Treatment of tibial diaphyseal fractures following plateless tibial tuberosity advancement to manage cranial cruciate disease

R. De Sousa*†, P. Egan†, K. Parsons‡, S. Butterworth§, I. Calvo¶, S. Roch|| and A. P. Moores*

*Anderson Moores Veterinary Specialists, Winchester, Hampshire SO21 2LL, UK
†Fitzpatrick Referrals Ltd, Eashing, Surrey GU7 2QQ, UK
‡Langford Veterinary Services, University of Bristol, Langford, Bristol BS40 5DU, UK
§Weighbridge Referral Services Ltd, Swansea, Wales SA6 8QF, UK
¶The Queen Mother Hospital for Animals, The Royal Veterinary College, Hatfield, Hertfordshire AL9 7TA, UK
||Kentdale Veterinary Orthopaedics Ltd, Milthorpe, Cumbria LA7 7NU, UK

1Corresponding author email: Ricardo.DeSousa@Andersonmoores.com

OBJECTIVE: To report diaphyseal fractures of the proximal tibia following tibial tuberosity advancement without plate stabilisation for the management of cranial cruciate ligament rupture in dogs.

METHODS: Members of the British Veterinary Orthopaedic Association’s online discussion forum were invited to submit revision cases of tibial diaphyseal fracture following tibial tuberosity advancement without plate fixation. Data collected included signalment, surgical revision technique, pre- and postoperative revision radiographic findings, complications and veterinary assessment. Owners were invited to complete the Liverpool Osteoarthritis in Dogs questionnaire.

RESULTS: A total of 17 dogs were included in the study. Eleven dogs had OrthoFoam-wedge modified Maquet procedures and six had the tibial tuberosity advancement rapid procedure. Tibial tuberosity advancement was maintained in 14/17 cases. Postrevision surgery complications occurred in eight cases: minor complications in 3/17 dogs; major in 5/17 and no catastrophic complications. Surgical site infection was the most common complication (4/8). Final clinical outcome found 8/17 of dogs to have excellent, 8/17 satisfactory and 1/17 poor clinical outcome. The median Liverpool Osteoarthritis in Dogs score was 12/52 (range 2 to 28). Final outcome was 6/13 owners that were very satisfied, 2/13 owners indifferent and 5/13 owners very disappointed.

CLINICAL SIGNIFICANCE: This is the first case series reporting tibial diaphyseal fractures following tibial tuberosity advancement without plate stabilisation. The authors report here a wide spectrum of potential fixation strategies should one of these fractures occur.

INTRODUCTION

Cranial cruciate ligament rupture is one of the most common orthopaedic disorders in dogs (Lampman et al. 2003). Numerous techniques have been described to stabilise the cranial cruciate-deficient stifle but, over the past two decades, tibial osteotomies have become increasingly popular. The aim of all tibial osteotomies is to alter the geometry of the stifle joint to achieve dynamic stabilisation (Aragon & Budsberg 2005, Kim et al. 2008, Duerr et al. 2014).
Tibial tuberosity advancement (TTA) was first suggested in 2002 and aims to neutralise cranial tibial thrust by advancing the tibial tuberosity to form an angle of 90° between the tibial plateau and the patellar tendon, when the stifle is at an angle of 135° of extension (Montavon et al. 2002). In the original description of the procedure, the advanced tibial tuberosity is stabilised with a plate. More recently, TTA has been described without plate stabilisation of the advanced tibial crest (Etchepareborde et al. 2011, Ness 2014, Ramirez et al. 2015, Samoy et al. 2015). Although different ways of achieving this have been described, such procedures are collectively known as modified Maquet procedures (MMP) after a procedure performed in human surgery to relieve patellofemoral pain (Maquet 1976, Mendes et al. 1987). In the United Kingdom (UK) two proprietary MMPs have gained in popularity; the OrthoFoam-wedge MMP procedure (OF-MMP; Orthomed Ltd®), (Ness 2014) and the TTA Rapid procedure (Rita Leibinger Medical; Samoy et al. 2015). Both techniques are marketed as being quick and easy to perform with a low risk of complications (Orthomed 2016, Leibinger 2016). Although based on limited case numbers, an overall complication rate of 34% has been reported for TTA Rapid procedures (Samoy et al. 2015). Tibial fractures have been encountered most frequently at the level of the distal cortical hinge of the advanced tibial crest and do not always require surgical revision (Ramirez et al. 2015, Samoy et al. 2015). To our knowledge, a single clinical case has been reported with tibial diaphyseal fracture following a new modified Maquet technique (Ramirez et al. 2015). Complications data are not available for the OF-MMP procedure.

