Case Report

Contralateral bone widening and transfer for limb sparing in a cat

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Keywords
Distraction osteogenesis, free cortical autograft, bone defects, circular external fixator, bone-widening

Summary
Objective: To report on a novel surgical procedure to treat a long segmental tibial defect in a five-year-old 5 kg spayed female Main Coon cat using transverse distraction osteogenesis in the contralateral tibia to create a free autograft.

Methods: A long free bone segment was created from the cranial half of the normal tibia. A circular external fixator was constructed to give the segment 7 mm of cranial distraction. After 42 days the widened section of tibial bone was removed and transferred to the defect in the contralateral tibia. Locking plates were used to stabilize the graft and to protect the donor tibial sites.

Results: By 27 months, both tibias were healed, all implants had been removed, function was excellent, and the overall limb length was 90% of the normal side.

Clinical relevance: Compared with longitudinal distraction osteogenesis in long bone defects, transverse distraction of a normal bone requires a significantly shorter distraction distance to produce a similar amount of bone. Thus, distraction time is reduced, with less likelihood of significant soft tissue damage. New bone may be more reliably regenerated in a normal limb due to better tissue health, and native bone may be more readily incorporated than allografts in compromised sites. Disadvantages include the increased morbidity, as well as the risk and expense associated with involvement of a normal limb.

Introduction
Massive segmental bone loss from trauma, tumour or infection is a challenging, limb-threatening problem. Distraction osteogenesis is a limb-salvage option for regenerating large bone defects by mechanical induction of new bone formation between bone surfaces that are gradually pulled apart (1-4). In recent years, various techniques have been used to treat large segmental bone defects using distraction osteogenesis by means of bone transport and the Ilizarov technique (5, 6). Single or double longitudinal bone transport and transverse bone transport have been described to treat massive tibial bone defects (6–14). It has been demonstrated that distraction osteogenesis leads to lengthening along the longitudinal axis of a bone, but it can also occur along the transverse axis, perpendicular to the bone axis, since the new bone always develops parallel to the distraction forces (5, 14). Double longitudinal bone transport and transverse distraction osteogenesis have been performed to reduce the external fixation index or healing index (total treatment time equal to lengthening time and consolidation time in months divided by total length in cm gained) and lengthening index (lengthening time in months divided by total length gained in cm) (6, 8, 13–17). Ipsilateral ulnar and radial bone transports to treat large segmental radial and ulnar bone defects have been reported in the human literature (5, 15). Transverse ulnar bone-transport osteogenesis to treat a large distal radial segmental defect was described for treatment of canine osteosarcoma (16–17). Free vascularized fibular grafting has become a standard salvage procedure for reconstructing large or subtotal tibial bone defects in human patients (18). In 1998 Catagni introduced a method of ipsilateral fibular transport with the Ilizarov frame, describing its application in patients with massive tibial bone loss (19). Lim and colleagues reported a case of free fibular graft lengthening in a child after neonatal osteomyelitis of the humerus using circular external skeletal fixation (20). Ipsilateral fibular bone transport osteogenesis and tibial enlargement by means of longitudinal osteotomy and transverse distraction osteogenesis have been reported for the treatment of severe bone atrophy and osteomyelitis in humans (5, 21).

The purpose of this report is to describe the treatment of a large bone defect in a cat by means of contralateral tibial bone widening using the Ilizarov technique followed by an autograft transfer. Treatment was performed in three surgical steps of bone widening, bone transport and finally staged disassembly.

Clinical report

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Clinical presentation

A five-year-old 5 kg spayed female Main Coon cat was admitted with a five month history of non-weight bearing right hind-limb lameness secondary to distal tibial and fibular fractures and nonunion. The fractures, and subsequently the nonunion, had been treated unsuccessfully first with an internal fixator and later with an external fixator. Radiographs were unavailable for evaluation. Bone transport via distraction osteogenesis and an Ilizarov descending procedure was also attempted with distractions of 1 mm/day (3 times daily), also without success, leaving a longitudinal diaphyseal bone defect of 60 mm.

The cat was in good health. The results of a complete blood count, serum biochemical profile, and urinalysis were within the normal range.

