Equine Veterinary Education

EQUINE VETERINARY EDUCATION
Equine vet. Educ. (2021) **33** (5) e155-e160
doi: 10.1111/eve.13238

Case Report

Surgical treatment of a complicated distal tibia epiphyseal Salter–Harris type I fracture in a yearling

A. C. Noguera Cender*, C. J. Lischer and K. Mählmann

Equine Clinic at the Faculty of Veterinary Medicine, Free University of Berlin, Berlin, Germany
**Corresponding author email: andrea.noguera@fu-berlin.de*

Keywords: horse; fracture; tibia; physis; internal fixation; transfixation pin cast

Summary

This article describes the management of a complicated distal epiphyseal Salter–Harris type I fracture of the left tibia in a yearling horse. Closed reduction and internal fixation was attempted in the first surgery using tension band wires. Due to fracture instability 2 weeks after surgery, a full-limb transfixation pin cast was applied to the tibia and maintained for 7 weeks to prevent further fracture displacement and to achieve axial alignment. The full-limb cast was maintained for a total of 12 weeks, including the time with the transfixation pin cast. Cast sores and tendon laxity resolved without further complications. Ten months after the first surgery, the fracture had radiographically healed, and the horse was sound at the walk and trot in a straight line.

Introduction

Physeal fractures of the tibia account for 10% of all physeal fractures in the horse (Embertson *et al.* 1986). The most common type of physeal fracture in the tibia is located in the proximal physis. Typically, this type of fracture occurs in foals and shows a Salter–Harris type II configuration, with a lateral metaphyseal component that involves up to one-third of the physeal surface (Wagner *et al.* 1984; Embertson *et al.* 1986). The distal physis of the tibia is rarely affected, with the most commonly reported configuration being Salter–Harris type II, involving the lateral metaphysis of the distal tibia (Levine and Aitken 2017).

Treatment options for physeal fractures of the distal tibia include external coaptation alone or in combination with internal fixation, depending on the fracture configuration and the size of the foal (Bramlage 2012). Surgical options involve lag screw fixation, which can be combined with a tension band wire (Levine and Aitken 2017).

To our knowledge, there have been no publications reporting the prognosis for this type of fracture after internal fixation. The contour of the distal articular surface of the tibia and the undulating morphology of the distal physis makes implant placement especially difficult (Bramlage 2012), leading to a challenging fracture repair in this area.

In this report, we describe the treatment of an American Paint Horse yearling that presented at our clinic with a distal physeal fracture of the tibia.

Case history

A 1-year-old, 320-kg American Paint Horse female yearling was presented at the equine department for treatment of a distal tibia fracture in the left hindlimb. The yearling was found in the field with acute left hindlimb lameness after a thunderstorm. A radiographic examination of the left hock revealed a fracture of the distal tibia, and the yearling was referred to the clinic for fracture treatment. The referring veterinarian administered nonsteroidal anti-inflammatory therapy and immobilised the left hindlimb with a full-limb Robert Jones bandage and a lateral splint that extended up to the level of the tuber coxae to counteract the valgus-inducing forces and to add stability to the bandage.

Clinical findings

On presentation, the yearling's general condition was depressed; the heart rate was 48 beats/min, the respiratory rate was 40 breaths/min, and the rectal temperature was 38.0°C. Orthopaedic examination revealed severe left hindlimb lameness (grade 5/5 on the AAEP scale), mild swelling and an unstable valgus deviation of the left tarsus that could be manually reduced. No skin lacerations were visible. Four standard radiographic views of the left tarsus were obtained (lateromedial, craniocaudal, DLPMO and PLDMO), revealing a displaced, multiple-piece, articular fracture of the distal tibial physis (**Figs 1** and **2**). The fracture plane propagated across the tibial growth plate from medial to lateral extending approximately two-thirds the width of the bone, where the orientation of the fracture line changed from transverse to vertical, entering the articular surface of the tarsocrural joint. A further fracture component was seen involving the lateral aspect of the physis showing a cranially displaced epiphyseal fragment.

