberosity transposition and advancement in cats. A benefit of this approach is concomitant alignment of the extensor mechanism and neutralization of the femorotibial shear force. Our case series describes successful use of tibial tuberosity transposition advancement in cats.

Keywords: Cranial cruciate ligament; medial patellar luxation; tibial tuberosity advancement; concomitant

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Introduction

Cranial cruciate ligament (CrCL) rupture is reported far less commonly in cats than in dogs.[1] Potential explanations for this include the CrCL being larger than the caudal cruciate ligament in cats,[2–4] the lower amount of differentiation of fibrocartilage in the cat[5] and the potential for many cats with CrCL rupture never being evaluated by a veterinarian.[2] Historically, a traumatic event has been assumed to be the main cause for CrCL rupture in cats;[1,6] however, the actual cause is not entirely clear in every case.[7,8] The percentage of cats with clear evidence of a traumatic inciting injury varies from 16% to 80%.[6,9] Additionally, the more recent literature contains an increasing number of reports detailing CrCL rupture in

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indoor cats;[2,10] an overview of these cases reveals some parallels with the reports of degenerative CrCL rupture in dogs, in that these cats tend to be older, heavier and can be affected bilaterally.[2] Indeed, a recent study showed that up to 14% of cats appear to develop bilateral disease.[11] In addition, although one study[5] failed to confirm any histologic evidence of degeneration as a contributing factor to CrCL rupture, other studies have demonstrated the presence of degenerative changes such as calcification in the CrCL prior to complete rupture,[12] and moderate-to-severe stifle osteoarthritis (OA), despite an acute onset of lameness.[13] These latter findings would tend to support a degenerative process in at least a subset of cats with CrCL injury.

As for CrCL rupture, medial patellar luxation (MPL) is reported less commonly in cats than in dogs;[14,15] however, the incidence may be underestimated, as many cats are not overtly lame.[16] In the sparse literature available, both traumatic and developmental patellar luxations have been reported, in addition to breed predispositions and an association with hip dysplasia.[17–21] As in dogs, the most common deformities seen with patellar luxation are a shallow trochlear groove and medial displacement of the tibial tuberosity.[15] Secondary changes, such as cartilage erosions on the trochlear ridges and underside of the patella, as well as OA, can be seen in more severe or chronic cases.[15] Clinically normal cats have some degree of laxity in the stifle joint, with subluxation of the patella considered to be a normal finding.[17] The standard Putnam grading scheme of I–IV as used in dogs[22] can be employed, but an alternative scheme of A–D has also been proposed for use in cats, which takes this physiological laxity into consideration.[12] In clinically affected cats, grade II and III MPL (Putnam grading scale) are most commonly encountered.[23,24]

In dogs, concomitance of CrCL pathology and MPL is well recognized, with 13–25% of dogs presented for patellar luxation also being found to have CrCL rupture.[25,26] Dogs with MPL may have an increased risk of developing CrCL disease owing to malalignment of the extensor mechanism and internal rotation of the proximal tibia, which in turn increases tension on the CrCL, predisposing it to deterioration.[7,25] In addition, MPL can be associated with OA that produces an enzymatic environment leading to degradation of the CrCL.[7,27]

In theory, the risk of developing concomitant MPL and CrCL rupture is similar for cats; however, there is a paucity of information regarding treatment of cats presenting with both conditions. In one study, approximately 13% of cats were reported to have concomitant CrCL rupture and MPL.[28] Another study that evaluated 42 cats with patellar luxation only reported one case with concurrent CrCL rupture,[23] while a case report detailing a cat with an excessive tibial plateau slope and CrCL rupture reported accompanying grade I MPL bilaterally.[29]

Surgical intervention for CrCL rupture has been proposed to produce a quicker and more durable recovery in cats over medical management.[2,3,9] Meniscal damage occurs in up to 67% of cats with CrCL rupture,[28] and therefore surgery for meniscal assessment and concurrent stifle stabilization has been recommended. The most commonly used technique in cats is static stabilization with a lateral extracapsular suture using either bone anchors or tunnels.[2,11,30,31] However, a recent study found that non-surgically treated cats had a lower Feline Musculoskeletal Pain Index (FMPI) score over those treated with a lateral suture, indicating less chronic pain.[11] In addition, the postoperative complication rate in this study was 27.3%. As such, exploration of other stabilization methods may be warranted.

Treatment of MPL is recommended in cats with associated clinical signs,[15] and surgical repair has been reported to provide favorable results over non-surgical management.[14,32] The main aim of surgery is to deepen the trochlear groove and restore normal alignment between the quadriceps muscle, patella and tibial tuberosity. Surgical techniques reported for the correction of MPL in cats include femoral trochleoplasty, tibial tuberosity transposition, soft tissue balancing and partial parasagittal patellectomy,[14,23,24] with a combination of techniques being employed in a single stifle as required to achieve stability.