In November 2013, catastrophic fractures of the proximal tibia (fractures of the tibial crest through the distal drill hole combined with tibial diaphyseal fracture) were reported on the British Veterinary Orthopaedic Association (BVOA) discussion forum (https://groups.google.com/forum/#!topic/bvoa/K9pj-ffF07o). Responses to the initial post indicated that this was a well-recognised complication. The purpose of this study was to report the specific complication and surgical repair of tibial crest fracture combined with proximal tibial diaphyseal fracture in dogs that had undergone TTA via either the OF-MMP or TTA Rapid procedures.

MATERIAL AND METHODS

Case selection
Members of the BVOA online discussion forum were invited to participate in the study. Medical records of the revision surgery were collected for dogs that sustained tibial diaphyseal fracture following either OF-MMP or TTA Rapid procedures (henceforth referred to as the index surgery). Inclusion criteria included preoperative, postoperative and follow-up radiographs of the fracture repair surgery (henceforth referred to as the revision surgery) to be available for review as well as a detailed surgical report, postoperative treatment and final clinical assessment (minimum six weeks). Cases were excluded when fractures solely involved the tibial tuberosity/crest or when complete medical records and radiographic data were not available.

Medical records review
Individual surgeons were asked to retrieve data on breed, temperament (age, sex, body weight, body condition score and neutering status), history, physical examination findings, imaging investigation, type of fracture configuration, and surgical revision (Appendix S1). The qualifications of the revision surgery surgeon, the nature of the surgical revision, intraoperative and postoperative complications and outcome were determined and recorded on an Excel spreadsheet (Microsoft® Office Excel, 2007, Microsoft Corporation).

Radiographic interpretation
Surgeons were asked to submit all radiographic studies performed for each case. Radiological evaluation was performed independently by two observers (Author R. de Sousa/A. Moores) and were reviewed for the type and level of fracture, surgical implants used and positioning and progression of osseous union using a grading system developed by the International Society of Limb Salvage (Glasser & Langlais 1991): Grade (1) poor healing – union <25%; (2) fair-union 25 to 50%; (3) good-union 50 to 75%; and (4) excellent-union >75%.

Complications
Complications were recorded as defined by Cook et al. (2010). Briefly, minor complications were described as those requiring no additional medical or surgical treatment. (e.g. wound inflammation, seroma formation). Major complications described those associated with morbidity that required further medical treatment or surgery. Catastrophic complications were described as those associated with morbidity that caused permanent unacceptable function. Time frame for complications was defined as “perioperative” (pre, intra, and postoperative to three months), “short-term” from three to six months, “mid-term” as 6 to 12 months and long-term complications as >12 months (Cook et al. 2010).

Follow-up and outcome measurement
Physical examination was performed by veterinary orthopaedic assessment at six to eight weeks after revision surgery and subsequently as required. Subjective clinical outcome performed by the revision surgeon was classified as “excellent function” when restoration or maintenance of the intended activity level and overall performance was achieved without pain, as “satisfactory function” when restoration or maintenance of the activity level and overall performance was limited in level or duration, and as “poor function” if there was severe lameness and stifle pain.

Revision surgery surgeons were asked to contact owners to obtain verbal consent for their dog’s clinical data to be included in the study. Owners were sent the Liverpool Osteoarthritis in Dogs (LOAD; Walton et al. 2013) questionnaire. An aggregate mobility score (LOAD score) was generated for each dog.