The results of a complete blood count and plasma biochemical analyses were within reference values, except for mild leukocytosis (12.35×10^9/L [rr 5.3–10.3 $\times 10^9$/L]). The packed cell volume (PCV) was 33% (rr 31–47%), and the total protein was 72 g/L (rr 52–78 g/L).

Diagnosis

The yearling was diagnosed with a closed, complicated, articular Salter–Harris type I fracture in the left distal tibia physis.

Treatment

The intended treatment plan was closed reduction and internal fixation using lag screws in combination with a tension band wire and external coaptation of the affected limb.

Preoperative amoxicillin[1] (Amoxisel, 10 mg/kg bwt i.v.), gentamicin sulphate[2] (Gentacin, 6.6 mg/kg bwt i.v.) and flunixin meglumine[3] (Flunidol, 1.1 mg/kg bwt i.v.) were administered.

***Fig 1:** Day of admission: craniocaudal radiographic view of the distal aspect of the left tibia showing a disruption with a severe dislocation of the medial tibia physis and a fracture line entering the articular surface of the tarsocrural joint at the level of the lateral trochlear groove of the tibia.*

***Fig 2:** Day of admission: PLDMO radiographic view of the distal aspect of the left tibia showing a dislocation of the caudal physis and a cranial displacement of an articular fragment involving the craniolateral physis.*

The yearling was premedicated with xylazine hydrochloride[4] (Xylariem, 0.6 mg/kg bwt i.v.) and butorphanol tartrate[5] (Dolorex, 0.02 mg/kg bwt i.v.). General anaesthesia was induced with diazepam[6] (Ziapam, 0.05 mg/kg bwt i.v.), followed by ketamine hydrochloride[7] (Ketamidor, 2.2 mg/kg bwt i.v.) and maintained with isoflurane[8] (IsoFlo) in oxygen and xylazine hydrochloride[4] (Xylariem, 1.3 mg/kg bwt i.v. bolus followed by 0.05 mg/kg/min bwt i.v. CRI).

The yearling was positioned in right lateral recumbency, with the affected limb uppermost. Routine aseptic preparation and draping of the left distal tibia and tarsal region were performed. The procedure was assisted by fluoroscopy. Fracture reduction was accomplished by manual traction and rotation of the distal limb and maintained using pointed bone reduction forceps. Before implant placement, an arthroscopic evaluation of the tarsocrural joint was performed to assess the quality of the reduction and to further investigate the configuration of the intra-articular component of the fracture. After the removal of blood clots and lavage of the joint, a nondisplaced vertical fracture line in the epiphysis became visible with the scope inserted in the plantarolateral recess. The articular cartilage appeared normal. Skin portals were closed routinely at the end of the procedure. A minimally invasive surgical approach through skin stab incisions was used for the implant placement. The locations for the screws and the growth plate were identified by inserting various 20 gauge needles under fluoroscopic guidance, and a 4.5-mm cortical screw was inserted in lag fashion across the physis in the medial malleolus of the tibia. Then, a second screw was inserted proximally, and a 1.5-mm cerclage wire was applied as a tension band. The same procedure was repeated caudolaterally, placing the distal screw in lag fashion across the articular fracture line to reconstruct the joint surface (**Fig 3**).

Post-operatively, a sterile bandage was placed, and a full-limb cast was applied (including the hoof to the proximal tibia). Recovery was assisted with head and tail ropes. The horse struggled considerably to recover with the full-limb cast but was finally able to stand up without further complications. Amoxicillin[1] (Amoxisel, 10 mg/kg bwt, q. 8 h i.v.) and gentamicin sulphate[2] (Gentacin, 6.6 mg/kg bwt, once daily, i.v.) were administered for 5 days; flunixin meglumine[3] (Flunidol, 1,1 mg/kg bwt q. 12 h i.v.) and a prophylactic dose of omeprazole[9] (Gastrogard, 1 mg/kg bwt once daily, per os) were administered for 1 and 2 weeks, respectively.

Five days after surgery, the yearling was slightly depressed, showed a mild lameness of the operated hindlimb, and a body temperature of 38.5°C was measured.