In the dog, dynamic stabilization of the CrCL deficient stifle with tibial tuberosity advancement (TTA) is a popular technique and is supported by ex vivo mechanical studies.[33–36] Three cases of TTA with good clinical outcomes have also been reported in cats,[10,37] although an ex vivo study advised caution in the translation of this technique to the feline stifle.[38] Surgical treatment of concomitant CrCL disease and MPL can be achieved using staged procedures or by combining procedures in a single event such as the modified tibial plateau levelling osteotomy (TPLO), TPLO with tibial tuberosity transposition (TTT) or the TTT advancement (TTTA).[39–41] Standard stabilization techniques such as extracapsular stabilization for the CrCL component can also be combined with TTT and trochleoplasty, with or without soft tissue stabilization techniques for the MPL.[42] However, these have been associated with higher complication rates and poorer outcomes than TTTA in medium-sized dogs.[43] A study evaluating TTTA for dogs weighing <12 kg found the procedure to be of comparable success to traditional extracapsular stabilization and TTT.[44]

In the small number of cats reported to date with concomitant CrCL rupture and MPL, most have been treated with lateral fabellotibial suture[28] in combination with traditional MPL surgery. One case report, in the non-English-language literature, described the use of the modified Maquet procedure combined with tibial tuberosity lateralization in a cat.[45] To our knowledge, there are no peer-reviewed reports of TTTA with a complete osteotomy for treatment of feline concomitant CrCL rupture and MPL. As such, the purpose of this case series is to detail the adaptation and use of this technique in three cats (four stifles), in addition to the mid-term outcomes.

Case series description

Case 1

Case 1 – a 10-year-old neutered male domestic medium-hair cat – presented for evaluation of an acute right pelvic limb lameness with no inciting cause. Bilateral MPL had been diagnosed at 4 years of age and managed non-surgically. Orthopedic examination revealed a moderate weightbearing right pelvic limb lameness. Effusion of the right stifle was palpable, in addition to laxity in cranial tibial thrust (CrTT) and cranial drawer. Bilateral MPL – Putnam grade II/IV on the left and III/IV on the right (feline scheme grades B and C, respectively) – was also noted.[12,22]

Orthogonal radiographs of both stifles were taken with the stifle positioned at 120° of flexion, based upon the standing angle of the contralateral limb.[10] Radiographs revealed effacement of the infrapatellar fat pad and mineralization in the cranial aspect of both stifle joints. The right tibia was cranially subluxated and both patellae were medially displaced with mild secondary periarticular osteophytosis evident.

Custom-planning software (Materialise OrthoView) was used to measure the advancement distance and plate size required. It was determined that a two-prong plate and a 6mm cage would be appropriate. Stifle exploration through a medial arthrotomy revealed a shallow trochlear groove and a comparatively wide patella (Figure 1a,b). A complete CrCL rupture and a bucket-handle tear of the caudal horn of the medial meniscus were present. Following complete medial meniscectomy, a block recession trochleoplasty was performed, but this failed to establish contact between the patella and recessed sulcus, with the patella continuing to articulate with the trochlear ridges. The width of the recessed trochlear sulcus was 8mm, while the patella measured 11mm at the widest point. As such, partial parasagittal patellectomy was performed as previously described to achieve appropriate patellar tracking.[24,46] A TTTA was completed in a standard fashion[41] using a 6mm cage, two-prong plate and 4mm spacer (TTA; KYON) with the following modifications: (1) owing to the paucity of bone stock available for screw purchase, in the cranial ear of the cage a 2.0mm screw with a washer was applied rather than the 2.4mm screw conventionally placed; (2) no Kirschner wire was used to maintain lateralization of the osteotomised tibial tuberosity; and (3) to lateralize the tibial tuberosity, a titanium spacer (TTA; KYON) was used beneath the cranial cage ear instead of a recessed notch caudally (Figure 1c).

Following this, the patella was stable with no soft tissue balancing deemed necessary. Osteoallograft was placed within the osteotomy gap (Figure 1d) (Orthomix; Veterinary Transplant Services) and standard closure was performed, including advancing the caudal belly of the sartorius muscle over the TTA cage. Postoperative radiographs showed anatomical alignment with satisfactory implant positioning (Figure 2a). As has been reported previously, the positioning of the osteotomy left a paucity of caudal tibial bone stock at the level of the second prong.[10] Patellar tendon angle (PTA) was 88°. Clinically, there was no laxity in CrTT and the patella could not be luxated. Twenty-four hours postoperatively the cat was toe-touching lame and was discharged with instructions for strict cage rest for 8 weeks. Analgesia was provided for 10 days with gabapentin (7mg/kg PO q8h [Neurontin; Pfizer]) and meloxicam (0.05mg/kg PO q24h [Metacam; Boehringer Ingelheim]).

