Fracture of the Long Bones

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Fracture management in alpacas and llamas presents a unique and interesting challenge to the veterinary surgeon. The increasing popularity of camelids in North America means veterinarians are more likely to see them as patients; therefore, dealing with camelid fractures is quickly becoming part of the normal caseload. Because of the relatively high commercial value of most camelids, clients will usually be willing to pursue treatment.

Camelids are considered to be excellent patients for the treatment of orthopedic injuries because of their relative low body weight, their ability to ambulate on three legs postoperatively, and tolerate external coaptation devices and prolonged periods of recumbency for recuperation after surgery.[27] For these reasons, the veterinary surgeon has a full repertoire of repair techniques available to choose from when determining the ideal repair option. Not surprisingly, the scientific literature has lagged behind the relatively rapid rise in camelid popularity; there are currently 62 case reports on camelid long bone fracture fixation.[1,7-12,17,19-28] This paper will review the published literature on the management of long bone fractures. Fracture management includes the preoperative, intraoperative and postoperative time periods. Emergency treatment, clinical workup, principles of fracture repair, treatment, and prognosis for specific long bone fractures and their complications will be discussed.

Diagnosis

The hallmark clinical sign of a limb fracture is a non-weight-bearing lameness; however, other differential diagnoses need also be considered.[9] Other clinical signs include swelling, pain, and crepitation at the fracture. In the author's experience, fractures involving the femoral head tend to be more subtle, since some weight bearing is possible. The neurovascular supply to the distal limb must be assessed prior to surgery to critically evaluate for neural or vascular compromise. Compromise to these structures can have a significant impact on the success of any fracture repair and may change the treatment options. Good quality radiographs of at least two orthogonal views are required to properly access the configuration of the fracture in order to determine repair options. Proper patient positioning and a good technique chart are fundamental in producing good quality radiographs. Open or closed fractures, hairline or non-displaced fractures, the degree of comminution, or joint surface involvement will have a significant bearing on the fixation method that is ultimately chosen to provide the best option. Sedation, using xylazine hydrochloride (alpacas 0.3 mg/kg IV, llamas 0.2 mg/kg IV), can facilitate patient positioning during radiographs and therefore prevent further soft tissue damage and result in better quality radiographs. Though xylazine is reported to be contraindicated in pregnant animals since it may precipitate early parturition during the third trimester, the authors have not observed any pregnancy complications associated with the use of xylazine. In the event of insufficient sedation achieved using xylazine alone, butorphanol tartrate (0.05 mg/kg IV or 0.1 IM/SQ) can be added to provide greater analgesia.

Patient Care During Recovery from Fracture

Postoperative management

Postoperative management plays a crucial role in the success of fracture healing, and cannot be emphasized enough. Though the surgery may have been successful, improper management of the patient postoperatively can lead to frustrating complications: implant failure, re-fractures, cast sores, and nerve damage have been reported in the literature. Fortunately, we have observed these complications rarely. Regardless, a second repair attempt increases expenses and potential for complications, therefore decreasing the likelihood for a successful outcome.

The type and duration of antibiotic therapy is determined on a case-by-case basis. Open fractures, the greater degree of soft tissue damage and fracture comminution typically require longer periods of antibiotic therapy, compared to simple closed fractures. Postoperative analgesia is predominantly provided by using non-steroidal anti-inflammatories (NSAIDs) such as flunixin meglumine, phenylbutazone, and etodolac (Etogesic®). The use of NSAIDs is not without some risks, including gastrointestinal ulceration (ie: C3), delayed bone healing, and kidney failure. The prolonged use of NSAIDs should be under veterinary guidance. The cardinal signs of adverse effects include inappetence, oral ulceration, and edema formation. Opioids, such as butorphanol or fentanyl transdermal patches, may be used to provide more potent analgesia during the immediate postoperative period in selected cases.

The length of hospitalization varies on a case-by-case basis. Depending on the fracture configuration and the inherent strength of the repair method, a couple of days hospitalization may be all that is required. Postoperative transportation represents an additional challenge that requires additional planning and careful thought. Though most patients may lie down during transportation, they should be transported in a separate compartment away from direct contact with herd mates. There are some situations when prolonged hospitalization is required until sufficient callus has formed, or to allow intensive wound management for open fractures. The disadvantages of prolonged hospitalization include increased costs and patient stress. Stress associated with the initial injury and prolonged hospitalization in a strange environment may predispose the development of complications, including inappetence (ie: stall sickness) and gastric ulceration. The use of NSAIDs can compound the risks of these complications developing. The oral administration of omeprazole may help reduce the formation of gastric ulcers; however, the efficacy of oral omeprazole in camelids has recently been questioned.[28] A quiet, docile companion during hospitalization may help prevent the development of stall sickness, improve appetite, and may even reduce stress.