***Fig 3:** Intraoperative fluoroscopic image obtained at the end of the surgical procedure showing the internal fixation construct using screws and wires as a tension band on both sides of the physis (medial and lateral). The green arrow points to the intra-articular fracture line, which is crossed by the distolateral 4.5-mm cortical screw placed in lag fashion.*

The blood count and plasma biochemical parameters, including fibrinogen and serum amyloid A values, were within normal limits. The cast was removed standing, and no signs of incisional infection were detected. Radiography of the affected hock revealed a poor reduction of the articular fracture component located craniolaterally and a mild bending of the distal screw located in the medial malleolus of the tibia (**Fig 4**). A new full-limb cast was applied in a normal weightbearing position, and the yearling was treated with phenylbutazone[10] (2.2 mg/kg bwt, twice daily, i.v.) for 7 days. The fever resolved, but the weightbearing ability of the affected hindlimb deteriorated further during the following week (grade 3–4/5 on the AAEP scale). At this point, 2 weeks after surgery, repeated radiographic examination revealed further displacement of the craniolateral fragment and a dislocation of the medial physis. Due to the instability of the fracture, the decision was made to apply a transfixation pin cast to reduce axial loading and bending forces at the unstable fracture.

The yearling was positioned in right lateral recumbency. The pins were inserted from lateral to medial using an aiming device[11] and fluoroscopic guidance. The first pin was located in the metaphysis of the tibia. After the holes were drilled, tapping was performed slowly by hand, and a 6.3-mm positive profile centrally threaded pin[12] was inserted. A second pin was placed approximately 5 cm proximal to the first pin in the distal diaphysis of the tibia. The third pin was placed 5 cm distal to the first pin, proximal to the physis. All three pins were drilled in at an approximately 30° divergent angle from the frontal plane. The pins were cut, and a sterile bandage was placed and covered by a stockinet. Orthopaedic felt was placed to add extra padding to the heel bulbs and the proximal aspect of the tibia. Ten 12-cm rolls of fibreglass cast[13] were applied over the stockinet with the leg held in a neutral position. When the cast was dry, the pins were enclosed with PMMA and the solar hoof surface was covered with a cotton mesh impregnated with a thermoplastic biodegradable resin[14].

Recovery using head and tail ropes was uneventful. Post-operative antimicrobials and anti-inflammatories were administered as described for the first surgery. Three weeks after the pins had been placed, the cast broke circularly at the level of the proximal cannon bone and had to be replaced by a new one under general anaesthesia. There was no palpable loosening of the pins. Pressure sores were present on the heel bulbs and the caudoproximal tibia. Intraoperative radiographs showed new periosteal callus formation around the physis and craniolaterally within the articular fracture gap (**Fig 5**). There was some bone resorption visible at the bone–pin interface (BPI), especially at the lateral aspect of the proximal pin. A new full-limb cast was applied, and the horse recovered uneventfully using head and tail ropes.

Six days after recovery, the yearling started to show a reduced weightbearing ability of the affected hindlimb. Pain management therapy was changed to the administration of intramuscular ketamine hydrochloride[7] (Ketamidor, 0.5 mg/kg bwt, twice daily) and morphine[15] (Morphin-ratiopharm, 0.05 mg/kg bwt, twice daily), which allowed the horse to comfortably bear weight on the affected hindlimb over the next 2.5 weeks. Seven weeks after the insertion of the transfixation pins in the tibia, radiographs revealed additional periosteal callus formation around the fracture. The cast and pins were removed with the yearling standing. All three pins were still firm in the bone and showed no pin loosening. Pressure sores remained equal when compared to those seen previously. The limb showed a mild valgus deformity of the tarsus, a moderate stiffness of the tarsal joint and a laxity of the flexor tendons. Thereafter, a standard full-limb cast was applied in a normal weightbearing position for an additional 3 weeks. After pin removal, the yearling showed a good weightbearing ability. Radiography was repeated to confirm the healing of the fracture, and the cast was then replaced