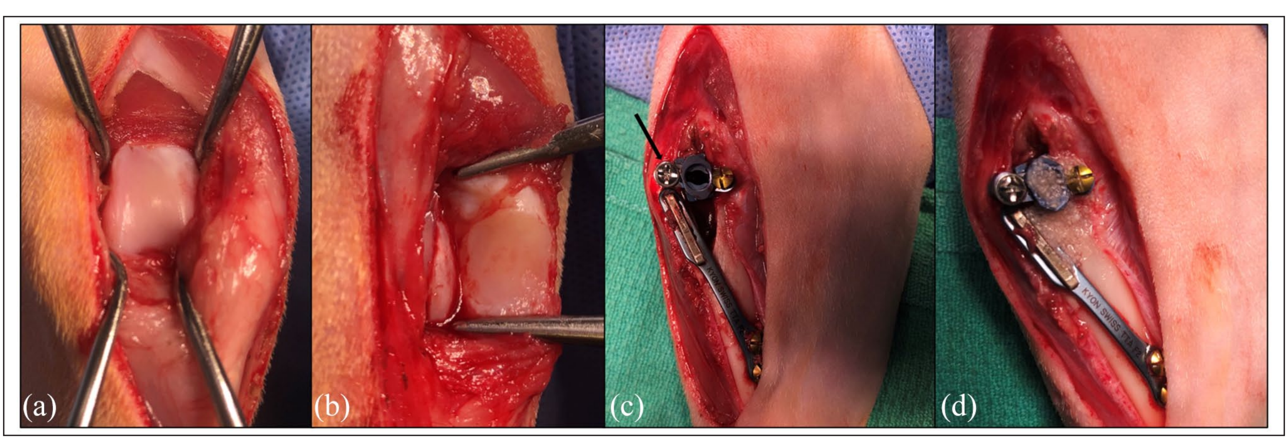

Figure 1 (a) Stifle exploration through a medial arthrotomy revealing a shallow trochlear groove and (b) a comparatively widened patella with remodeling and cartilage degeneration. Illustration of tibial tuberosity transposition advancement implant positioning prior to (c) and after (d) osteoallograft placement. A 6mm cage, two-fork plate and 4mm spacer were used. As indicated (arrow), a 2.0mm screw and washer was placed in the cranial cage ear rather than the 2.4mm screw conventionally placed

