Surgical management of large segmental femoral and radial bone defects in a dog

Through use of a cylindrical titanium mesh cage and a cancellous bone graft

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Keywords
Titanium mesh cage, long segmental defect, cancellous bone graft

Summary
In this case report, we describe the use of a cylindrical titanium mesh cage combined with cancellous bone graft to surgically manage large segmental bone defects in a dog. A seven-year-old, neutered male cross-breed dog, with highly comminuted fractures of the right femur and the left radius and ulna, was referred for treatment. Previous open reduction and internal fixation of these fractures had failed. Following implant removal and debridement of each bone, a 71 mm segmental femoral defect and a 27 mm segmental radial defect were present. A commercially available cylindrical titanium mesh cage was filled with ß-tricalcium phosphate crystals mixed with an equal volume of autogenous cancellous bone graft. The mesh cage was aligned with the proximal and distal parts of each bone using an intramedullary pin passing through the cage, and a locking plate was applied to the proximal and distal fracture fragments to produce compression against the titanium cage. The dog had a successful long-term clinical outcome, and radiographic examination at 22 and 63 weeks after surgery showed the formation of remodelling bridging callus that was continuous across the titanium cage in each of the fractures. Due to the relative simplicity of the technique and the favourable outcome in this case, it should be considered an option when managing comminuted fractures with large bone defects.

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Introduction

The repair of a large segmental defect in a long bone is a major surgical challenge (1). Numerous surgical techniques have been devised to address this problem, but most of these techniques have major limitations. The use of a cortical allograft combined with a metal implant provides mechanical stability, but the allograft is susceptible to infection and is rarely fully incorporated (2, 3). Distraction osteogenesis requires a docile patient, cooperative owners, and the prolonged stabilisation of the fractured bone with an external fixator, which is potentially uncomfortable (4). Additionally, this method has a high complication rate during the convalescent period (4). Use of a vascularised cortical autograft requires a technically complex procedure involving microvascular surgical techniques and is therefore not yet widely used in veterinary surgery (5).

In the past several years, osteoconductive and osteoinductive substances, such as canine demineralised bone matrix, canine autogenous cancellous bone graft, and bone morphogenetic proteins have gained popularity for the treatment of bone defects associated with comminuted fracture repairs (6). The use of demineralised bone matrix as a substitute or adjunct for autogenous cancellous bone graft has been evaluated experimentally in dogs, and clinically in cats and horses (6–8).

Titanium mesh cages have been used effectively to restore bone continuity in various anatomic regions in humans (9–11). This device is now being widely used in spinal surgery for anterior spinal reconstruction after thoraco-lumbar corpectomy (11). Recently, titanium mesh cages packed with cancellous bone graft and demineralised bone matrix or ß-tricalcium phosphate crystals were successfully used in combination with bone plating or interlocking nails to treat extensive bone loss in the human tibia and humerus (9, 10). The biological and biomechanical characteristics of bone healing in a large femoral segmental defect reconstructed with a titanium cage were studied in a canine model (12). The major advantages of the mesh cage method are the maintenance of cancellous bone graft continuity and quantity throughout the large bone defect, thus permitting osteoinduction and osteoconduction; this provides immediate stability sufficient to permit early, active weight bearing use of the limb (9, 12). The success of the titanium mesh cage technique in these applications suggest that it may be useful for the restoration of large segmental defects in long bones in small animals as well. We believe this to be the first report of the clinical use of this technique for the treatment of large segmental bone defects in a dog with multiple limb injuries.

Case report

A seven-year-old male neutered crossbreed dog, weighing 25 kg, was referred to our clinic for treatment of multiple limb injuries with two failed fracture fixations. The dog had jumped from a height of about six meters and fractured the left radius and ulna. The referring clinician had originally repaired these mid-shaft fractures by applying a bone plate to the radius. Unfortunately, seven days later the dog had jumped again, resulting in a highly comminuted right femoral fracture, and breaking the repair of the radius and ulna. An open reduction and internal fixation of the highly comminuted femoral fracture with cerclage wires, screws and a plate was performed. In addition, the bone plate was removed from the radius, thus creating a mid-diaphyseal bone defect approximately 25 mm in length together with stripped screw holes in the radius.