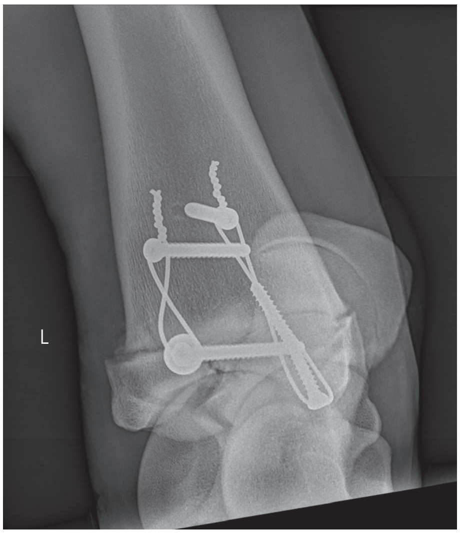

***Fig 4:** Four days post-admission: PLDMO radiographic view of the distal aspect of the left tibia showing a poor reduction of the articular fracture component located craniolaterally and a mild bending of the distal screw located in the medial malleolus of the tibia.*

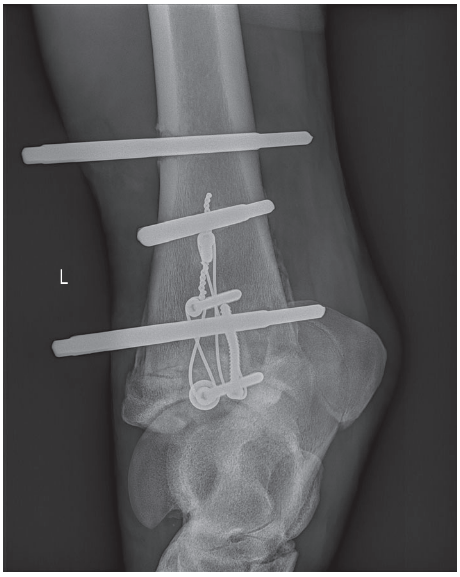

***Fig 5:** Five weeks post-admission: PLDMO radiographic view of the distal aspect of the left tibia showing periosteal callus formation at the cranial and caudal aspects of the physis and craniolaterally within the articular fracture gap. Note the bone resorption visible at the bone-pin interface (BPI) at the lateral aspect of the proximal pin.*

by a Robert Jones bandage. At this time, the cast sores at the tibia had increased slightly in size but remained superficial, and the valgus deviation and tarsal joint stiffness remained stable; tendon laxity had progressed, with hyperextension of the fetlock and lifting of the toe. To facilitate a planar ground contact, a hoof shoe with a heel extension was applied. In addition, the horse was placed in a swing lifter[16] to reduce weightbearing on the affected limb for a further 2 weeks. Then, the bandage was removed, and the yearling was kept in a box and hand walked for a few minutes every day.

After 15 weeks of hospitalisation, the horse was discharged. At the time of discharge, the horse was sound at the walk and showed a mild valgus deformity and a decreased range of flexion of the left tarsus. The tendon laxity had improved, and the skin sores and pin wounds healed without further complications.

Radiographs taken at the time of discharge showed a mild irregular surface of the lateral trochlea tali and the central and third tarsal bone at the dorsolateral and dorsal aspects. At the distomedial aspect of the tibia and at the medial site of the talus, smooth new bone formation was noted.

***Fig 6:** Ten months post-admission: PLDMO radiographic view of the left hock showing periosteal new bone formation at the dorsal aspect of the distal intertarsal joints and a mild irregular bone surface at the distal aspect of the lateral trochlea tali and the distal tibia. The physeal fracture has healed completely. The implants are in position, no reaction is seen around the screws.*

Outcome

Ten months after the initial surgery, the horse was rechecked by the referring veterinarian and was sound at the walk and trot in a straight line. Radiographic examination of the left hock showed moderate to severe periosteal new bone formation at the dorsal aspect of the distal intertarsal joints and mild irregular bone surface at the distal aspect of the lateral trochlea tali and the distal tibia (**Fig 6**). The implants were in position, and no reaction was seen around the screws. The tendon laxity had resolved completely, the valgus deviation of the tarsus remained unchanged (<8°), and the range of flexion of the tarsus was normal. The horse is now being trained to be used for equine-assisted therapy, fulfilling its intended use by the owner.