The patient's activity after surgery and throughout the convalescent period must be restricted. A small, dry, well bedded and ventilated stall that is protected from the elements is ideal. Limited outside access is permitted, provided it is dry and the area small. The affected limb should be inspected daily for use, warmth, signs of swelling, and surgical site infection. If the patient suddenly stops using the affected limb, or there is a sudden change in appearance, swelling, or pain tolerance, veterinary attention is required, since these signs indicate complications. Bandages, when used, need to be kept dry; wet bandages can cause severe skin irritation and infection. Bandages can get wet less obviously by wicking moisture directly from the ground. Ideally, bandage changes can be done on the farm by the client. On rare occasions, the referring veterinarian may need to facilitate bandage changes, especially if sedation is required.

The timing and frequency of follow-up visits is determined on a case-by-case basis. Follow-up visits are important since they allow assessment of the healing fracture, modification or alteration of the repair (cast or splint changes, staged destabilization), and ideally, identify potential complications before they occur. Radiographs are often used to objectively assess fracture healing. Radiographic union (defined as bone union with resolution of the fracture line) lags behind clinical union (defined as sufficient bridging callus to allow weight bearing without additional support to the limb) by a minimum of two weeks. Follow-up visits permit informed decision-making regarding the timing of cast, splint, external skeletal fixation (ESF), and/or implant removal sequentially over time to gradually increase the weight bearing of the affected limb, and clinical union. Usually, two additional weeks of stall rest is recommended after clinical union has occurred before the patient may safely reintegrate with the herd.

Complications

The perceived incidence of morbidity and mortality associated with camelid fractures is now believed to be higher than what previously published case reports have suggested.[17,22] Possible explanations for this apparent increased incidence include the reporting of more subtle complications combined with long-term follow-up, the attempted repair of more complicated fractures by surgeons, and case report bias. Similar to other species, complications of fracture repair include malunion, delayed union, non-union, osteomyelitis, implant failure, sequestrum formation, and disuse osteopenia.[7,17,20-22,26] Unlike in other species, soft tissue complications also include chronic lameness, hyperextension, osteoarthritis, and were more common than implant failure.[22] If the patient suddenly stops using the affected limb, or there is a sudden change in appearance, swelling, and pain tolerance, veterinary attention is immediately required, since these signs indicate complications. The incidence of complications was not affected by the fixation method.[1]

Open fractures are more likely to have complications such as osteomyelitis, compared to closed fractures.[22] Non-union due to the presence of osteomyelitis is a frustrating and expensive complication. Successful management requires rigid stabilization, and often requires a second surgery to débride and to place an autogenous cancellous bone graft.[21,22] Typically these cases also require prolonged parenteral antibiotics. Culture and antimicrobial sensitivity testing may be useful for determining antibiotic therapy. Antibiotic-impregnated polymethylmethacrylate (PMMA) beads placed adjacent to the site of infection may be useful, based on the author's clinical impressions.

On occasions when the fractured limb is unable to be repaired, amputation may become a viable option and is well tolerated by camelids in our experience and others.[27] Camelids tend to be amenable to prosthetic limbs in our experience and others;[27] however, excellent client compliance is a necessary prerequisite to ensure success.