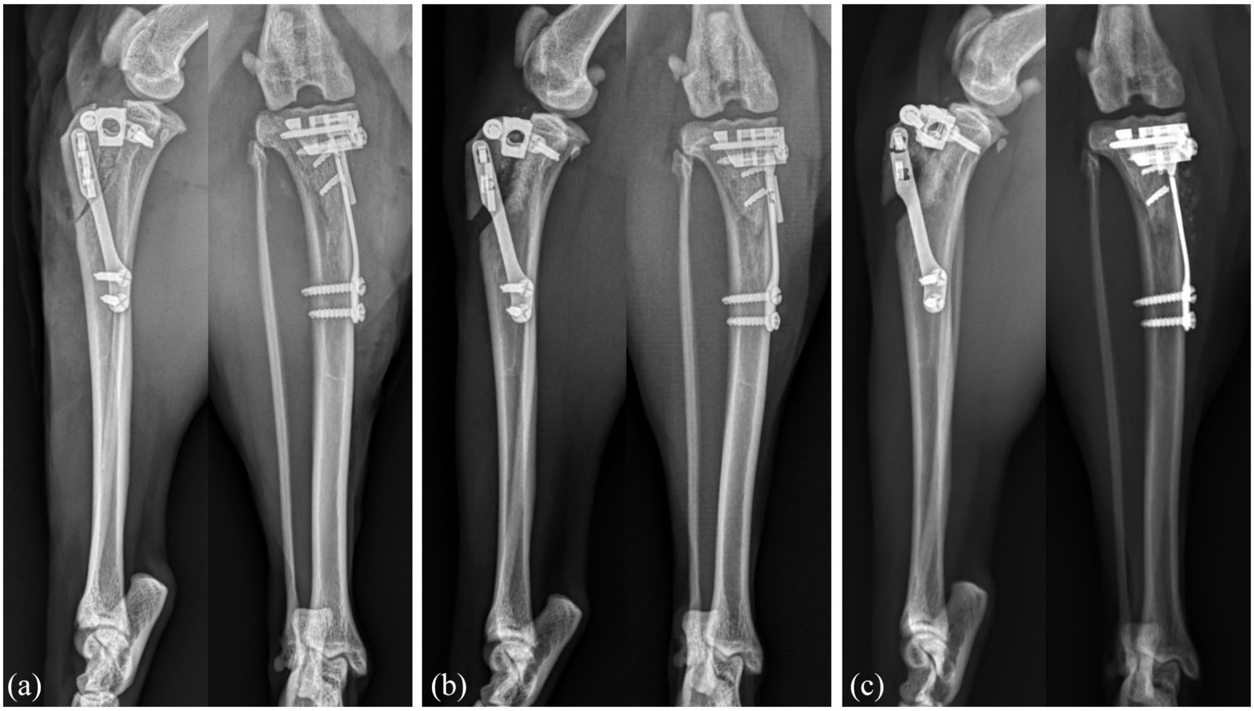

Figure 2 Immediate postoperative radiographs (a) show appropriate alignment and implant positioning. (b) Eight week postoperative radiographs reveal fracture of the distal fork and widening of the osteotomy gap distally. (c) By 14 weeks, a second fracture of the proximal plate was evident. Nonetheless, healing of the osteotomy was satisfactory, and the stifle remained stable, with no associated lameness. In all radiographs on the craniocaudal views, note the presence of an appropriately seated patella within the femoral trochlear groove. Narrowing of the patella is also evident secondary to the partial parasagittal patellectomy performed

At the 8-week recheck, the right pelvic limb lameness had resolved and a mild left pelvic limb lameness was apparent. Instructions for cage rest had not been complied with. The right stifle was stable in CrTT and the patella could not be luxated. There was no pain upon full range of motion of the right stifle, although a mild pain response was evident upon direct palpation over the plate distally. Radiographs evidenced a fracture of the distal prong with resultant loss of contact between the distal extent of the osteotomised segment and the parent tibia and subsequent delayed union (Figure 2b). However, there was no change in PTA. Continued cage rest was advised pending a second recheck in an additional 6 weeks. Approximately 14 weeks after surgery, findings on orthopedic examination of the right stifle remained static other than resolution of pain response during palpation over the plate. Radiographs revealed progressive osseous union at the mid- and proximal-levels of the osteotomy with continued delayed healing distally (Figure 2c). Additionally, a fracture through the proximal TTA plate between the first and second prongs was evident. Despite this, the PTA remained unchanged and there was no evidence of CrTT affecting the right stifle. Mild instability in CrTT affecting the left stifle was evident, which had not been noted during previous examinations.

Owing to the progression of clinical signs on the left and satisfactory clinical progress on the right, surgical intervention was elected on the left. Radiography, surgical planning and surgical procedure were as detailed for the right side, except that an abrasion trochleoplasty was performed and a partial CrCL tear was evident rather than a complete tear. Postoperatively, the PTA was 89°, the patella was stable and there was no instability in CrTT. Implant positioning was considered acceptable, although the plate was angled slightly more caudally at the distal extent of the tibial tuberosity and the same concern regarding the paucity of caudal tibial bone stock at the level of the second prong was noted (Figure 3a). The cat was discharged with the same postoperative care instructions and medications as detailed for the right side.

Six weeks postoperatively, the cat escaped crate confinement at home, jumped and became acutely lame on the left pelvic limb. Orthopedic examination revealed a severe, weightbearing left pelvic limb lameness and a pain response upon palpation over the mid-to-proximal tibia. Radiographs revealed fracture of the parent tibia just distal to the second prong with minimal displacement (Figure 3b). The PTA had been maintained, but due to the severe lameness and instability, revision surgery was recommended. A 10-hole 2.0 mm locking notched