Discussion

To our knowledge, this is the first report of the successful treatment of a distal physeal fracture of the tibia using internal fixation combined with a transfixation pin cast of the tibia in a yearling.

Regarding the fracture configuration, it is evident, based on radiographic images, that the medial physis is disrupted. However, we assumed that the lateral physis was also fractured, leading to a cranial displacement of a fragment involving the craniolateral epiphysis and the lateral trochlear groove. We therefore proposed as general configuration a complicated Salter–Harris type I fracture of the distal tibia, even though the fracture had also characteristics of a Salter–Harris type III, since there is a fracture line entering the articular surface of the tarsocrural joint at the level of the lateral trochlear groove of the tibia. Yet, we were not able to fully understand the exact fracture configuration by the sole use of radiography. Arthroscopic evaluation allowed inspection of only the joint margins, but complete visualisation of the intra-articular fracture lines was not possible because the articular surface of the distal tibia was not accessible. Computed tomography would have provided superior information about the fracture configuration in order to better plan the placement of implants, but this modality was not available in our hospital.

Fracture reduction is crucial and is the first step to achieve a stable fixation. This was especially difficult at this location due to the undulating surface of the physis. A closed reduction technique was attempted in order to follow minimal invasive principles and due to the limited size and relatively soft composition of the bone in the epiphysis and metaphysis of the yearling. Reduction was accomplished by manipulation of the distal limb and the hock, pulling and rotating the fracture along the longitudinal axis of the bone until intraoperative radiographs suggested satisfactory realignment of the physis. However, post-operative radiographs revealed incomplete reduction at the craniolateral physis, which lead to fracture instability. In retrospect, an open reduction technique through a longitudinal incision at the level of the craniolateral physis might have helped to expose the fracture plane and accomplish good alignment, reduction and interfragmentary compression.

Due to incomplete reduction of the craniolateral physis and the fragmentation of the epiphysis, a considerable piece of bone remained cranially displaced, leaving a gap in this location, which predisposed the fracture to instability.

The combination of incomplete reduction and the misplacement of the implants due to the lack of complete understanding of the fracture configuration resulted in a construct that was insufficient to neutralise and resist the counteracting forces in this 320-kg yearling.

A different fixation option might have been a 4.5 LCP tibia plate[11], which would have allowed for the insertion of a maximum of three locking head screws in the epiphyseal segment of the fracture. Otherwise, given the morphology of the distal tibial epiphysis and the limitations of contouring the plate around the malleolus of the tibia, it would only have been possible to insert short locking head screws at the T-part of the plate in order to avoid penetration of the tarsocrural joint. In contrast to the figure of eight cerclage, this plate could function as a tension band and a buttress plate simultaneously. Furthermore, appropriate placement on the craniolateral aspect of the distal tibia could eventually have helped to engage the craniolateral fragment in the epiphysis, providing a more stable fixation.

Given the instability of the fracture, we decided to apply a transfixation pin cast to reduce the bone strain in the distal tibia physis, protecting the fracture from collapse. Transfixation pin casts have been successfully used to treat unstable fractures of the distal limb in horses, including fractures of the third metacarpal/metatarsal bone and the first and second phalanx (Watkins 2006a, 2006b; Lescun *et al.* 2007; Rossignol *et al.* 2014). This technique transfers axial weightbearing forces from the bone to the transosseous pins and the cast, minimising the compressive forces to the fracture site and preventing the collapse of unstable fractures (Joyce *et al.* 2006). Whereas the treatment of tibial fractures with a transfixation pin cast has been reported in calves (St. Jean *et al.* 1991), its use has not been reported in tibial fractures of horses. The application of this technique in this case prevented further destabilisation and fracture collapse, allowing successful healing of the fracture.