Fig. 1 Preoperative craniocaudal (A) and mediolateral (B) views of the right femur. Two 3.5 mm cortical screws and a cerclage wire are evident from the procedure conducted prior to admission.

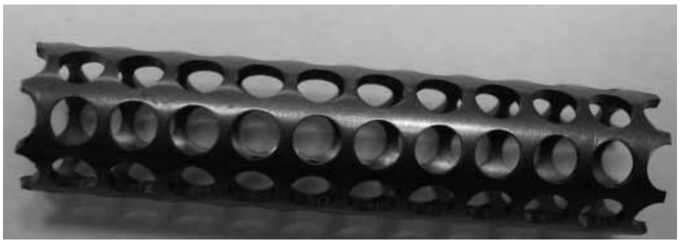


Fig. 2 Pure titanium mesh cage used in the bone defects.

At the time of the initial clinical examination at our hospital, the dog was haemodynamically stable, but lethargic and unable to stand. Radiographic examination revealed highly comminuted midshaft fractures of both the right femur (►Fig. 1) and the left radius and ulna (not shown).

Following a lateral surgical approach to the mid-shaft of the right femur, substantial soft tissue damage was observed, as well as numerous bone fragments denuded of soft tissue attachment. These bone fragments appeared macroscopically devitalised and therefore were discarded. The immense bone loss led to the decision to terminate the surgery and prepare the dog for a subsequent procedure involving the use of a titanium mesh cage implantation combined with cancellous bone graft. The proximal and distal ends of the femoral defect were trimmed with bone rongeurs to a level where the bone appeared to be viable. The end of each bone segment was shaped transversely to enable support of the titanium cage. Samples for aerobic and anaerobic cultures were taken, and the surgical site was closed in a routine fashion. No bacterial growth was observed in the cultures. The dog was hospitalised with cage restriction and treated with 10 mg morphine QID and 700 mg cefazolin TID until the next procedure. During this time, the radius and ulna fractures were supported with a modified Robert Jones bandage which extended from the level of the digits to the midshaft of the humerus.

Mediolateral and craniocaudal radiographic views of the fractured right femur and the normal contralateral femur were compared. From these we estimated that the femoral defect was 71 mm long. A lateral surgical approach to the mid-shaft of the right femur was performed. A 120 mm long, cylindrical titanium mesh cage[a] (►Fig. 2) was trimmed to a length of approximately 71 mm and filled with 5 g of commercially available ß-tricalcium phosphate crystals[b] mixed with an equal volume of autogenous cancellous bone graft taken from the right humerus. The mesh cage was placed between the proximal and distal parts of the femur and stabilised with a 2.6-mm-diameter intra-medullary pin, which was inserted by normograde technique through the mesh cage. The insertion of these implants assisted in bringing the bone into anatomical alignment. A 13-hole, 3.5 mm locking plate[c] with six 3.5-mm-diameter cortical screws[d] was then attached to the lateral aspect of the proximal and distal femoral segments so that

[a] ROM pure titanium mesh cage: GMReis®, São Paulo, Brasil
[b] SBM®, Science for BioMaterials, Lourdes, France
[c] SOP: Orthomed®, Portland, Oregon, USA
[d] Orthomed®, Portland, Oregon, USA