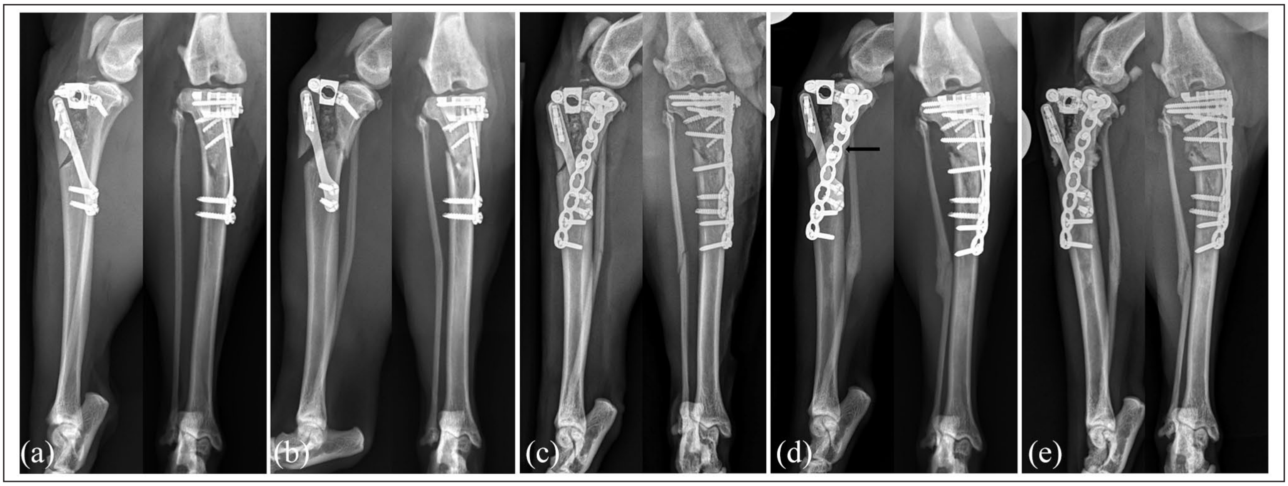

Figure 3 (a) Immediate and (b) 6-week postoperative radiographs showing development of a mildly displaced tibial fracture. (c) Revision surgery with a locking T-plate medially resulted in appropriate alignment and fracture apposition. (d) Eight weeks post-revision surgery, the fifth distal plate screw hole was noted to be fractured with no implant displacement (arrow). (e) By 14 weeks post-revision surgery, appropriate osseus union of the osteotomy and previous fracture site were evident, with resolution of clinical lameness. Note that in images (a) and (b), the patella appears appropriately seated within the trochlear groove, and narrowing of the patella is evident secondary to partial parasagittal patellectomy. In images (c), (d) and (e), radiographs were positioned to achieve consistent craniocaudal views of the tibia rather than the femur so as to allow assessment of tibial alignment following the fracture. As such, they are not appropriately positioned to assess patellar positioning. However, the patella remained stable and tracked normally clinically

T-plate (DePuy Synthes Vet) was contoured along the medial aspect of the tibia with an additional two circumferential PDS II (Polydioxanone; Ethicon) lasso sutures around the proximal osteotomy (Figure 3c). The previous PTA was maintained and CrTT remained negative postoperatively. At 8 weeks post-revision surgery, the fifth-from-distal screw hole of the plate was noted to be fractured at the cranioproximal extent; however, there was satisfactory progression of osseous union and no alteration in alignment (Figure 3d). Fourteen weeks postoperatively, lameness had resolved, the stifle remained stable in CrTT, the patella could not be luxated and there was no pain response noted through a normal stifle range of motion or during palpation. Satisfactory progression of osseous union was noted at both the TTTA osteotomy site and the tibial fracture site (Figure 3e) and the cat was released to normal activity levels. This visit corresponded with 34 weeks postoperatively for the right stifle, which remained stable in CrTT, with the patella tracking normally and no lameness being evident.

Case 2

Case 2 – an 8-year-old neutered female domestic shorthair (DSH) cat – presented for an acute exacerbation of a chronic right pelvic limb lameness of approximately 8 months duration. Orthopedic examination revealed a moderate weightbearing right pelvic limb lameness with bilateral MPL, Putnam grade III/IV on the left and grade II/IV on the right (feline scheme grades D and B, respectively). Effusion, mild thickening and laxity in CrTT were evident, affecting the right stifle. Mediolateral stifle radiographs were taken at 115° of stifle flexion based upon the standing angle of the contralateral limb. Orthogonal radiographs of both stifles demonstrated effacement of the infrapatellar fat pad with cranial mineralization and periarticular osteophytosis bilaterally (Figure 4a). Preoperative planning indicated that a 6 mm cage and two-prong plate were required. The cat underwent stifle exploration and TTTA surgery, as outlined for the right side in case 1. A complete CrCL tear was evident, the remnants of which were debrided. A bucket-handle tear of the caudal horn of the medial meniscus was noted and a partial medial meniscectomy was performed. The mineralization was located within the infrapatellar fat pad and was left in situ. A block recession trochleoplasty and partial parasagittal patellectomy were performed. A TTTA was completed using a 6 mm cage, two-prong plate and 4 mm spacer with the same screw sizes as case 1 and subsequent osteoallograft placement. Postoperative radiographs showed satisfactory implant positioning and a PTA of 90° (Figure 4a). The cat was weightbearing the day after surgery and was discharged with instructions for strict cage rest for 8 weeks. Analgesia was provided with gabapentin (10 mg/kg PO q8h [Neurontin; Pfizer]) and amantadine (3 mg/kg PO q24h [Symmetrel; Novartis]), each for 10 days. Orthopedic examination 8 weeks postoperatively revealed resolution of lameness and a normal range of motion of the stifle with no crepitus or pain response. The stifle remained stable in CrTT and the patella could not be luxated. Orthogonal radiographs revealed appropriate progression of osseous union and no evidence of