Bone widening

Preoperative assessment and planning

The cat was premedicated with methadone (0.2 mg/kg SC). Anaesthesia was induced with propofol (4 mg/kg IV) and maintained with isoflurane (1.5% in oxygen. Standard mediolateral and caudocranial radiographic images of both tibias revealed nonunion with massive right tibial bone loss. Bone loss, as a proportion of the contralateral tibia, was 60 mm/124 mm = 48% (Figure 1). Tibial length, measured along the mechanical axis on the sagittal plane, was 112 and 124 mm for the affected right and unaffected left tibia, respectively. The right tibial length discrepancy was 124 – 112 = 12 mm or 10%. Radiographs were scaled using a radiodense ball of known dimension to assure accuracy of linear measurements. All radiographic measurements were performed using commercial software.

Treatment options, including amputation, were presented to the owner who elected to have the cat undergo a limb-sparing procedure using contralateral bone widening and transfer.

Surgical method

The Ilizarov apparatus used previously for longitudinal bone transport on the right tibia was left in place to allow the cat to use the limbs, preserving function and bone length, while widening the contralateral tibia for autograft transfer. The cat was anaesthetized using the same protocol used for the imaging tests. Intra-operative analgesia consisted of continuous fentanyl infusion (10 μg/kg/h). Cefazolin sodium (22 mg/kg, IV) was administered prior to surgery. The patient was positioned in dorsal recumbency and a standard surgical approach to the medial aspect of the left tibia diaphysis was performed (22). A 70 mm skin incision along the medial aspect of the left tibia was made, extending from the tibial tuberosity to the distal diaphysis.

An external skeletal fixator composed of one proximal 50 mm diameter half-ring connected with a distal 50 mm diameter three-quarter-ring using two 4 mm diameter rods was applied to the left tibia. The two incomplete rings spanned the bone segment to be enlarged. The frame was secured to the proximal tibia by means of two 1 mm diameter wires, inserted in the bone in craniomedial to caudolateral and medial to lateral directions, and a 2 mm positive profile threaded pin was inserted in a mediolateral direction, and connected to the proximal half-ring. Distal fixation was obtained by means of two 1 mm diameter wires, inserted in craniomedial to caudolateral and craniolateral to caudomedial directions, connected with the distal half-ring (Figure 2).

A 65 mm long osteotomy of the tibia was performed in the frontal plane using an oscillating saw. Two transverse osteotomies were performed proximally and distally to free the bone to be enlarged cranially. The site was irrigated during the osteotomy to avoid thermal necrosis. The osteotomy was compressed in a craniocaudal direction using two pointed reduction forceps. The bone segment was transfixed with two 1 mm diameter wires in a mediolateral direction about 10 mm from its proximal and distal extremities (Figure 2). The two wires were secured to the transport apparatus comprised of one proximal three-quarter-ring and one distal half-ring. The transport apparatus was...
connected to the proximal and distal rings of the main frame using flags, plates, bolts and nuts (▶Figure 2, ▶Figure 3a). Soft tissues were closed routinely.

Immediate postoperative patient care and imaging

The apparatus was wrapped with sterile foam sponges impregnated with chlorhexidine\(^h\) 0.05% and packed around the fixation pins between the skin and the frame to limit postoperative swelling, protect the wire and pin insertion wounds, and restrict soft tissue movement relative to the fixation pins and wires. Passive flexion and extension of the hip, stifle and tarsus twice a day to prevent muscle contracture were performed bilaterally.

Convalescent care, bone widening and monitoring

The cat was able to bear weight on the limb the day after surgery. Amoxicillin and clavulanic acid\(^i\) (20 mg/kg/BID PO) were prescribed for seven days after surgery. The pin-skin interface was cleaned meticulously twice a day with a gauze sponge using a chlorhexidine\(^h\) solution (0.05%). The cranial cortical fragment of the tibia was gradually shifted cranially; the tibia transport started seven days postoperatively at a rate of 0.5 mm twice daily for seven days to obtain a bone graft segment measuring approximately 65 mm in length and 7 mm in width. The author performed all the bone-widening procedures. The pin sites remained clean and dry and the patient was able to walk during the treatment period; and there were no neurovascular problems. The cat had difficulty standing up from a lateral lying position due to the external skeletal fixators. Distraction was discontinued two weeks later after achieving the planned osteogenesis. The dynamic external skeletal fixator was removed at six weeks after a four-week consolidation phase. The bone formation was radiographically satisfactory for transport (▶Figure 3b, c). The lengthening index was 0.04 (0.25 months / 6.5 cm) while the external fixation index or healing index was 0.23 (1.5 months / 6.5 cm).