Repair Techniques for Specific Fractures

Metacarpal and metatarsal

Ideally the fracture configuration of metacarpal/metatarsal fractures determines the best repair option(s); however financial limitations and the surgeon's preference may also be determining factors. External fixation techniques include cast,[12] transfixation cast,[8] ESF,[24] and circular ESF (CESF).[21] Internal fixation technique is currently limited to dynamic compression plating (DCP);[10,28] however, newer implants including limited contact dynamic compression plating (LC-DCP), and locking compression plate (LCP) may become readily available in the future. A cast, with the leg placed in flexion, was used to repair a proximal comminuted metacarpal fracture in an adult male llama.[12] Limited extension of the distal limb was possible when the cast was removed at eight weeks; however, full mobility returned later.[12] Transfixation casts were used to repair metacarpal fractures in three llamas,[8] including one 18-month-old female with bilateral metacarpal fractures.[8] Depending on the fracture configuration, it may be beneficial to place a pin through unaffected bone either proximal or distal to the fracture,[8] thus facilitating repair without open reduction.[9] A single DCP has been used in six alpacas,[10,22,24,26,28] including a six-year-old pregnant female;[24] however, a fissure detected on postoperative radiographs became a complete fracture when re-evaluated 14 days later.[24] Osteomyelitis was also believed to be a contributing factor to the initial implant failure. The plate and screws were removed, and a Type 1B ESF was placed on the palmar aspect of the limb in order to permit full carpal flexion for kneeling. The ESF was destabilized in stages, beginning at seven weeks and ending 10 weeks after surgery. This alpaca was clinically sound four weeks after removal of the ESF.[24] Two DCP were used to repair an open metatarsal fracture in a three-year-old female alpaca.[22]

Complications were not observed in nine cases.[8,10,12,22,26,28] Complications associated with fractures of the metacarpal/metatarsal bones included fracture displacement,[21] implant failure,[24] osteomyelitis,[22,24] pin loosening,[8] delayed union,[8] non-union,[22] mild lameness,[22] carpal hyperextension,[22] and metatarsophalangeal hyperextension in the contralateral limb.[22] A closed, comminuted diaphyseal metatarsal fracture in a three-year-old male alpaca was initially repaired using a cast.[21] Radiographic evidence of inadequate stabilization was present five days after surgery. The cast was removed seven days after surgery and a circular external fixator was applied; healing progressed uneventfully.[21] Pin loosening in transfixation cast and ESF constructs is caused by infection of the pin tract, thermal necrosis to the adjacent bone during pin insertion, or pin motion. The carpal hyperextension resolved by bandaging the affected limb for four weeks.[22] Infection and non-union were complications associated with an open metatarsal fracture in a 10-year-old intact male llama which was euthanized 41 days after surgery.[22]

The surgical treatment for closed metacarpal/metatarsal fractures should have a good prognosis provided the neurovascular supply to the distal limb is not compromised. Complications are more likely encountered with open metacarpal/metatarsal fractures.[22] The surgical treatment for open metacarpal/metatarsal fractures should have a fair prognosis in the author's experience if rigid stabilization using either an ESF or CESF is provided, and antibiotic-impregnated PMMA beads and autogenous bone grafts are used to manage osteomyelitis; however, these cases also tend to require multiple surgeries and a financially committed owner.

Humerus

With the humerus, fracture configuration determines the best repair options. Fractures of the humerus have been managed conservatively with stall confinement[27] or with internal fixation.[7,17,20,27] Internal fixation avoids complications associated with stall rest, including limb contracture, delayed union, and malunion.[27] Intramedullary pins and cerclage are ideally suited for long oblique fractures.[17,20] In selected cases (i.e. crias), the IM pin has been substituted for cortex screws; however, a Valpeau sling was used for additional support.[17] Depending on the fracture configuration, another repair option for humeral fractures would be an IM interlocking nail.[20] The caudal cortex must be intact when considering internal fixation using a plate(s). The integrity of the radial nerve should be assessed prior to surgery, since it is prone to damage associated with diaphyseal fractures. Furthermore, special attention must be given to the radial nerve during open reduction as it is located between the brachialis muscle and the mid-diaphyseal region of the humerus, and can be easily damaged. In select cases of long, spiral fractures of the humerus, the authors have used lag-screw fixation for stabilization of the fracture.

Specific complications associated with using a single DCP without additional support have included carpal contractual deformity due to implant failure (plate bending and partial pull out of cortical screws) five days after fracture repair,[7] and a new fracture occurring distal to the DCP that resulted in limb amputation.[27] In the one case, a substantial delay prior to surgical repair may have contributed to postoperative complications, including worsening of a carpal contractual deformity (no evidence of radial nerve paralysis was observed), non-use of the affected limb, and implant failure five days after surgery.[22] The bent plate was left in place at the owner's request, and the fracture healed. Though long-term passive flexion and extension of the carpus did resolve the carpal contractual deformity, a chronic lameness persisted.[22] No complications were observed when a full-limb fiberglass cast supplemented the internal fixation using a single DCP plate for a comminuted mid-diaphyseal fracture in a five-year-old male castrated alpaca.[17] In two adult llamas, two DCP were used to repair fractures of the humerus.[20]

