Received: 27 December 2022 | Accepted: 29 April 2023

DOI: 10.1111/eve.13822

CASE REPORT

Equine Veterinary Education BEVA AAEP

Alternative approach for fracture fixation following implant infection in a Salter-Harris type-II fracture of the proximal phalanx in a Warmblood foal

Andrey Kalinovskiy | Anna Ehrle | Eva Müller | Christophorus Lischer

Equine Clinic Freie Universitaet Berlin, Berlin, Germany

Correspondence: Andrey Kalinovskiy
Email: a.kalinovskiy@fu-berlin.de

Summary

A 2-day-old female Warmblood foal (70 kg) presented with a closed, displaced Salter-Harris type-II fracture of the proximal physis of the left hind first phalanx. The fracture was repaired with four 4.5 mm cortical screws and a wire in a figure-of-8 pattern applied on the lateral and medial aspect of the phalanx, respectively. A 4.5 mm cortical screw was additionally inserted in lag-fashion to engage the lateral metaphyseal spike. Three days postoperatively, medial and proximal displacement of the distal fracture fragment and implant infection were apparent and revision surgery was performed. Previous implants were removed and two 4.5 mm transphyseal cortical lag-screws were placed in proximolateral–distomedial and dorsoproximal–plantarodistal direction across the physis and the fracture line. Postoperatively, the fracture healed rapidly and the implants were removed 6 weeks later. Nineteen months after implant removal, the horse did not show any sign of lameness, despite a shortening of the proximal phalanx compared to the contralateral limb. In cases of postoperative implant instability and infection, implant removal often becomes necessary. However, new implants cannot be placed safely in the previous location. To avoid this problem, this report describes an alternative approach for screw positioning in case of previous implant infection in a Salter-Harris type-II fracture of the proximal physis of the first phalanx.

KEYWORDS

horse, first phalanx, foal, implant infection, Salter-Harris fracture type-II

INTRODUCTION

The Salter-Harris type-II fracture is one of the most common fracture configurations of the first phalanx (P1) occurring in foals (Levine & Aitken, 2017; Richardson, 2020). In complicated or displaced fractures, internal fixation is recommended (Auer, 2015; Richardson, 2020).

Surgical site infection following internal fracture fixation occurs in 10–28% of horses and is one of the most dreaded postoperative complications (Ahern et al., 2010; MacDonald et al., 1994). The high numbers might be explained by the affinity of infectious pathogens for bone, joint surfaces and particularly implants (Goodrich, 2020). Foals are additionally predisposed to postoperative osteomyelitis (Clegg, 2011; Goodrich, 2020).

Systemic and local antimicrobial therapy, curettage, implant removal or replacement and bone grafting are components of osteomyelitis treatment (Biasutti et al., 2021; Dernell, 1999; Lischer & Mählmann, 2022; Markel, 2020; Newman et al., 2013). In case of implant infection, bacteria produce a biofilm that is very difficult to penetrate for the immune system or antimicrobial agents (Borriello et al., 2004; Stoodley et al., 2005). Recent reports showed that despite local and systemic antimicrobial therapy, wound debridement and removal of infected implants are essential for the elimination of the infection and prevention of further damage to the surrounding tissues (Donati et al., 2021; Goodrich, 2020; Nunamaker, 2020). However, if the fracture has not healed sufficiently at the time of infection, removal of the implants can result in a high risk of instability, refracture and delayed- or non-union (Goodrich, 2020; Ruggles, 2020). In these cases, alternative methods for stabilisation, such as a transfixation pin casting or implant replacement may be required (Ortved & Richardson, 2021).

Whilst placing new implants in the previously infected locations should be avoided, finding alternative positions for the insertion of new implants poses a challenge, especially in small bones like the P1 of a foal with a short segment fracture configuration. To the best of the authors' knowledge, this is the first report that describes an alternative approach for screw replacement in case of previous implant infection in a Salter-Harris type-II fracture of the proximal P1 physis in a foal.

CLINICAL REPORT

History

A female Warmblood foal was found with an acute left hindlimb lameness one day after birth. A P1 fracture was diagnosed by the referring veterinarian. The fracture was immobilised with a distal-limb cast and the foal was referred for surgical repair.

Clinical and radiographic findings

On admission, the foal was alert and responsive and in good body condition (bodyweight 70 kg). Left hindlimb lameness grade 4/5 (AAEP) was evident at the walk. Physical examination, blood haematology and biochemistry were unremarkable.