Bone transport

Surgical method

Once bone consolidation was radiographically complete, the external skeletal fixation frames were removed and bone transfer was performed. Premedication, induction, anaesthesia maintenance, analgesia and perioperative antibiotic were the same as for the bone widening surgery. A standard medial surgical approach to the left tibia was performed (22) (▶Figure 4a). A medial 93 mm long, 1.5 mm thick mini locking plate\(^j\) with six 2.5 mm locking head screws was applied to protect the tibial donor site (▶Figure 4b). The cranial edge of the plate was used to guide the oscillating saw blade during the osteotomy (▶Figure 4c). The bone graft was transferred to the right tibia and stabilized by means of a 100 mm long, 1.5 mm thick mini locking plate\(^k\) with six locking head screws and a precontoured mini plate (Fixin Straight Support, mini series, Ref. V2203: Intramia, Rivoli (Turin), Italy). The bone graft was stabilized with two 4.7 mm cancellous bone screws (Synulox: Zoetis S.r.l., Rome, Italy). The small 1.5 mm cortical cancellous bone screws were used to increase stability and promote bone remodeling. The bone transport was radiographically monitored to ensure adequate bone formation. The bone transport was monitored radiographically to ensure adequate bone formation. The bone transport was monitored radiographically to ensure adequate bone formation.

Figure 2

a) Mediolateral and b) caudocranial views of the left tibia showing the circular external fixator frame for used for bone widening.

Figure 3

a) Left tibia clinical aspect six weeks after surgery. Mediolateral view of the left tibia b) six weeks after surgery and c) after frame removal.

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\(^{h}\) Clorexzyderm: ICF, Palazzo Pignano (Cremona), Italy

\(^{i}\) Synulox: Zoetis S.r.l., Rome, Italy

\(^{j}\) Fixin Straight Support, mini series, Ref. V2203: Intramia, Rivoli (Turin), Italy

\(^{k}\) Ref. V2203: Intramia, Rivoli (Turin), Italy
2.5 mm and two 1.9 mm locking head screws. Silicate calcium phosphate bone graft substitute\(^{\text{k}}\) was applied at the bone-graft interfaces. Equine collagen sponges\(^{\text{l}}\) were used to fill the transport bone defect in the left tibia.

**Postoperative patient care and imaging**

Postoperative left tibial radiographs showed correct positioning of the plate (▶Figure 5 a, b). Postoperative right tibial radiographs showed fixation of the bone graft and acceptable alignment of the bone (▶Figure 5 c, d). Amoxicillin and clavulanic acid\(^{\text{k}}\) (20 mg/kg/BID PO) were prescribed for seven days after surgery. A bilateral Robert Jones bandage was applied to avoid postoperative oedema for 48 hours. The owners were trained to perform passive flexion and extension of the hip, stifle and tarsus twice a day, bilaterally, for four weeks, to prevent muscle contracture. Cage rest was recommended.

**Staged disassembly**

Six weeks after surgery there was no radiographic evidence of change in fracture alignment or implant failure bilaterally. At this time, staged disassembly was initiated as follows: screws 2, 3, 4 and 5 were removed from the left tibia, and screws 2 and 3 were removed from the right tibia. At 13 weeks the mediolateral view of the left tibia showed remodelling and thickening of the cranial cortex. Radiographs showed satisfactory healing of the right tibia with the bone graft successfully replacing the massive tibial bone loss. At 18 weeks, the remaining implants were removed from the left tibia, and screws 4, 5, 6 and 8 were removed from the right tibia. Right side implant removal was planned at 22 weeks. At this time, non-union and implant failure were diagnosed. Revision surgery was performed and a medial 63 mm long, 1.5 mm thick mini locking plate\(^{\text{n}}\) was implanted with three proximal and two distal 2.5 mm locking head screws. An autologous cancellous bone graft was collected from the proximal metaphyseal ipsilateral humeral head. Clinical and radiographic follow-up examinations were performed six and nine weeks post-revision. At 20 weeks, healing of the non-union was evident radiographically and the implants were removed.

