DISTAL EXTREMITY INJURIES
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Injuries of the distal extremities in dogs and cats frequently involve significant skin disruption/de-gloving or deficits and sometimes significant soft tissue loss. Salvage is dependent on ability to retain weight-bearing capability with functional pad tissue, appropriate neuro-vascular supply and adequate digital and meta-carpal or meta-tarsal bone stock for transfer of ground reaction forces to the limb. Minimising propensity for on-going pain and optimising functional capability are key goals and these injuries can be career-ending for some working dogs, or at least lifestyle changing for many dogs and cats.

Various skin and soft tissue reconstruction techniques such as podoplasty, digital pad transfer, muscle and skin grafts can be effectively employed and are well described in the veterinary literature, as are multiple fracture and joint reconstruction techniques. The percentage of circumferential injury where second intention healing or skin-stretching techniques prior to secondary closure can be utilized is 30%. Free skin grafts can be used to facilitate wound resolution once sufficient debridement and preparation of a good quality granulation bed has taken place. The reverse saphenous conduit flap is useful for treatment of wounds involving the tarsus and metatarsus. A prerequisite for the success of this flap is the absence of trauma to the medial saphenous vascular system as well as maintenance of the deep vascular structures of the metatarsus and paw. Hinge or pouch flaps, where the limb is inserted in a pocket of skin on the flank of the animal can be useful in the management of distal limb traumas where significant soft tissue injury is involved. However, these flaps require on-going patient hospitalization and patient compliance can be a problem. Microvascular free tissue transfer can also be implemented in the treatment of distal limb soft tissue deficits but specialist training and equipment and is required.

Crush injuries are a particular challenge and various novel external frames may be very helpful for supporting osseous structures and also facilitating appropriate wound care with topical hydrogels and dressings. Vacuum-assisted closure is also a recently-available and very valuable adjunct to facilitate functional recovery of skin and soft-tissue. The aim of this presentation is to present some advances in treatment options for challenging distal limb trauma. Some examples are listed.

Tarsocrural disruption: Minimally Invasive Plate Arthrodesis (MIPA)

In extremely distal tibial fractures, and in other cases of tarsal injury (including talo-crural luxations, shearing injuries, articular talar fractures, tibial articular fractures), pantarsal arthrodesis may be indicated, and this can be technically challenging, particularly in cats or toy breed dogs. Dorsal plate application is technically simplest but is mechanically unfavourable, being on the compression surface of the hock joint. The author has developed a pre-contoured tapered extended length plate with ovoid holes adjacent to the talocrural joint allowing for greater screw angulation and aiding placement of at least one screw through the plate into the calcaneus (FitzPTA plate - canine). This implant facilitates a minimally invasive approach (minimally invasive plate arthrodesis, MIPA) and appropriate tibio-tarso-metatarsal alignment. Documented clinical outcomes have been favourable. The author has experienced challenges with metatarsal anchorage and stress-risers using medially-applied plates. In cats the author has previously harnessed the biomechanical benefits of plate-rod stabilization by application of the Acutrak Fusion™ screw (Acumed, Hillsboro, Oregon, USA) as an intra-medullary calcaneo-talo-tibial rod in conjunction with dorsal 2.0 mm plate and screw application with excellent results in a large number of cats while avoiding issues with soft tissue implant coverage. Although associated with good outcomes the procedure can be technically challenging and thus a new hybrid 2.4/2.0 dorsal hybrid tapered plate has been developed (FitzPTA plate - feline) which is biomechanically resilient and has yielded very favourable results. Freeze dried allograft bone chips or autograft may be used to augment healing.

In some situations with specific paucity of soft-tissue cover, custom external skeletal fixation with combined intramedullary pin and pin-arch constructs have been successfully employed. The author favours pin-arch constructs for this region in preference to wire-ring fixators which are time-consuming to apply and type II fixators which employ pins across the narrow ovoid cross-section of
the distal tibia and may transfix excessive muscle mass at the proximal tibia. On occasion a custom locking intramedullary pin has also been employed for arthrodesis where soft-tissue cover is problematic.

In the thoracic limb, MIPA dorsal or medial plate application is favoured for pancarpal arthrodesis.

**Multiple Metacarpal & Metatarsal Fractures: SPIDER**

Metatarsal and metacarpal injuries account for 8.1% and 3.3% of fractures in dogs and cats respectively. Various management techniques are reported (including plates, screws, pins, wires, dowel pins, and external fixation devices) but selection guidelines, pre-operative planning and validated outcome measures are lacking. Restriction of physical exercise or external coaptation may be adequate for minimally displaced and solitary metacarpal or metatarsal injuries, particularly of digits 2 and 5, but in the majority of clinical circumstances, surgical intervention is indicated. A novel, inexpensive ESF (Secured Pin Intramedullary Dorsal Epoxy Resin, SPIDER) frame has been designed for stabilization of metacarpal and metatarsal fractures and subsequently adapted to allow for management of metacarpo- or metatarso-phalangeal luxations and for tarsometatarsal arthrodesis. Anatomical landmarks were established and techniques for pin placement to optimize biologic fixation principles were elucidated. SPIDER technique is sufficiently robust to avoid requirement for post-operative external coaptation, which has been implicated as a significant cause of morbidity. Lack of requirement for coaptation also facilitates management of concomitant soft tissue injuries which are common with fractures and luxations in this location. Implant removal is straightforward and can be performed under sedation without an additional sterile surgical procedure.