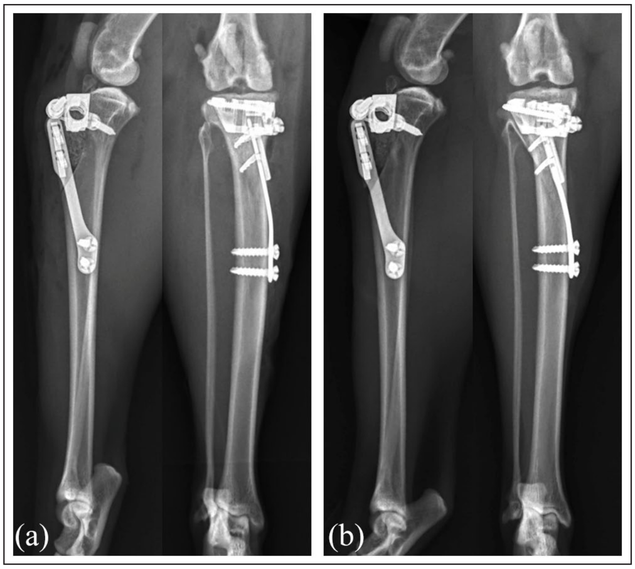

Figure 4 (a) Immediate postoperative radiographs illustrate satisfactory alignment and osteotomy placement. (b) Eight week postoperative radiographs show static implants with progression of osteoallograft incorporation and clinical union. In all radiographs on the craniocaudal views, note the presence of an appropriately seated patella within the femoral trochlear groove. As with the previous cases, narrowing of the patella is evident secondary to the partial parasagittal patellectomy performed

implant-associated complications (Figure 4b). A return to normal activity levels was advised.

Case 3

Case 3 – an 8-year-old neutered female DSH cat – presented for assessment of chronic progressive bilateral pelvic limb lameness, which was worse on the left. Orthopedic examination revealed a moderate weightbearing left pelvic limb lameness with MPL affecting both stifles – Putnam grade III/IV on the left and grade I/IV on the right (feline scheme grade C and A, respectively). Instability in the cranial drawer and CrTT affecting the left stifle was noted. Mediolateral stifle radiographs were taken at 110° of stifle flexion based upon the standing angle of the contralateral limb. Bilateral orthogonal radiographs showed similar findings as in case 2 with mineralization evident cranially. Stifle arthrotomy revealed a complete CrCL tear, mineralization, and tearing of the medial meniscus and diffuse cartilage degradation within the trochlear groove. Debridement of the CrCL remnants and a complete medial meniscectomy were performed. The cat underwent TTTA surgery in the same manner as in the other two cases in conjunction with an abrasion trochleoplasty and partial parasagittal patellectomy. Immediately postoperatively the stifle was stable in CrTT and the patella could not be luxated. Postoperative radiographs showed satisfactory osteotomy and implant positioning, and a PTA of 90°. The cat was toe-touching lame 24 h postoperatively and was discharged with instructions for strict cage rest, with analgesia being provided with gabapentin and meloxicam at the same dosages as for case 1. At the 9-week postoperative recheck, a very mild weightbearing lameness persisted on the left pelvic limb. The range of motion of the stifle was normal and pain-free with stability in CrTT and normal patellar tracking. Orthogonal radiographs showed a mild loss of contact between the tip of the tibial tuberosity and the parent tibia but with satisfactory progression of osseous union. At 16 weeks postoperatively, the left pelvic limb lameness had resolved. Radiographic assessment revealed progressive osseous union, with no evidence of complications and a return to normal activity was advised.

All cases

All cats were assessed again for mid-term follow-up ranging between 8 and 12 months postoperatively. In all cats, lameness had completely resolved both according to owners and based on in-clinic assessment. Case 2 was reported to abduct the operated limb without full flexion when sitting, while the other two cases were reported to have a normal sitting posture. Orthopedic examination revealed stability in CrTT, normal patellar tracking and a normal stifle range of motion in all cats, with no associated pain response. Radiographs revealed progressive osseous infilling of the osteotomy site in all four stifles, with complete bony union proximally and within the TTTA cage. An FMPI questionnaire[47] was completed by each owner and resulted in good-to-excellent scores in all cases, with no impairment in mobility described. On a 68-point scale with a higher score indicating less impairment, the scores were 64, 66 and 68 for cases 1, 2 and 3, respectively. This corresponded to limb function of 94%, 97% and 100%, respectively, that of normal.

Discussion

There is a paucity of peer-reviewed literature regarding the management of concomitant CrCL rupture and MPL in cats. This case series details resolution of CrTT, restoration of normal patellar tracking and excellent mid-term outcomes in three cats (four stifles) following TTTA and establishes this technique as an option for the treatment of CrCL and MPL in cats when they are encountered simultaneously.

Controversy remains regarding the etiopathogenesis of feline CrCL rupture. While it appears likely that a proportion of cats may be affected by degeneration of the CrCL, which may precede rupture,[2,11–13] in the absence of supportive ultrastructural histology, this association remains putative. The cases in this series lend credence to the argument for a potential degenerative etiology in cats. The advanced degenerative changes evident radiographically despite an acute onset of lameness, the presence of a partial CrCL tear and the bilateral nature of the disease in case 1 may be supportive of this. However, with small case numbers and concomitant conditions in this population, definitive conclusions cannot be drawn.

The cases in this series indicate that cats with MPL may have an increased risk of developing CrCL disease. Case 1 had a chronic history of bilateral MPL with severe lameness only becoming apparent following CrCL rupture. While cases 2 and 3 did not have pre-existing definitive diagnoses of MPL, they both had bilateral MPL with unilateral CrCL rupture, indicating that the MPL likely preceded the ligamentous injury. Based on these cases, either increased tension on the CrCL ligament due to malalignment of the quadriceps mechanism,[7,25] or the OA associated with MPL[7,27] may predispose the CrCL to degeneration. As such, when MPL is diagnosed as an incidental finding, it may be appropriate to warn owners of the potential for future loss of CrCL integrity.