Radiographic examination through the distal-limb cast confirmed a displaced Salter-Harris type-II fracture of the left hind proximal P1. A metaphyseal spike was present on the lateral aspect and severe dislocation of the distal P1 fragment in a medial direction was evident (Figure 1).

Initial surgery

Flunixin-meglumine (Flunidol; 1.1 mg/kg bwt i.v., CP-Pharma Handelsgesellschaft mbH), ceftiofur (Excenel; 4.4 mg/kg bwt i.v., Zoetis Germany GmbH) and tetanus serum (Tetanus–Serum; 8.000 I.U./kg bwt i.m., WDT-Wirtschaftsgenossenschaft Deutscher Tierärzte eG) were administered prior to sedation. The foal was sedated with butorphanol (Butorgesic; 0.025 mg/kg bwt i.v., CP-Pharma Handelsgesellschaft mbH) and general anaesthesia was induced with midazolam (Midazolam-Ratiopharm; 0.25 mg/kg bwt i.v., Ratiopharm GmbH) and ketamine (Ketamin; 2.2 mg/kg bwt i.v.,

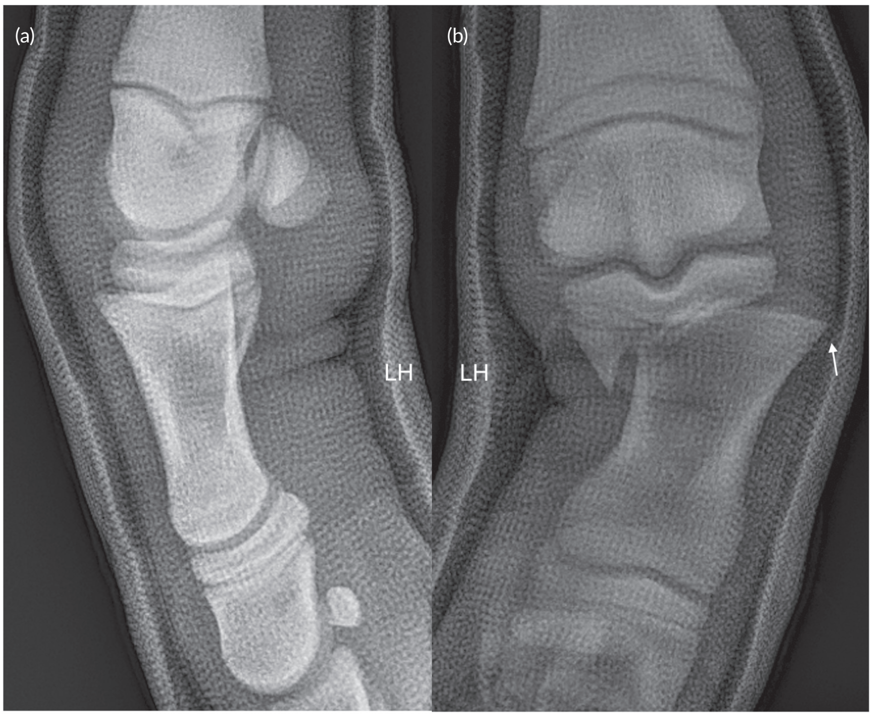

FIGURE 1 Lateromedial (a) and dorsoplantar (b) radiograph of left hind Salter-Harris fracture type-II in a 2-day-old Warmblood foal with distal-limb cast in place. Note the displacement of the distal first phalanx fragment in a medial direction with close proximity to the skin/subcutaneous tissue (white arrow).

CP-Pharma Handelsgesellschaft mbH). The foal was hand-supported during the induction phase. General anaesthesia was maintained with isoflurane (Isofluran CP; minimum alveolar concentration 1.0, CP-Pharma Handelsgesellschaft mbH). The foal was placed in left lateral recumbency, and the cast was removed.

Besides the instability of P1, soft tissue swelling and a superficial cast sore were noted on the medial aspect of the fetlock. There was however no evidence for a skin penetration that would suggest an open fracture. Following routine aseptic preparation and draping, the fracture was reduced using pointed reduction forceps under fluoroscopic guidance (C-arm, BV Pulsera, Philips Medical System DMC GmbH). Temporary fracture stabilisation was achieved by inserting a Steinmann pin (2 mm) through a stab incision into P1 across the fracture plane (Figure 2).