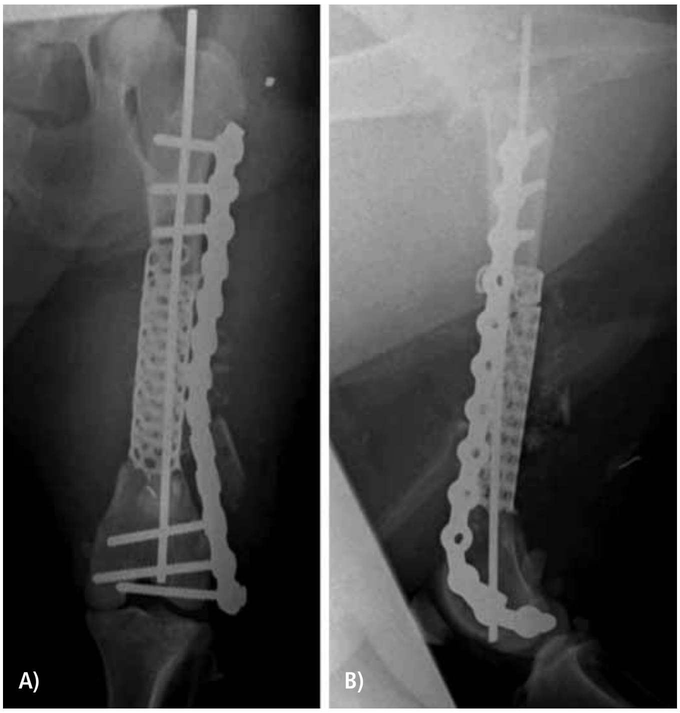


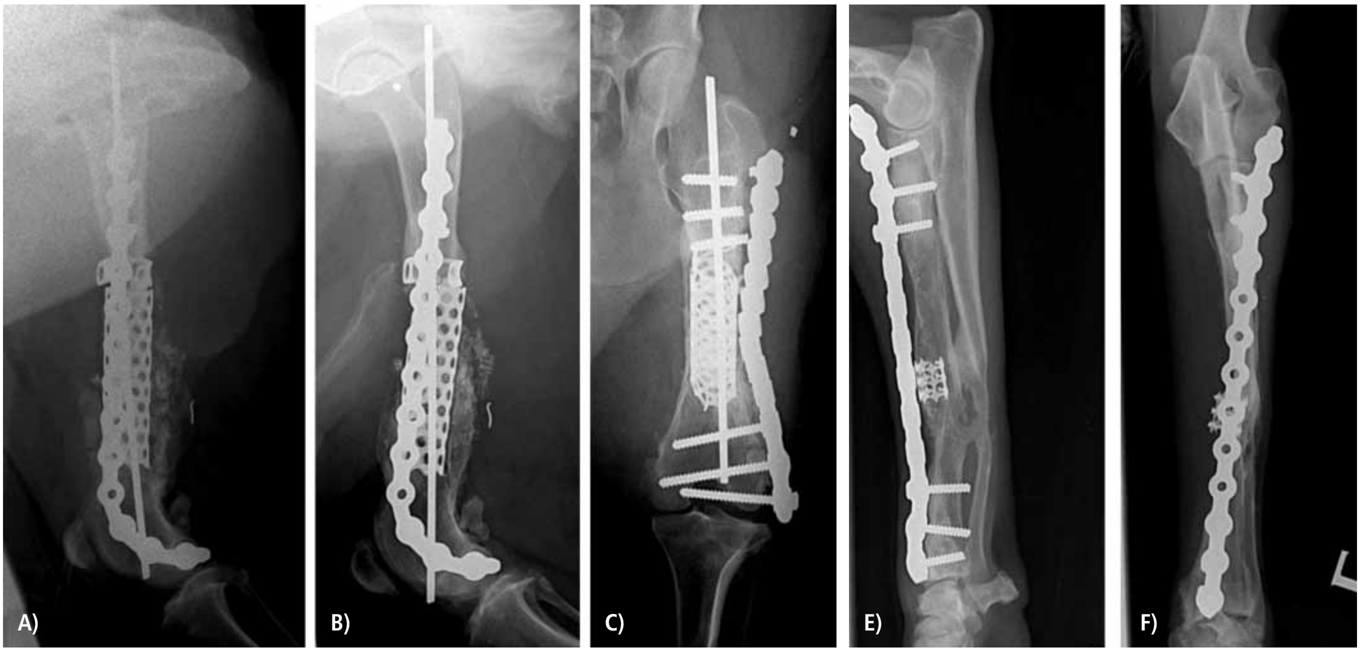
Fig. 3
Post operative craniocaudal (A) and mediolateral (B) views of the femur. The titanium cage, locking plate and intramedullary pin are in place. The distal screw appears to be passing through the intercondylar notch.

both ends of the fracture were held against the titanium cage (▶Fig. 3). In this configuration, the cancellous bone graft was captured within the mesh cage. Axial alignment of the femur was good, however there was torsional malalignment with excessive anteversion of the proximal femur. The distal screw in the locking plate passed through the intercondylar notch of the femoral condyles. Once recovered from general anaesthesia, the dog was capable of standing but was not weight bearing on the operated limb.