RESULTS
A total of 10 veterinary surgeons contributed the case material. Data were retrieved for 22 cases that sustained a comminuted tibial shaft fracture (Figs 1 and 2), but only 17 dogs met the...
inclusion criteria. Surgeon questionnaire data were obtained for all 17 dogs, but owner questionnaire data were obtained for 13/17 cases. All dogs presented with clinical signs including (but not limited to) acute onset of non-weight bearing lameness and pain following the index surgery. The breed of dogs included springer spaniel (3), bichon frise (3), beagle (3), golden retriever (2), cocker spaniel (1), cross-breed (1), boxer (1), bearded collie (1), miniature schnauzer (1) and Shetland sheepdog (1). The mean age was 79 months (SD±26 months) with a mean body weight of 21 kg (range 6·7 to 44 kg) and mean body condition score of 3 (Likert scale from 0 to 5). There were 10 males (eight neutered) and seven females (six neutered). The median duration of presentation following the index surgery was 22 days (range, 1 to 98 days). In two cases, an unsuccessful revision surgery was attempted by the first opinion veterinary surgeon prior to the final revision; case 5 received a double 2·7-mm string of pearls plate which failed by screw breakage, and case 14 that received a single 2·7-mm dynamic compression plate which failed by refracture at the fracture site. Both cases had the implants removed before final revision.

Surgical procedure
A summary of the surgical information is shown in Table 1. Index surgeries included 11 OF-MMP procedures and six TTA Rapid procedures. All but two index surgeries were performed by non-specialist surgeons. Seven dogs had surgery on the right pelvic limb and 10 dogs on the left pelvic limb.

Revision surgeries were performed by six European Veterinary Specialists in Small Animal Surgery and/or Royal College of Veterinary Surgery (RCVS) Recognised Specialists and four RCVS certificate holders. Index surgery implants were completely removed in 6/17 cases whereas in 7/17 only the distal wire (three OF-MMP cases) or staple (two OF-MMP cases) or combination of wire/staple and Kirschner wire (K-wire) (two cases) were removed. In the remaining 4/17 cases the original implants were maintained in situ. TTA was maintained in 14/17 cases with 3/14 cases having the original TTA Rapid cage replaced by a standard TTA cage (Kyon Veterinary Surgical Products®). In the three cases in which the TTA was not maintained, one (case 1) was deemed stable at subsequent follow-ups, one was further stabilised with an extracapsular suture at six weeks after revision surgery (case 2) and one was still awaiting second revision at the time of writing the manuscript (case 15).

Radiographic interpretation
Revision surgery postoperative radiographs revealed appropriate implant positioning in all cases with satisfactory reduction and alignment of the tibia. Mean radiographic follow-up was 10 weeks (ranging from 6 to 14 weeks). Using the International Society of Limb Salvage radiographic criteria, seven cases had excellent progression of osseous union, nine had good progression of bone union and one had fair progression of bone union. Incidental implant complications were noted in two cases; in case 5 there was breakage of the 2·7 mm LCP medial plate at the level of the fourth screw hole (Fig 3) and in case 6 there was bending of the K-wire with slight cranial tilting of the distal aspect of the tibial tuberosity. Neither required further treatment.
Complications
Revision surgery complications were encountered in 8/17 cases (complication rate of 47%), Table 1. Minor complications were encountered in 3/17 dogs; case 3 sustained a proximal tibial tuberosity fracture with minimal displacement. This was an incidental radiographic finding at six weeks postoperatively and subsequent radiographs at 12 weeks showed good bone union at the osteotomy site (Fig 4). Implant failure was identified in two cases (cases 5 and 6) as an incidental finding and no treatment was subsequently required.

Major complications occurred in 5/17 dogs. Surgical site infections (SSIs) occurred in four cases: in three cases in which culture was performed two were positive for methicillin-resistant Staphylococcus pseudintermedius and one was negative. Three of these cases required implant removal (all but the OF-MMP foam wedge) at 9 (case 16), 14 (case 17) and 26 weeks (case 13) after revision surgery. The remaining infection (case 1) resolved with a protracted course of antibiotics (more than weeks). One case (case 2) in which the original TTA was lost, was diagnosed with a meniscal tear at six weeks after surgical repair. Meniscectomy was performed and an extracapsular suture was applied to stabilise the stifle joint. There were no catastrophic complications following any revision surgery.