Detailed information on the surgical treatment of concomitant CrCL rupture and MPL in cats is lacking. Use of a lateral fabellotibial suture alone, or in combination with wedge recession trochleoplasty, lateral imbrication or TTT has been mentioned,[28] but specifics and postoperative results were not detailed. Additionally, while this may not be directly translatable to cats, such combination techniques have been associated with higher complication rates and poorer outcomes than TTTA in dogs.[43] The modified Maquet procedure that has been reported in one cat for treatment of CrCL rupture,[37] and was adapted in the only other reported feline TTTA,[45] was considered unlikely to be feasible in the cases reported herein despite postulated advantages, including the requirement for fewer implants and proposed procedure simplicity. Preoperative planning for the cases in this report indicated that 6 mm of advancement would be required to achieve the appropriate PTA. Intraoperatively, it was found that an additional 4 mm of lateralization was required to align the quadriceps mechanism for treatment of the MPL. In an ex vivo study where the modified Maquet technique was used,[38] advancement of the tibial tuberosity of greater than 6.8 mm was reported to consistently lead to catastrophic avulsion of the tibial tuberosity before stabilization of the CrCL-deficient stifle could occur. In the corresponding canine study by Apelt et al,[33] the tibial tuberosity was completely sectioned and subsequently stabilized, allowing greater advancement to be achieved without such complications. Owing to the significant advancement required, in addition to the lateralization in the cats reported here, the decision to completely section the tibial tuberosity was made, followed by stabilization using the tension-band plate, as traditionally described in the TTA technique.[48]

An additional consideration was that the results of the ex vivo study[38] indicated that when the appropriately calculated degree of advancement was carried out, persistent cranial tibial subluxation was noted in cadaveric specimens. As such, the authors felt that it was important that the possibility of advancing the tibial tuberosity further in these cats was retained in case this became necessary. If persistent instability had been noted intraoperatively, the technique adopted here would have allowed the next cage size up (a 7.5 mm cage) to be substituted. However, if a modified Maquet procedure had been used, this would likely not have been possible without risking tibial tuberosity avulsion.

Although there are reports in dogs of residual CrTT following TTA,[34,36] our aim was to eliminate CrTT with the stifle held at a standing angle and this was achieved in all four procedures reported here. Based on the cadaveric study by Retournard et al,[38] persistent instability in CrTT following TTA may be more likely in cats than in dogs, but this is not consistent with our early clinical experience. The validity of the ex vivo model used in the aforementioned study[38] and its ability to correlate with the in vivo situation can be questioned as the passive stabilizers of the stifle, most importantly the hamstrings, cannot be replicated in an ex vivo model, and these play important roles in maintaining stifle stability. We surmise that the limitations of a cadaveric model explain the difference between this study and our clinical results. However, it should also be considered that the cadavers used were free of orthopedic disease, while the cats in this clinical series had significant joint capsule thickening; theoretically, this could also play a role. In this series, appropriate positioning during preoperative radiography, careful preoperative planning and intraoperative assessment to confirm elimination of CrTT were likely contributors to the satisfactory stifle stability achieved.

Femoral trochleoplasty helps to stabilize the patella and is a fundamental component of surgical treatment for patients with inadequate trochlear depth. Two different femoral trochleoplasty techniques were used in this case series: block recession trochleoplasty and abrasion trochleoplasty. The choice of technique was based upon the surface area of trochlear hyaline cartilage that could be salvaged. In cases with healthy hyaline cartilage, a block recession trochleoplasty was elected. However, in cases with severely degenerate cartilage or trochlear eburnation, where preservation of cartilage was rendered a moot point, abrasion trochleoplasty was performed. The effects of abrasion trochleoplasty in cats have not been examined in depth. In dogs, the exposed cancellous bone is eventually covered by fibrocartilage, which has been proven to be rough, irregular and weak in comparison with hyaline articular cartilage,[49–51] resulting in patellar articular cartilage erosions[50] and progressive OA.[27,52–54] However, the impact of this on clinical outcome is uncertain as positive results in up to 92% of small dogs have been reported following abrasion trochleoplasty.[27,52] The medium-term positive results reported here indicate that, similarly, abrasion trochleoplasty can be well tolerated in cats; however, this should only be pursued as a treatment option in the face of severely degenerate cartilage within the trochlear groove that cannot be salvaged.