Six days after this operation, the left ulnar and radial fractures were stabilised. A medial approach to the left radius was performed, and a denuded bone fragment 27 mm in length was discarded. A 30 mm long titanium mesh cage was used, based on a bone-gap estimation of 27 mm. The cage was packed with ß-tricalcium phosphate crystals mixed with an equal volume of autogenous cancellous bone graft harvested from the left humerus. A 13-hole, 3.5 mm locking plate was applied to the craniomedial surface of the radius with three 3.5 mm cortical screws in the distal radial fragment and three screws in the proximal fragment. A 1.8-mm-diameter intra-medullary pin was inserted normograde into the ulna from the olecranon. While placing the locking plate we found that it was one hole too long, but refrained from removing and cutting the plate as most screws were already attached. Therefore, the most proximal screw hole of the plate was left empty. The postoperative radiographs showed functional bone alignment (▶Fig. 4). Based on the findings of the postoperative radiographs, the intramedullary pin was removed because it did not appear to be providing any additional stability or anatomical reduction of the ulnar fracture (▶Fig. 4).

Postoperatively, systemic antibiotic therapy (cephalexin 750mg TID and enrofloxacin 150mg BID), and pain management (fentanyl patch 75ug and carprofen 50mg BID) were prescribed for 10 days following each operation. Strict rest was recommended for the first 12 weeks following the operations, followed by restricted short walks with a lead. The owner was also instructed to perform passive range-of-motion exercises.

Fig. 4
Postoperative mediolateral (A) and craniocaudal (B) views of the radius and ulna fractures.



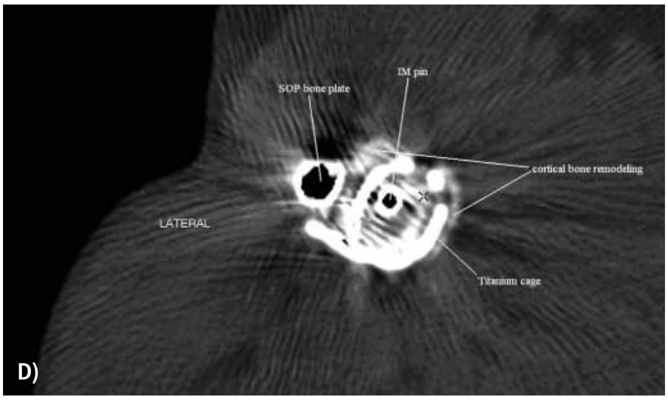


Fig. 5 Postoperative radiographs from 22 and 63 weeks after surgery. (A) A mediolateral view of the femur 22 weeks after surgery. Callus formation is evident on the distal part of the diaphysis, covering 70% of the titanium cage length. (B) Mediolateral and (C) craniocaudal views of the right femur 63 weeks after surgery. (D) CT imaging 63 weeks after surgery. Axial view of mid shaft femur showing 360 degrees cortical bone remodeling and filling of the medullary canal with bone. (E) Mediolateral and (F) craniocaudal views of the left ulna and radius 63 weeks after surgery showing healing of the fractures with formation of a synostosis.

On follow-up assessment ten days after surgery, the dog was lame on the right hindlimb while walking, but was weight bearing. On examination 22 weeks after surgery, the dog was fully weight bearing but lameness was still observable. The stifle joint had a normal extension angle,however there was a a 45° decrease in flexion, and marked joint crepitation. Slight muscle atrophy was noted. Radiographic examination at this time revealed callus formation at the distal part of the femoral diaphysis, covering 70% of the titanium cage (▶Fig. 5A).

On examination 63 weeks following the surgical procedure, the dog walked and ran with full weight bearing, although lameness was still observed during running. The range of motion had not improved. Dense callus formation and cortical bone remodeling were observed continuously along the entire length of the femoral titanium cage (▶Fig. 5B-C). The cranio-caudal view showed three broken proximal screws and plate attachment only to the distal region of the bone. A complete continuous callus, in a remodeling process, was observed at the medial side of the femur (▶Fig. 5C). There were minor signs of radiolucency in the bone surrounding the distal screw in the plate. A computed tomography scan of the femur showed cortical bone remodeling 360°around the titanium cage, with bone occupying the medullary canal within the cage (▶Fig. 5D). Radiographic examination of the left antebrachium showed callus formation in the remodelling process at the fracture line of both the ulna and radius (▶Fig. 5E-F). It also appeared that the new bone formation had formed a synostosis between the radius and ulna, just distal to the titanium cage. The owners were advised that removal of the locking plates and the intramedullary pin is recommended; they declined this additional surgical procedure due to the associated costs.