Complications were not observed in seven cases.[17,20] Complications associated with humeral fracture repair are common, including permanent radial nerve damage, temporary radial neuropraxia, osteomyelitis, implant failure, and limb amputation;[7,17,20,22,27] one llama was euthanatized four weeks post-surgery due to chronic osteomyelitis.[20] The surgical treatment for humeral fractures in camelids should have a good prognosis.[17]

Radius / Ulna

Both internal and external fixation techniques have been used to repair fractures of the radius/ulna. Ideally the fracture configuration determines the best repair option(s); however, surgeon's preference may also be a determining factor. Though IM pins are not an option for repairing radial and ulnar fractures, the location of these bones allows for external skeletal fixators. Transfixation casts have been used successfully to repair fractures of the radius and ulna.[8,22] Open reduction of the articular surface of the proximal radius using lag screws combined with a transfixation cast has also been used; however, the development of degenerative osteoarthritis in the humeral/radial joint can result in chronic severe lameness.[22] Closed fractures of the radius and ulna have been typically repaired using either a single DCP with additional external support (ie: Robert Jones bandage or splint)[7,19,26] or two DCP.[25] A small wound along the dorsal aspect of the mid antebrachium did not adversely affect the repair using a single DCP in a young cria.[26]

Fractures involving the proximal radius may result in radial nerve damage, and this was observed in at least two cases.[22,26] Temporary radial neuropraxia was observed after removal of the transfixation pins in another case.[14] No complications were observed in four cases.[8,19,22,25] The surgical treatment for radius and ulnar fractures in camelids should have a good prognosis provided the radial nerve and articular joints are not involved.

Femur

Though most femur fractures likely arise from trauma, a pathological fracture developed at the sequestrum site seven days after sequestrectomy,[7] and adjacent to multifocal polyostotic aneurysmal bone cysts in a three-year-old llama.[1] Both modified dynamic IM cross pins and crossed Steinman pins have been used to repair physeal fractures of the distal femur in several crias.[23,27] Simple, long oblique, diaphyseal fractures may be repaired using IM pin and cerclage wires. In contrast, short oblique or transverse fractures are likely better candidates for DCP or IM interlocking nails. Most femur fractures have been repaired with mixed results using either intramedullary pins[1,9,23] or DCP.[7,9] An IM interlocking nail was used (with some difficulty due to size limitations of the IM interlocking nail equipment) to repair a comminuted diaphyseal fracture in a three-year-old female alpaca without complications.[11] The availability of an appropriately sized IM interlocking nail (the availability of appropriate stable bone stock at either end of the femur) and newer plate designs may potentially improve the surgical treatment and success of femur fractures in both immature and mature camelids.

Complications were observed in all but three cases[11,23] and included pin migration, implant/bone failure, osteomyelitis, peroneal nerve damage, and chronic lameness.[7,22,23] A one-month-old cria died during recovery due to pulmonary edema of undetermined etiology.[23] Malunion of a femoral neck fracture was treated by performing a femoral head arthroplasty; however, this treatment option was not well tolerated and resulted in a non-functional limb that later required amputation.[27] Another limb was amputated due to complications that arose after an attempted femoral fracture repair; complications (immobility and a ruptured bladder) developed post-operatively resulting in euthanasia.[22] Amputation of the hind limb appears to be well tolerated by camelids[27] and should be considered as an alternative to euthanasia, in the author's experiences. Catastrophic failure of the femur distal to the DCP occurred 17 days after surgery in a four-year-old male alpaca, and this alpaca was euthanized due to the poor prognosis.[23] An incisional infection without radiographic evidence of bone/implant involvement 14 days after surgery was flushed with chlorhexidine solution; however, multiple draining tracts originating from the implants were observed six months later.[7] This infection resolved without complications after implant removal and antimicrobial therapy.[7] The majority of case reports on femur fracture repairs are in younger (< 1 yr) camelids where the softer bone density and thinner cortices compared to older camelids tend to make fracture repair difficult. A four-day-old male alpaca cria underwent a second surgery to replace the initial repair due to IM pin backout with a DCP. The degree of comminution, eburnation, and loss of bone stock led to a second implant failure in the distal bone fragment, and the cria was euthanized two days postoperatively.[22] The presence of multifocal polyostotic aneurysmal bone cysts caused implant failure and a new, comminuted femur fracture of the proximal metaphysis and neck in a 3.3-year-old male llama; this llama was euthanized due to the grave prognosis.[1]

The surgical treatment of distal physeal fracture of the femur in immature camelids should have a good prognosis. The surgical treatment of metaphyseal and diaphyseal fractures of the femur should have a guarded prognosis.