Follow-up and outcome measurement
Mean time for final veterinary follow up was 23 weeks (ranging from 6 to 106 weeks) with 8/17 dogs deemed to have excellent, 8/17 satisfactory and 1/17 poor surgical outcome.

Thirteen LOAD questionnaires were completed at a mean of 21 months (range 3 to 52 months) after revision surgery. At the time of questionnaire completion, only two owners reported their dog to be receiving non-steroidal anti-inflammatory medication.

The mean LOAD score was 12/52 (range 2 to 28) (0=normal, 52=severely disabled). Owner satisfaction with treatment and the final outcome found six owners to be very satisfied, five to be very disappointed, two to be indifferent and unknown outcome for the remainder. When asked whether they would undertake the index surgery again, 9/13 said yes, 3/13 said no and 1/13 was unsure.
MMP have increased in popularity for the treatment of dogs with cranial cruciate ligament disease. Despite this, there is little peer-reviewed literature on complications and outcome (Etchepare-borde et al. 2011, Ramirez et al. 2015, Samoy et al. 2015). In this series surgical revision resulted in a favourable outcome and owner satisfaction in the majority of cases.

A variety of orthopaedic implants and configurations can be applied to comminuted diaphyseal tibial fractures (Piermattei et al. 2006). In the current study, all tibial fractures were repaired using plate and screw fixation. Selection of bone plates included

**DISCUSSION**

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### Table 1. Surgical details and intraoperative complications of MMP and TTA rapid procedures

| Case number | Original surgery | Original implants removed | Fracture configuration | Surgical revision | Tibial tuberosity advancement maintained | Complications (minor, major and catastrophic) |
|-------------|------------------|---------------------------|-----------------------|------------------|-----------------------------------------|-----------------------------------------------|
| 1           | OF-MMP<sup>*</sup> | All                       | Three-fragment tibial fracture (through the staple hole), fibula fracture | Medial 2-0 DCP, Tuberosity/crest K wires, tension band wire; interfragmentary lag screw | No | Surgical site infection (Major) |
| 2           | OF-MMP<sup>†</sup> | All                       | Three-fragment tibial fracture, distal fissures, fibula fracture | Medial 3-5 LCP; Tuberosity/crest K wires, tension band wire, interfragmentary lag screws | No | Delayed meniscal tear (Major) |
| 3           | TTA rapid        | All                       | Three-fragment tibial fracture, fibula intact | Medial 2-7 LC-DCP, cranial 2-4 LCP | Yes, Standard TTA cage used | Fracture of the proximal tibial tuberosity with minimal displacement (Minor) |
| 4           | TTA rapid        | All                       | Three-fragment tibial fracture, fibula intact | Medial 2-7 LCP; cranial 2-4 LCP | Yes, Standard TTA cage used | None |
| 5           | TTA rapid        | All                       | Four-fragment tibial fracture post double SOP plate revision, fibula fracture | Medial 2-7 LCP and cranial 2-4 LCP | Yes, Standard TTA cage used | Medical LCP plate breakage (Minor) |
| 6           | OF-MMP<sup>†</sup> | Wire only                 | Three-fragment tibial fracture, fibula fracture | Medial 3-5 SOP plate | Yes (original wedge) | Cranial tilting of the distal aspect of the tibial crest with bending of the K-wire (Minor) |
| 7           | OF-MMP<sup>†</sup> | Wire and K-wire           | Three-fragment tibial fracture, fibula fracture | Medial 3-5 DCP cranial 2-0/2-7 VCP (2-7 screws) | Yes (original wedge) | None |
| 8           | TTA rapid        | No                        | Three-fragment tibial fracture, fibula fracture | Medial 2-4 VI locking plate, caudo-medial 2-0 SOP | Yes (original cage) | None |
| 9           | TTA rapid        | No                        | Three-fragment tibial fracture, fibula intact | Medial 3-5 DCP, cranial-caudal tibial crest positional screw | Yes (original cage) | None |
| 10          | TTA rapid        | No                        | Three-fragment tibial fracture, fibula intact | Medial 2-0/2-7 VCP (2-4 screws) | Yes (original cage) | None |
| 11          | OF-MMP<sup>†</sup> | Wire                     | Five-fragment tibial fracture, fibula fracture | Medial 2-7 Biological Healing Plate, tension-band wire, interfragmentary 2-0 lag screw, | Yes (original wedge) | None |
| 12          | OF-MMP<sup>†</sup> | Wire                     | Three-fragment tibial fracture, fibula intact | Medial 2-7 DCP, tibial crest wire | Yes (original wedge) | None |
| 13          | OF-MMP<sup>†</sup> | No                       | Three-fragment tibial fracture (through the staple hole), fibula intact | Medial 3-5 DCP | Yes (original wedge) | Surgical site infection (Major) |
| 14          | OF-MMP<sup>†</sup> | Staple and K-wire       | Four-fragment tibial fracture following revision attempt with medial DCP (original fracture through the staple hole), fibula fracture | Cranial closing wedge osteotomy, medial Synthes 2-7 TPLO plate, cranial polyaxial 2-4 Evolox plate | Yes (original wedge) | None |
| 15          | OF-MMP<sup>†</sup> | All                      | Three-fragment tibial fracture (through the staple hole), fibula fracture | Medial 2-4 LCP, cranial 1-5/2-0 VCP, K-wire/tension-band wire | No | None |
| 16          | OF-MMP<sup>†</sup> | Staple only               | Three-fragment tibial fracture (through the staple hole), fibula fracture | Medial 3-5 LCP; K-wire/tension-band wire | Yes (original wedge) | Surgical site infection (Major) |
| 17          | OF-MMP<sup>†</sup> | Staple only               | Four-fragment tibial fracture (through the staple hole), fibula fracture | Medial 3-5 LCP, caudal 2-7 LCP, K-wire/tension-band wire | Yes (original wedge) | Surgical site infection (Major) |