**Outcome and long-term follow-up**

Twenty-seven months after bone transfer, the patient was able to fully bear weight bilaterally, and was fully active. At 12 and 27 months postoperatively, posture upon standing was normal. Goniometric measurement of passive range of motion in the unaffected left stifle and tarsus was unchanged from preoperative measurements (stifle range of motion = 140°, tarsal range of motion = 150°). Goniometric measurement of pass-

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\(^{\text{k}}\) Fixin Straight Support, mini series, Ref. V2202: Traumavet S.r.l., Rivoli (Turin), Italy

\(^{\text{l}}\) Actifuse™ ARX, Silicated Calcium Phosphate Bone Graft Substitute 80% Porosity: ApaTech Ltd, Borehamwood, UK

\(^{\text{m}}\) Cutanplast 20 standard: Mascia Brunelli SpA, Milan, Italy

\(^{\text{n}}\) Fixin Straight Support, mini series, Ref. V2102: Intrauma, Rivoli (To), Italy
ive passive range of motion on the affected stifle and tarsus could not be performed during the distraction and consolidation phases because of interference from the external skeletal fixation frame. At implant removal at 12 and 27 months postoperatively, right stifle passive range of motion was 130°, and right tarsal passive range of motion was 138° when measured in lateral recumbency. Twenty-seven months after bone transfer, radiographs showed adequate remodelling and reshaping of both tibias and radiographic signs of tarsus osteoarthritis (Figure 6). Right tibial length measured along the mechanical axis on the sagittal plane was 110 mm. Three and a half years after surgery the situation was unchanged both clinically and radiographically. Long-term follow-up was obtained by telephone five years after surgery. The cat was living a normal life indoors and outdoors.

Discussion

Autogenous bone grafts provide support, fill gaps, and enhance biological repair of skeletal defects. Limitations include additional operative time for graft harvest, donor site morbidity, graft resorption, moulding challenges, and limited availability.

We elected to use contralateral tibial widening and transfer rather than single or double longitudinal tibial bone transport with the Ilizarov method, because of the massive tibial bone loss (48%). In addition, the time required for lengthening would have been excessive, increasing the risk of failure and complications. Tibial widening and transfer was also chosen for two more reasons: 1) the residual tibia was unsuitable for lengthening due to poor local bone conditions; 2) a previous attempt to lengthen the tibia failed to replace the bone lost due to inadequate bone regeneration.

Conventional tibial lengthening by means of distraction osteogenesis was attempted but failed due to inadequate bone regeneration probably caused by poor bone quality. Poor bone quality is generally the result of tissue devascularisation. Degeneration might have resulted from the numerous surgeries performed to treat both the fracture and, later, the non-union. The failure rate for distraction osteogenesis was reported as 10% in a review of complications in 100 consecutive cases of longitudinal bone transport in humans (23).

The healing index (total treatment time in months divided by total length gained in centimetres) is a measure of the efficiency of bone lengthening, where a lower index value indicates a faster, more efficient lengthening treatment (24). The index has been reported as approximately 0.5 month/cm in immature to young adult dogs undergoing correction of antebrachial deformities or femoral lengthening (24, 25). A healing index of 0.2 was reported in a four-month-old puppy undergoing femoral alignment and lengthening, with a short latency period (3 days), faster lengthening rate (3 mm/day for three weeks), and a short consolidation phase (7 days) (26).

In this patient, the healing index was 0.23 month/cm. The rapid healing index was due to the longitudinal, rather than transversal, osteotomy, which effectively enlarged a long bone segment rather than lengthening a short one.