Discussion

The dog in this case report was admitted with multiple limb injuries, and suffered from substantial bone loss and excessive soft tissue damage due to the original injury and the previous surgeries. In our judgment, the titanium mesh cage technique was the best option to salvage the limbs. This method has several major advantages over the alternative surgical techniques: (i) it involves a commercially available implant with minor modification easily performed at the surgery table; (ii) it is a relatively 'technically uncomplicated' procedure; (iii) the tricalcium phosphate is commercially available and the autograft is harvested during the surgery; (iv) the rigidity of the construct provides stability, thus permitting early weight bearing and limb mobilisation; and (v) limb length and alignment are easily restored during the surgery.

Although the original prognosis for recovery was guarded due to the high-energy fracture, soft tissue damage and the multiple limb injuries, the clinical outcome of the surgery was successful, as evidenced by the ambulation of the dog with full weight bearing on the treated limbs. Lameness was still present while running, and a 45° decrease in stifle flexion with marked crepitation was observed in the stifle joint. This may have been a result of soft tissue damage, distal placement of the plate, distal migration of the intra-medullary pin, or from the distal screw passing through the intercondylar notch.

Bridging of the fracture and titanium cage with new bone was relatively slow in this case in comparison to that observed in experimental animals because at 22 weeks after the operation, only 70% of the mesh cage was covered by callus (12). This delayed union could have stemmed from the soft tissue damage and blood supply loss associated with the fracture, or from the relatively large bone gap of 71 mm in this case. Addition of bone morphogenetic protein to the cancellous bone graft may have improved fracture healing (13).

Radiographic imaging 63 weeks after the surgery did not clearly indicate that a continuous column of bone was present on the lateral aspect of the femur, but the computed tomography scan confirmed 360° of cortical bone formation. With breakage of the three proximal screws, the bone plate was not contributing to stability or load sharing, and thus it was assumed that the healed bone with the titanium cage and the intra-medullary pin were providing sufficient stiffness.

In 2006, the developers of the original cylindrical titanium mesh cage technique for medical use in humans conducted a pre-clinical trial using canine animal models (12). In their trials, a 30 mm segmental femoral diaphyseal defect was surgically created in 18 dogs, and a titanium mesh cage was used to reconstruct the missing bone. Six to eighteen weeks following surgery, the dogs in this pre-clinical trial were euthanatized and femora were mechanically and histologically evaluated. The trial showed that after 18 weeks, the bones had regained 72.5% torsional stiffness of normal bones, and reached 83.4% of torsional strength. Histopathology showed new bone formation spanning the defect. A more recent, similar study in sheep showed effectiveness of the titanium mesh cage technique in correcting 35 mm long segmental defects in the tibia (14).

To our knowledge, this case is the first report of the clinical treatment of large diaphyseal bone defects using a titanium mesh cage in dogs. The bone defect in this case was associated with severe soft tissue damage and loss of blood supply, while the experimentally created bone defects had minimal soft tissue damage (12). This difference might explain why the bone reconstruction was observed earlier than in the our case. Moreover, the dogs in experimental study were euthanatized after 18 weeks, and long-term recovery, including regain of locomotion, was not tested. Our follow-up of greater than one year shows a satisfactory active mobilisation of the limb. Finally, the segmental femoral defect in our case was more than twice as long as that tested experimentally, indicating that the titanium cage technique is adequate for treating even large segmental defects in dogs. Indeed, such a technique was used to reconstruct a 122 mm segmental bone defect in a human tibia (15).

In summary, the outcome of surgical management of large segmental defects of the femur and radius using cylindrical titanium mesh cages in this case suggest the that the technique has advantages of relative simplicity, and it has the potential of becoming commonly used for treatment of long segmental bone defects. However, further systematic clinical studies are needed in order to evaluate the efficacy, complications, and spectrum of clinical use of this method.

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