Surgical technique entails a single midline dorsal incision directly over the site of fracture or luxation. Where arthrodesis is required (e.g. of a tarso-metatarsal joint), articular cartilage should be removed and autogenous cancellous bone graft applied. K-wires (50%-75% medullary diameter) are directed retrograde through the fractures or luxations to exit the metatarsal or metacarpal bones at the dorsal aspects of the distal articular surfaces. Fractures or luxations are then manually reduced and the k-wires driven proximally into the proximal metacarpal or metatarsal bones (and through the tarsometatarsal joints or carpo-metacarpal joints where arthrodesis at this level is indicated). One or two K-wires are then placed transversely across the bases of the metatarsal/metacarpal bones or distal row of tarsal bones and calcaneal base or carpal bones. All exposed pin ends are finally bent dorsally such that they converge over the dorsal aspect of the pes or manus. The surgical site can be closed routinely prior to application of epoxy resin which is compressed over the ends of the K-wires (additional contouring of the k-wires at this site may improve stability of the epoxy resin bolus). Wooden spatulas (to a thickness of 4-10mm) are placed between the epoxy resin bolus and the patient skin surface to avoid thermal injury during resin curing, and to allow for postoperative swelling.

Cage confinement or equivalent is routinely enforced for 4-6 weeks depending on predicted rate of healing (based on injury and patient factors). Frame removal can be performed upon documentation of radiographic union. Twelve month post-operative evaluation in general did not reveal radiographic progression of osteoarthritis of metatarso/metacarpo-phalangeal joints or clinical discomfort.

**Distraction-Compression Osteo-Integration (DCOI)**

Non-union following fracture repair or primary loss of significant MT or MC bone stock due to trauma is uncommon and may be associated with infection, inadequate blood supply and shearing injuries. Revision surgical procedures can compound the underlying reason for suboptimal bone healing by further compromising the biologic envelope. The author has operated a number of cases of fracture non-union or massive traumatic bone loss including canine and feline femora, canine tibiae
and canine manus/pes using a novel biologic stimulation technique featuring sequential distraction and compression in order to stimulate incorporation of large cortico-cancellous autogenous bone graft blocks. This technique was developed from reports of cyclical distraction and compression in humans for successful treatment of non-unions of femoral fractures.

The technique, termed DCOI, uses autogenous cortico-cancellous bone blocks to fill the bone defects. The bone blocks are generally autogenous coccygeal vertebrae (or less commonly blocks from the iliac crest and wing). These are incorporated into the defect by being “skewered” onto kirschner wires which themselves are placed as intramedullary pins across the fracture defect. Additional autogenous cancellous bone graft is placed and the fractures and bone defects stabilized using modified hybrid circular pin-arch external skeletal fixator constructs. Dynamic phases of distraction and compression are performed daily for several weeks to enhance bone regeneration and to promote incorporation of the autogenous cortical bone blocks into the defects. The majority of the cases that we have treated had undergone multiple previous surgical procedures, with many associated complications prior to presentation and the DCOI technique was employed as a last resort before considering amputation.

The use of bone morphogenic proteins (BMP) is becoming more common for management and prevention of non-unions within human and veterinary orthopaedics. As availability increases and costs decrease the prophylactic use of BMP in complex distal limb fractures may become ubiquitous.

Pedal Arch Wire Scaffold (PAWS)

The author has encountered a number of cases of multiple MC- or MT-phalangeal luxation, in conjunction with either infectious arthritis or severe soft tissue injury. In this circumstance, skewer wires can be used to facilitate stability or phalangeal arthrodesis and if protection from weight-bearing is required for healing, a customized wire-arch hybrid frame can be constructed which allows ambulation on metal arches whilst providing a “tent” for healing, dressing of pad or palmar/plantar lesions or abscess-drainage. This technique has also been applied for management of trophic ulceration of bilateral pelvic limb pads secondary to spinal disease, and by a colleague for management of severe acid burns of all paw pads of three feet. The walking external fixation frame, transmits load bearing forces directly to the appendicular skeleton, by-passing the pads and other soft tissues of the paw.

Intraosseous Transcutaneous Amputation Prosthesis (ITAP™)

Where irreparable neuro-vascular trauma accompanies osseous compromise and amputation is required, recent advances in prostheses now prompt consideration of partial limb amputation and application of ITAP. The ITAP was developed for use in the human digit to circumvent challenges associated with stump-socket prostheses or with skin-implant interfaces and was inspired by deer antler, where the bone-pedicle continuously remodels throughout the antler cycle whilst the dermal tissues are adherent to the osseous structure with sufficient strength to prevent infection, marsupialization and ultimate failure of the soft-hard tissue interface. ITAP successfully applied ultrastructural geometry gleaned from this natural biomimetic model to create a soft tissue-implant interface which acts as a barrier to exogenous agents, and in particular prevents epithelial down growth, providing a resilient anchor for attachment of an appropriate exoprosthesis.

ITAP comprises a titanium alloy stem for intraosseous (intramedullary) press-fit placement, a perforated umbrella-shaped flange seated subcutaneously for skin in-growth and a distal extracutaneous peg that functions as a link between the stem and flange portion and the exoprosthesis attachment. The three ITAP components are custom manufactured on an individual-patient basis as a single integrated unit and each subunit has specialized biological and/or mechanical properties to meet their required functions.

The author has had success in application of these prostheses in distal thoracic and pelvic limbs in both cats and dogs. Iterations of exoprostheses are rapidly evolving for both human and canine limb-salvage, and subsequent to our initial case series, application of the endoprosthesis in select human amputees is now underway. Most recently, application of the prosthesis to the calcaneus has resulted in near-normal gait pattern for dogs with sub-talar amputation and for a cat with bilateral sub-talar amputation in conjunction with custom-engineered exoprosthetic blades.
References