Partial parasagittal patellectomy was necessary in all four surgeries described in this case series in order to establish patellar tracking in contact with the recessed sulcus and to stabilize the patella. This technique has been previously reported clinically,[24] and was shown to improve the depth of patellar recession over that achieved with block recession trochleoplasty alone in a cadaveric study using CT.[55] The feline patella is relatively wider than the feline femoral trochlear sulcus,[56] and ex vivo studies in cats have shown that following block recession trochleoplasty alone, the feline trochlea becomes too narrow to accommodate it.[55] Instead, the patella rides the trochlear ridges and loses contact with the trochlear sulcus. The clinical impact of partial parasagittal patellectomy long term has not been reported; however, no intra- or postoperative complications related to this procedure were encountered in our cases. Based on the limited literature available and our experience with this case series, measuring the comparative widths of the patella and the recessed trochlear sulcus, as well as careful assessment of patellar tracking should be performed intraoperatively, with partial parasagittal patellectomy being considered in the absence of appropriate patellar recession.

In a previous case report featuring two TTA procedures in cats, no major complications were encountered.[10] One minor complication was reported, where loosening of the cranial cage screw and fracture of the tibial tuberosity proximal to this occurred.[10] To avoid this complication, performing the osteotomy as caudally as possible, drilling the holes for the prongs of the plate as distally as possible, tilting the ears of the cage such that a screw can be inserted proximal to the plate end, electing not to place a screw in the cranial ear of the cage at all, or use of a 2.0 mm screw and washer have been proposed.[10] In this case series, all screws placed in the cranial ear of the cage were 2.0 mm screws with a washer, and no complications related to this were encountered.

The major complication rate in this case series was one in four (25%). This is considered comparable to the major complication rate of 14.5%, which was reported in the first case series of TTTA in dogs.[41] This complication rate is also similar to reports detailing isolated MPL correction in cats where major complication rates of 20–25% have been reported.[21,23,24] Specifically, complications associated with TTT have been shown to occur more frequently in the cat.[21,24] Factors that have been postulated to explain this include the use of relatively oversized implants, the increased brittleness of feline bone and the tibial tuberosity fragment being relatively smaller and less robust.[24] It has also been proposed that the feline tibial tuberosity may be exposed to proportionately higher avulsive forces associated with the cat's behavior of being likely to jump onto high surfaces or the feline stance with the stifle being held in a more flexed position.[24]

While revision surgery resulted in an excellent midterm outcome following the major complication encountered here, this entailed additional patient morbidity. The positioning of the osteotomy in all cases within this series left a paucity of caudal tibial bone stock at the level of the second plate prong. This has been reported in one previous case in the literature[10] with no adverse consequences, and had no clinical impact in the other cases in this case series. However, in addition to the failure in postoperative exercise restriction, this likely contributed to the development of the tibial fracture in case 1. It is critically important when performing this technique to accurately gauge the compromise between sufficient bone stock for prong and cage anchorage and an excessively large tuberosity, which risks iatrogenic tibial fracture. At the narrowest point of the tibia, the osteotomized segments in this case series represented 47% of tibial width for both tibiae in case 1, 43% in case 2 and 50% in case 3. A mechanical study would be required to make definitive recommendations regarding the ideal size of this fragment, but aiming for 40% of tibial width as a maximum may be a reasonable initial guideline to minimize risks of tibial fracture. Additionally, as fracture only occurred in case 1, despite similar fragment ratios in the other three procedures, the absolute necessity for strict cage rest following this procedure should be emphasized.

Minor complications occurred in two cases within this case series, both of which involved loss of continuity between the distal tip of the osteotomized fragment and the parent tibia, leading to delayed healing. One of these was associated with implant failure secondary to fracture of the distal plate prong, while the other occurred without any evidence of implant failure. To minimise the risk of loss of reduction in future cases, the authors propose that the use of an additional tension-band wire, or – alternatively – a cerclage wire at the level of the distal tibial tuberosity, may facilitate uncomplicated and timely healing in future cases. Alternatively, in cases where the advancement required is guaranteed to be less than the 6.8 mm reported to be associated with catastrophic avulsion,[38] the modified Maquet technique may represent a reasonable alternative.

Conclusions

Cats with MPL may be at increased risk for developing CrCL rupture. In such cases, TTTA represents a potential treatment option. Care must be taken with surgical planning and execution to limit complication risk; however, the mid-term assessment of this small group of cats indicates that excellent functional outcomes may be achieved. This technique appears to warrant further investigation with mechanical, as well as larger, clinical studies.

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Ethical approval The work described in this manuscript involved the use of non-experimental (owned or unowned) animals. Established internationally recognized high standards ('best practice') of veterinary clinical care for the individual patient were always followed and/or this work involved the use of cadavers. Ethical approval from a committee was therefore not specifically required for publication in *JFMS Open Reports*. Although not required, where ethical approval was still obtained it is stated in the manuscript.

Informed consent Informed consent (verbal or written) was obtained from the owner or legal custodian of all animal(s) described in this work (experimental or non-experimental animals, including cadavers) for all procedure(s) undertaken (prospective or retrospective studies). No animals or people are identifiable within this publication, and therefore additional informed consent for publication was not required.

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