Delayed distraction in bone lengthening of lamb limbs was reported to improve the quality of the regenerated bone, with quicker, denser and more homogeneous bone formation (27). In general, a latency period of seven or more days has been recommended for lengthening long bones in most species even though clinical success with a latency of zero to three days has been reported in dogs (24-30). In retrospect, the rapid formation of regenerated bone in this patient suggests that a shorter latency period might have been biologically necessary. A shorter latency period would have lowered the healing index even further.

A distraction rate of 1 mm/day is commonly reported for humans, dogs and other species (3, 27, 28, 31, 32). Ilizarov reported that a rate of 1 mm/day led to more favourable healing than either slower or faster rates in a canine tibial model (2). Slower rates were associated with premature consolidation whereas faster rates resulted in retarded osteogenesis or detrimental changes in the surrounding soft tissues (2). There are, however, previous reports of clinical success with distraction rates as high as 3 mm/day in the femur, tibia, and radius-ulna of dogs (24–26, 33).

The limitation of using higher distraction rates arises from soft tissue concerns (myotendinous and nervous units) rather than the bone. In adult mongrel dogs, 45–48 days after 14–16% lengthening,
there was evidence of reversible histological transformations of the structure of some spinal ganglia neurons. The changes were most remarkable in the ganglia of limbs lengthened at a rate of 3 mm/day while lesser changes were seen in limbs lengthened at a rate of 1 mm/day (34). Further investigations would help assess distraction rate limits in cats. Potential soft tissue concerns were allayed by lengthening the bone on the transverse plane (bone widening technique).

In the end, the right tibia was shorter than the contralateral tibia (11%). Changes in posture were minimally apparent at our follow-up examinations. Dogs can compensate for up to 20% loss of femoral length by extending the stifle and the hock joints (35). Cats may also make a similar adaptation.

The number of screws in the plate on either side of the fracture line significantly affects the rigidity of the construct (36). Screws can be removed from the locking bone plate to permit incremental decreases in fixation stiffness (37). This is similar to the principles of external skeletal fixation disassembly (38, 39). The less rigid external skeletal fixation stimulates bone formation and healing (40). Staged removal of external skeletal fixation should begin six weeks after surgery or as soon as immature bridging callus is evident radiographically (41).

From the start of the disassembly procedure, the bone transplant appeared to be incorporated. It is possible, however, that the bone substitute was masking the healing of the transplant and that its proximal position was only simulating healing.

Positioning the cat for surgery in dorsal recumbency allowed the surgeon to approach the medial, cranial or lateral aspect of the tibia, as required, and for the stifle and hock to be flexed and extended to check that the Ilizarov apparatus was not impinging on the soft tissues or touching the contralateral Ilizarov device during the bone widening surgery.

Contralateral tibial widening and transfer involve considerable risk as it may damage the unaffected limb. Complications such as infection, nerve injury and ankle instability on the contralateral, previously unaffected, limb are described in fibular grafting and cortical bone transportation in humans (18, 21).

Ipsilateral fibular transport with the Ilizarov frame has been described in the human literature to treat wide tibial bone defects (42). The cat and dog fibula are too thin to allow for longitudinal osteotomy, wire-fixation and widening.

The mean normal full range of motion of the feline stifle joint is around 140°, from 159–164° in full extension to 21–24° in full flexion. The mean normal full range of motion of the feline tarsal joint is around 148°, from 168° in full extension to 20° in full flexion (43). The right limb displayed a 10° loss of passive range of motion at the stifle and a 12° loss at the tarsal joint. A correlation between predicted loss of stifle flexion-extension and final length of quadriceps-hamstring muscle groups has been reported in humans (44). In this case, the length of the treated tibia never changed, making it likely that the loss of range of motion was due to underuse of the limb or osteoarthritis of the tarsal joint.

The method of contralateral tibial widening and transfer was technically demanding, requiring multiple surgeries and entailed the risk of complications that may occur even when performed by experienced orthopaedic surgeons. However, the technique was a successful method in this patient with massive bone loss. This option might also be considered to manage huge bone loss following primary bone tumour resection.

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Conflict of interest
There are no conflicts of interest to declare.

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