Tibia

Tibial fractures can be treated solely by stall confinement,[7] or repaired using either transfixation pins and cast application,[9] IM pins,[9] DCP,[7,9] or IM interlocking nails[9] depending on the fracture configuration. Stall confinement was used successfully to manage a complete, non-displaced dorsal cortical fracture.[7] Full limb casts applied to the hind leg do not allow full range of motion, and may predispose rupturing the peroneus tertius tendon. Simple, long oblique, diaphyseal fractures of the tibia may be repaired using an IM pin and cerclage wire. In contrast, shorter oblique or transverse diaphyseal fractures of the tibia may be repaired using either an ESF, transfixation cast, or DCP, depending on the fracture configuration and surgeon's preference. Comminuted diaphyseal fractures of the tibia may be repaired using an ESF, transfixation cast, DCP, or IM interlocking nail in selected cases based on the fracture configuration and the surgeon's preference.

Complications were not observed in four cases.[7,22] Complications associated with repairs of the tibia include cast sores, slow fracture healing, peroneus tertius rupture, osteomyelitis, sequestra, peroneal nerve damage, hyperextension of the metatarsophalangeal joint, and fracture displacement.[22] There were no known instances of implant failure.[7,9,22] Only one case resulted in euthanasia due to complications.[7] The surgical treatment of diaphyseal fractures of the tibia should have a good prognosis.

Treatment Methods for Fractures

Fracture repair

The location of the fracture, the degree of soft tissue and neurovascular damage, open or closed fracture environment, patient temperament, budget, and the experience of the surgeon are important factors to consider when selecting the type of fracture repair.[3] Furthermore, the AO/ASIF techniques utilized in both small and large animals are well adapted to camelids.[27] The surgical approaches for each bone have been previously described in the literature.[1,7,8,10,11,17,19,21,23,24,26-28]

Due to their comparative size, orthopedic implants suitable for small animal patients are more appropriate than those used in large animals.[27] The methods of repair can be divided into either external or internal fixation techniques. External fixation techniques include the use of casts, splints (Schroeder-Thomas, and spica), transfixation cast, and an external skeletal fixator (ESF). Internal fixation techniques include the use of cerclage wire, screws, intramedullary pins, plates, and the intramedullary interlocking nail. External support using a cast, splint, Robert Jones bandage, or Velpeau sling is frequently used to protect internal fixation techniques.

The advantages of internal fixation include superior fracture alignment and anatomical reconstruction, which should result in optimal long-term outcomes. The disadvantages of internal fixation include increased costs and complications associated with anesthesia, surgery, and implants. Often a second surgery is required to remove the implants after healing. The advantages of external fixation include more flexibility in repair, wound management for open fractures, and usually less anesthesia, surgery, and implant costs. The disadvantages of external fixation include malalignment, delayed union, and non-union. Camelid fractures repaired using either internal or external fixation were observed to have similar morbidity rates.[22] By being familiar with the various repair techniques, including their associated strengths and weaknesses, the veterinarian can recommend the ideal repair technique on a case-by-case basis.

Alpacas and llamas tolerate casts quite well. Fiberglass is the preferred casting material since it is easier to work with, stronger, and much more resistant to environmental conditions after application compared to plaster of Paris. The limb must be padded using either the traditional stockinet or the newer foam resin. The potential pressure points of the limb (accessory carpal bone, calcaneus, talus, and the proximal sesamoid bones) should be carefully padded. Foam resin offers superior padding as it conforms to the limb without excessive bulking. Excessive padding is contraindicated since it can become compressed with time, which would leave room for the limb to move within the cast; therefore, increasing the risk of fracture displacement and possibly the development of an open fracture. Care must be taken not to leave finger impressions in either the resin foam or the fiberglass during cast application, since these may cause cast sores. Casts typically require six to eight layers of fiberglass to be sufficiently thick to provide adequate immobilization. The foot is always included in the cast, with the toes extended. Polymethylmethacrylate (PMMA) is used to coat the cast surface in contact with the floor to protect the fiberglass from abrasion.