DCP Dynamic compressive plate, LC-DCP Limited contact dynamic compressive plate, SOP string of pearls, VCP Veterinary cuttable plate

* With staple
† With distal wire
Fracture complications of TTA

locking and non-locking systems applied as a single medial plate (nine cases), or double medial-cranial (five cases) or medial-caudal (two cases) plates. One fracture was repaired with a cranial closing wedge osteotomy combined with a medial Synthes TPLO plate (Synthesis GmbH®) and cranial plate. The failure of the medial plate in case 5 (Fig 3), despite double-plating of the fracture in that dog, may be an indication of the large and repetitive stresses that these implants can be subjected to and potentially result in fatigue failure of the implant.

TTA was maintained in all but three cases, by preserving the index surgery wedge/cage or by replacing it with a standard TTA cage. Replacing the OF-MMP wedge/TTA Rapid cage with a standard TTA cage was performed in several cases because the smaller size of the standard cage provides greater flexibility for implant placement, particularly if a cranial plate is used. The small number of cases in this series does not allow us to make meaningful comparisons between the different repair techniques employed, or to assess outcome in terms of whether advancement was maintained. Nevertheless, in two of three cases in which TTA was not maintained the stifles were unstable with positive tibial compression tests at the subsequent re-examinations. While one was successfully managed with application of an extra capsular suture and meniscectomy the other was still awaiting surgical revision at the time of writing the manuscript.

We report a complication rate for revision surgeries of 47% dogs (8/17). Three dogs were diagnosed with implant failure (cases 5 and 6) and proximal tibial tuberosity fracture (case 3) as incidental findings at the six- to eight-week radiographic follow up. These three dogs continued to improve over the following months and did not require further medical or surgical treatment. In case 3 the repair was achieved with application of a cranial tibial plate, which did not extend proximally to the tibial tuberosity, and thus the top screw hole together with previous screw holes from the TTA cage may have acted as a stress-riser. The authors suggest that where a cranial plate is used consideration should be given to placing it proximally to incorporate the entire tibial crest (such as in case 5; Fig 3) so that an unprotected stress riser is not present distal to the insertion point of the patellar tendon.

The SSI rate was 23% (four cases), which is high compared to elective procedures such as TTA (5 to 7%) or tibial plateau levelling osteotomy (8%) (Frey et al. 2010, Worff et al. 2012, Yap et al. 2015). Similar to the risk factors identified by Yap et al. (2015), we propose that the high rate reflects the increased soft tissue dissection, disruption of local blood supply as a consequence of previous surgery, increased surgical times and large number of implants required for stabilisation.