There are several potential complications related to the application of a transfixation pin cast, such as premature loosening of the transfixation pins, pin breakage and catastrophic fracture of the long bone where the pins were inserted (Joyce *et al.* 2006; Lescun *et al.* 2007). None of these complications occurred in our case. Catastrophic fractures have been related to a proximal placement of the pins too close to the proximal end of the cast and to an excessively large pin diameter in relation to the bone diameter (Nemeth and Back 1991; Joyce *et al.* 2006). Special attention was given to drilling the pin holes as distal as possible, midway between the cranial and the caudal cortex, and to placing the pins in the distal tibia at a 30° divergent angle, with holes of sufficient diameter to hold under weightbearing forces that nonetheless did not exceed 10% of the dorsopalmar bone diameter, factors reported to avoid catastrophic fractures related to transfixation pins. One complication that occurred 3 weeks after pin placement was cast breakage at the level of the proximal MtIII, most probably due to the thinner width of the cast beneath the tarsus, as seen retrospectively in radiography, and the strong bending forces of the tarsus.

Other reported complications are related to the external coaptation during a prolonged period and include the development of cast disease, cast sores and tendon laxity in addition to peroneus tertius rupture (Riggs 1997; Abuja *et al.* 2013). In this case, the horse was placed in a full-limb cast for 12 weeks and demonstrated a few complications such as cast sores, tendon laxity and reduced range of motion of the tarsocrural joint, with the first two easily managed without further difficulties. This was in part possible because of the cooperative behaviour of this particular yearling, which tolerated the full-limb cast for such a long period without struggling and remained calm while resting in its box. However, the described complications could perhaps have been avoided reducing the time the yearling was placed in a full-limb cast. The rationale for maintaining the cast after pin removal was the comminuted fracture configuration, the previous experienced fracture instability despite a full-limb cast and finally the age and weight of the horse. Due to the complicated fracture configuration in combination with uncertain radiographic healing at the time of pin cast removal, the authors decided to keep the horse in a pinless cast for a transition period.

Axial limb deformities secondary to direct injury to the growth plate following a physeal fracture have also been reported in foals (Watkins 2006a). In this case, the valgus deformity of the tarsus could have been a consequence of a direct trauma to the lateral physis of the tibia. A further possible explanation is an incomplete reduction and fixation of a physeal fracture, as seen in the present case. It was to our advantage that the horse was 13 months old by the time it was referred to our clinic. Most of the growth from the distal tibial physis occurs during the first 6 months of life, which implies minimal remaining physeal activity after one year, leading in this case to a minor valgus deviation of the tarsus (less than 8°).

The final outcome of this case will be determined by the angular limb deformity and the development and degree of osteoarthritis (OA) in the talocrural joint. Risk factors for the development of OA include intra-articular fracture configuration, the development of angular limb deformity, cartilage degeneration due to prolonged immobilisation and cast disease. Currently, the horse is sound at the walk and trot in a straight line. Radiographic examination of the left hock shows mild periosteal new bone formation at the distal aspect of the lateral trochlea of the talus.

The long-term prognosis for this horse as a therapy horse depends on the development of clinical signs related to the radiographic findings. Currently, the horse fulfils its intended use.

Conclusion

This horse had a complicated Salter–Harris I fracture configuration, with disruption of both the medial and the lateral distal tibia physis. Ideally, the repair of such fractures should be attempted after a computed tomography scan has been performed to provide superior information about the fracture configuration in order to plan the adequate placement of the implants. Alternatively, if this modality is not available and a complete reconstruction and good fracture reduction is not possible, placement of a transfixation pin cast in the tibia is a valuable treatment option to minimise the compressive forces in the fracture, thereby preventing collapse and allowing the fracture to heal.

Authors' declarations of interests

No conflicts of interest have been declared.

Ethical animal research

The work described in this case report involved informed client consent. This was a clinical case presented to our clinic and ethical review was not required.

Source of funding

None.

Authorship

All three authors contributed to the case and A. Noguera Cender prepared the manuscript. C. Lischer and K. Mählmann edited the manuscript.