A cast may be either a full-limb or a half-limb, depending on the fracture location and configuration. Full-limb casts may be used to immobilize fractures up to the proximal metacarpal or metatarsal bones. Half-limb casts may be used to immobilize fractures of the distal metacarpal or metatarsal bones, including non-displaced physeal fractures (Salter-Harris type I or II), transverse diaphyseal fractures, and the phalanges.[9] Ideally, the cast must incorporate one joint above and one below the fracture. Severely comminuted fractures and fractures involving a joint surface or the metaphyseal region require greater stabilization than that provided by a cast alone.[9] Casts are considered inappropriate when applied to proximal limb fractures because this can lead to the creation of the "fulcrum effect" at the fracture site. This motion can increase soft tissue damage, thereby impairing angiogenesis and callus formation at the fracture site, resulting in malunion.

Most often casts may be maintained in juveniles for four to six weeks without being changed. Rapidly growing crias may require more frequent cast changes. The cast must be checked every day for odor, warmth, position, and use of the affected limb by the patient. A cardinal sign of developing cast sores is when the patient suddenly stops using the affected limb. Veterinary attention is promptly required, and would likely entail removal of the old cast, examining the limb and, depending on the fracture healing stage, either a new cast, splint, or a Robert Jones bandage applied.

Schroeder-Thomas splints

A Schroeder-Thomas splint is an appropriate technique for fractures distal to the mid-radius and mid-tibia to prevent the fulcrum effect. Insufficient length and padding are likely the most common faults when devising this construct. The length of the splint is measured while the patient is standing on its unaffected contralateral limb. If the distal phalanges touch the bottom of the splint then the length is too short and will not provide adequate stabilization. The loop of the splint must be firmly placed in either the axilla or inguinal area to facilitate maximal weight transference. Therefore, the loop must initially be made oversize to provide sufficient space for ample padding to reduce the development of decubital ulcers. The patient is placed in lateral recumbency using a combination of sedation and restraint. The fracture is reduced, and the limb is immobilized to the Schroeder-Thomas splint using tape. The limb must be firmly attached to the splint frame to prevent rotation of the limb along the splint during ambulation. Patients should be assisted to stand for the first couple days after splint application until they learn to rise under their own power. Initially, patients are usually unable to rise after lying down on top of the splint. Complications include poor alignment, malunion, delayed healing, and decubital ulcers.

Transfixation pinning and casting

A transfixation cast refers to the placement of transcortical pins through the bone proximal to the injury, followed by application of a cast. The cast begins proximal to the transcortical pins, and extends distally, incorporating both the pins and the entire limb including the foot. Therefore, the full body weight is transferred to the cast by the transcortical pins and transmitted through the cast to the ground. The advantages include minimal disruption of the fracture site, thus maximizing fracture biological osteosynthesis; relatively quick and inexpensive to apply, requiring little specialized equipment; and can be used to stabilize comminuted metacarpal and metatarsal fractures. Compared to a standard cast or splint, this technique requires a general anesthetic and increased surgical skill to ensure correct placement of the proximal pins. Intraoperative radiographs can ensure that joints or growth plates are not accidentally damaged during pin placement.

The pin size selected should not exceed 20% of the diameter of the bone. Larger pins cause marked loss of the bone's resistance to torsional loading. The most proximal pin takes the majority of the weight compared to the second pin. Therefore, using a larger diameter pin in the most proximal hole can increase the strength of this construct. The most distal pin should be at least six pin diameters away from the fracture line (e.g. a 4 mm pin should be placed at least 24 mm from the fracture site). The pins should be placed at least four pin diameters away from each other to minimize the risk of concentrating the mechanical forces between the two pins, called a "stress riser" effect. Pin divergence yields greater bone fracture resistance compared to parallel pin configuration.[13] Aligning the pins parallel to each other in a lateral to medial plane, but diverging at a 30 degree angle, dorsal to caudal, can also increase the torsional stability of the construct[5] but not the axial stability of the configuration.[14] We typically use centrally threaded, positive profile, self-tapping pins. Ideally, the holes are pre-drilled 0.05-0.10 mm smaller than the pin diameter to allow radial loading. Positive profile pins provide superior bone-implant interface. Pre-drilling is required to prevent significant thermal and mechanical injury to the bone prior to pin insertion (the exception to this rule might be when dealing with a neonatal patient). Thermal necrosis is reduced or eliminated by using sharp drill bits, low drill speeds (<250 rpm), continuous irrigation of the drill bit, and periodically cleaning out the accumulated debris between the flutes. The excess pin material is cut off, leaving sufficient length to be incorporated in the cast. Stockinette or foam resin padding is then applied. The pin ends are gently pushed through the first three layers of fiberglass as it is applied. The final three layers are applied over the pin ends. To prevent pin strike-through by abrasion, PMMA is applied on the fiberglass covering the pin ends and the bottom of the cast overlying the foot. This construct is significantly stronger than ESF since the distance between the bone and fiberglass is decreased compared to that between the bone and clamps in a Type II ESF. The primary disadvantages of this construct include poor access to wounds under the cast, greater difficulty in cast removal, and the potential for cast sores to develop.[3]