One dog (case 2) was diagnosed with a meniscal injury six weeks following revision surgery. Interestingly, TTA was not maintained at the time of the revision surgery and may have predisposed this case to a late meniscal tear. After meniscectomy and extracapsular lateral suture this dog progressed to full recovery.

At final examination, the majority of dogs (16/17) were classified as having satisfactory to excellent clinical outcome. Clinical outcomes were based on the last veterinary assessment, which in the majority of cases was six to eight weeks postoperatively and so these results must be interpreted cautiously. It is likely that these cases would have improved further over the following months, as shown by Krotscheck et al. (2016), in a study showing that peak vertical force and vertical impulse showed continued improvement at 12 months after stabilisation via tibial plateau levelling osteotomy, TTA or extracapsular repair.

In the present study, LOAD questionnaires were used to assess owner long-term outcome. Results from these questionnaires produced a mean score of 12/52, which is similar to the findings of a previous study in dogs that sustained tibial tuberosity fractures following TTA (Lorenz & Pettitt 2014). Further studies are warranted to correlate the level of owner satisfaction and LOAD questionnaire scores.

The OF-MMP and TTA Rapid procedures include drilling a hole at the distal aspect of the tibial crest osteotomy to dissipate stresses when the tibial crest is advanced cranially, and thus avoid fracture of the distal tibial crest. According to Brunel and oth-
ers (2013), the drill hole does not decrease the risk of fissure and fracture formation, as initially postulated by Maquet (Maquet 1976). This was in agreement with findings from Samoy and others (Samoy et al. 2015). The drill hole with or without augmentation of the constructs with tension band wires or staples certainly does not prevent fractures – all the tibial diaphyseal fractures we report here occurred through the distal drill hole. We consider it likely that the fractures were preceded by fracture through the drill hole to the cranial cortex, creating a stress-riser at that level which put the tibia at risk of diaphyseal fracture. With access to a larger number of cases, including those with and without fracture, it would be interesting to assess the size and position of the drill hole as a risk factor for fracture. Surgeon experience and expertise is also likely to play a role in the incidence of these complications. A recent study found that it took 22 procedures for a single experienced surgeon to reduce their major complication rate when learning to perform TTA (Proot & Corr 2013). OF-MMP and the TTA Rapid procedures are marketed towards non-specialist surgeons (Orthomed 2016, Leibinger 2016) and although we did not aim to evaluate the expertise of the surgeons who performed the index procedure, the majority of the OF-MMP/TTA Rapid surgeries in this series were performed by general practitioners (15/17). Inappropriate postoperative management and owner non-compliance could also have contributed to the complications.

This study has several limitations. Clearly, the variability introduced by the number of surgeons performing the revision

FIG 4. Mediolateral (A) and craniocaudal (B) radiographs taken at −1, 0, 28 and 55 days after revision surgery (case 3). Note the short work-length of the proximal aspect of the cranial plate positioned below the tibial tuberosity. An incidental proximal tibial tuberosity fracture was identified at six weeks after surgical repair with minimal proximo-distal displacement. Subsequent radiographs showed progression of bone union and satisfactory implant positioning.
surgery is not ideal. In addition, the small number of cases limits the strength of any conclusions that can be made. Intraoperative decisions and postoperative owner compliance may have had a role in the occurrence of these fractures. Furthermore, we did not evaluate the incidence of these complications, as we do not know what proportion of all patients these 17 fractures represent. It is also likely that there have been other similar fractures that have been treated by surgeons other than the authors. Further studies are warranted to evaluate the incidence and specific risk factors.

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Conflict of interest

None of the authors of this article has a financial or personal relationship with other people or organisations that could inappropriately influence or bias the content of the paper.

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Supporting Information

The following supporting information is available for this article:

Appendix S1. Surgeon questionnaire including the preoperative, surgery and post-operative follow up.

[Correction added on 3 August 2017 after first online publication: Liverpool Osteoarthritis in Dogs questionnaire (LOAD) cited as Appendix S2 is temporarily unavailable. Please email jsap@wiley.com for any queries.]