Manufacturers' addresses

[1]Selectavet, Weyarn, Germany.
[2]Bela-pharm GmbH & Co.KG, Vechta, Germany.
[3]CP-Pharma Handekges. mbH, Burgdorf, Germany.
[4]Bioveta, a.s. Ivanovice na Hané, Czech Republic.
[5]Intervet International GmbH, Unterschleiβheim, Germany.
[6]Cenexi, Fontenay sous Bois, France.
[7]Richter Pharma AG, Wels, Austria.
[8]Zoetis Deutschland GmbH, Berlin, Germany.
[9]Merial S.A.S 4, Toulouse, France.
[10]Medistar GmbH, Ascheberg, Germany.
[11]DePuy Synthes, Umkirch, Germany.
[12]IMEX® Veterinary, Inc., Longview, Texas.
[13]Nobamed Paul Danz AG, Wetter, Germany.
[14]VMDvet, Arendonk, Belgium.
[15]Ratiopharm GmbH, Ulm, Germany.
[16]PM Horse-Swinglifter, Michael Puhl GmbH, Losheim am See/ Rissentha, Germany.

References

Abuja, G.A., Bubeck, K.A., Quinteros, D.D. and García-López, J.M. (2013) Surgical treatment of distal tarsal joint luxations in three horses. *Vet. Comp. Orthop. Traumatol.* **26**, 304–310.

Bramlage, L.R. (2012) Tibia. In: *Equine Surgery*,4th Edn, Eds: J. Auer and J. Stick. Elsevier Saunders, St. Louis, Missouri. pp 1409–1419.

Embertson, R.M., Bramlage, L.R. and Herring, D.S. (1986) Physeal fractures in the horse. *I. Classification and incidence. Vet. Surg.* **15**, 223–229.

Joyce, J., Baxter, G.M., Sarrafian, T.L., Stashak, T.S., Trotter, G. and Frisbie, D. (2006) Use of transfixation pin casts to treat adult horses with comminuted phalangeal fractures: 20 cases (1993–2003). *J. Am. Vet. Med. Assoc.* **229**, 725–730.

Lescun, T.B., McClure, S.R., Ward, M.P., Downs, C., Wilson, D.A., Adams, S.B., Hawkins, J.F. and Reinertson, E.L. (2007) Evaluation of transfixation casting for treatment of third metacarpal, third metatarsal, and phalangeal fractures in horses: 37 cases (1994–2004). *J. Am. Vet. Med Assoc.* **230**, 1340–1349.

Levine, D.G. and Aitken, M.R. (2017) Physeal Fractures in Foals. *Vet. Clin. North Am.: Equine Pract.* **33**, 417–430.

Nemeth, F. and Back, W. (1991) The use of the walking cast to repair fractures in horses and ponies. *Equine Vet. J.* **23**, 32–36.

Riggs, C.M. (1997) Indications for and application of limb casts in the mature horse. *Equine Vet. Educ.* **9**, 190–197.

Rossignol, F., Vitte, A. and Boening, J. (2014) Use of a modified transfixation pin cast for treatment of comminuted phalangeal fractures in horses. *Vet. Surg.* **43**, 66–72.

ST-Jean, G., Clem, M.F. and DeBowes, R.M. (1991) Transfixation pining and casting of tibia fractures in calves: five cases (1985–1989). *J. Am. Vet. Med. Assoc.* **98**, 139–143.

Wagner, P.C., DeBowes, R.M., Grant, B.D., Kaneps, A.J. and Watrous, B.J. (1984) Cancellous bone screws for repair of proximal growth plate fractures of the tibia in foals. *J. Am. Vet. Med. Assoc.* **184**, 688–691.

Watkins, J.P. (2006a) Etiology, Diagnosis, and Treatment of Long Bone Fractures in Foals. *Clin. Tech. Equine Pract.* **5**, 296–308.

Watkins, J.P. (2006b) External skeletal fixation in the equine. Proc. Vet. Orthopaedic Congress and 33rd Annual VOS Meeting, 2nd World edn., USA, Keystone, CO. pp 29–30.