External skeletal fixators

External skeletal fixator requires two transfixation pins placed both above and below the fracture line. These pins can then be connected using connecting bars, or a fiberglass cast. This construct typically provides greater fracture stability than a transfixation cast and can be used to manage open wounds. Diaphyseal fractures of the radius/ulna, metacarpus, tibia, and metatarsus can be repaired using this technique, provided there is sufficient bone to place all four pins. An advantage of this technique is that normal range of motion for all joints is maintained; however, transarticular pins can be placed either above or below the fracture line to improve stability in certain instances.[2,9] Since the pins are equally loaded in this construct, they can be of the same diameter. Pin size and placement techniques have been previously mentioned. Unless fiberglass is used as a connecting bar, the pins must be aligned to facilitate clamping to the connecting bar. The connecting bar should be placed with the clamps towards the limb, approximately 1 cm away from the skin to allow for postoperative swelling. This distance should be kept to a minimum, since doubling the bone to connecting bar distance reduces the resistance to compressive loads by approximately 25%. If fiberglass is used as a connecting rod, the limb distal to the cast should be bandaged for the first few post-operative days to prevent swelling. Unlike other repair techniques, the ESF has an additional advantage in that the implants may be sequentially removed over time to gradually increase the axial weight bearing of the affected limb. These implants are completely removed under sedation once the fracture is clinically healed. The ring fixator is a modification of the standard ESF system. Though more costly, the superior flexibility and versatility of the ring fixator offers potential solutions for specific situations that may not be repairable using other fixation methods.

Intramedullary pins and cerclage wire

Not all bones and fracture configurations can be repaired using intramedullary (IM) pins and cerclage wire. Access to the longitudinal axis of the bone is required without damaging an adjoining joint; therefore, this technique is limited primarily to humeral and femoral bones, specifically when they have long, oblique fractures. This technique requires a minimum fracture line length that is twice the bone diameter when using cerclage. The IM pin should fill the medullary canal at the isthmus of the bone. Intraoperative radiographs can facilitate correct pin placement in the distal metaphysis to avoid inadvertent penetration of the adjoining joint. The complications of this particular technique include damage to the distal joint during pin placement, pin migration postoperatively, and osteomyelitis secondary to a pin tract infection. This configuration is not desirable for short oblique, transverse, comminuted, or segmental fractures. Once the fracture is healed, the pin and cerclage wires do not require removal unless they are causing lameness or other problems.

Bone plating of fractures

The techniques used to apply dynamic compression plating (DCP) to a fracture in a camelid are similar to those for other species.[4] Since the bone is relatively soft in juvenile camelids, care must be taken not to overtighten the screws and strip the cortical bone. Plate lutting, using antibiotic-impregnated PMMA, can be used to increase the bone implant contact.[4] The disadvantages of the DCP technique include the requirement for increased surgical skill, specialized equipment, surgical time, and cost. The implants can loosen or break, thus requiring removal at a later date. Once the fracture is clinically healed, the implants do not require removal unless they are causing lameness.

Intramedullary interlocking nails

The successful use of an intramedullary interlocking nail has been reported in the literature.[11] This technique likely requires the greatest degree of surgical skill, specialized equipment, and cost. This construct is best applied in buttress support of femoral, tibial[27] and humeral fractures.[20,27] The central location of this implant provides greater strength compared to other internal and external repair techniques.[15,16] This orthopedic implant typically does not require removal after the fracture is clinically healed unless it is causing lameness or other problems.

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