All implants were also positioned through stab incisions and care was taken to avoid injury to the proximal P1 growth plate. One 4.5 mm cortical screw (22 mm) was inserted proximal to the fracture gap into the P1 epiphysis and one (26 mm) distal to the fracture gap into the P1 metaphysis in mediolateral direction. Cerclage wire (1.2 mm) was used to engage the screw heads in a figure-of-8 pattern and tightened. The Steinmann pin was removed, and a 4.5 mm cortical screw (42 mm) was inserted in lag-fashion in a lateromedial direction in the lateral metaphyseal spike to reduce the vertical fracture line. The operating table was elevated to gain access to the lateral aspect of the limb. Similar to the medial side, one 4.5 mm cortical screw (22 mm) was placed proximal, and one (32 mm) distal to the fracture gap with a figure-of-8 cerclage wire on the lateral aspect of P1 (Figure 2).

The surgical wounds were flushed, and the stab incisions closed in simple interrupted pattern (USP 2-0 polypropylene). Regional limb perfusion with tobramycin (Gernebcin; 180 mg, Infectopharm Arzneimittel und Consilium GmbH) was performed and a distal-limb cast applied (Lischer & Mählmann, 2022; Newman et al., 2013). The hand-assisted anaesthetic recovery was uneventful.

Postoperative care

Anti-inflammatory (Flunixin-meglumine; Flunidol; 1.1 mg/kg bwt i.v. twice daily, CP-Pharma Handelsgesellschaft mbH) and antimicrobial therapy (Ceftiofor; Excenel; 4.4 mg/kg bwt i.v. twice daily, Zoetis Germany GmbH) was administered postoperatively. Three days after surgery, reduced weightbearing of the left hindlimb was noted and radiographic examination identified instability of the fracture fixation with medial axis deviation of P1 (Figure 3). Revision surgery was deemed necessary at this point.

Revision surgery

The setup and general anaesthesia were identical to the first surgery. However, the foal was placed in right lateral recumbency. Upon removal of the cast, dehiscence and purulent exudation with implant infection in the region of the medial surgical approaches became obvious. Bacterial culture found *Enterococcus faecalis* to be associated with the infection. Synoviocentesis of the metatarsophalangeal joint did not identify evidence for septic arthritis (white blood cell count: 0.96×10^9/L; total protein: 3.8 g/dL). All sutures and implants were removed, and ultrasonic-assisted wound debridement (UAW) (SONOCA-185, Söring GmbH) was performed. Temporary fracture stabilisation was achieved with a Steinmann pin as described previously.

A 4.5 mm cortical screw (54 mm) was inserted via a stab incision in a proximolateral–distomedial direction in lag-fashion across the proximal P1 physis. Following the removal of the Steinmann pin, a second 4.5 mm cortical screw (54 mm) was inserted transphyseal in a dorsoproximal–plantarodistal direction (Figure 4). The incisions were flushed and closed as described for the first surgery. The wounds from the initial surgery were left open for drainage and secondary intention wound healing. Regional limb perfusion with tobramycin (Gernebcin; 180 mg, Infectopharm Arzneimittel und Consilium GmbH) was performed and a distal-limb cast applied. Hand-assisted anaesthetic recovery was uneventful.

Postoperative care

Anti-inflammatory therapy was continued as described in a decreasing dosage regime for 2 weeks. Based on susceptibility testing, antimicrobial therapy was changed to benzylpenicillin-procaine (Procaine-Penicillin-G; 20.000 I.U./kg bwt i.m. once daily, WDT-Wirtschaftsgenossenschaft deutscher Tierärzte eG) and administered for 10 days.

Postoperatively, the foal was bearing full weight on the left hindlimb. During the first four postoperative weeks, the cast was changed once weekly under short general anaesthesia (see protocol above). The wounds from the initial surgery were treated with UAW and covered with gentamicin-impregnated swabs (Genta; 500 mg, CP-Pharma Handelsgesellschaft mbH). Regional limb perfusion (tobramycin; Gernebcin; 180 mg, Infectopharm Arzneimittel und Consilium GmbH) and radiographic examination were performed simultaneously.

The surgical wounds and the fracture healed without any further complications. The distal-limb cast was removed after 4 weeks and replaced with a Robert-Jones bandage. Digital hyperextension with moderate cast sores on the plantar surface of the fetlock were present at that point. Six weeks after revision surgery, radiographic examination confirmed adequate fracture healing, and the implants were removed via stab incisions under general anaesthesia (see protocol above) and fluoroscopic guidance.

Following implant removal, a glue-on hoof shoe with heel extension was applied to support the digital hyperextension. Weight bearing of the left hindlimb was consistently good, and the foal was discharged from the hospital one week later.

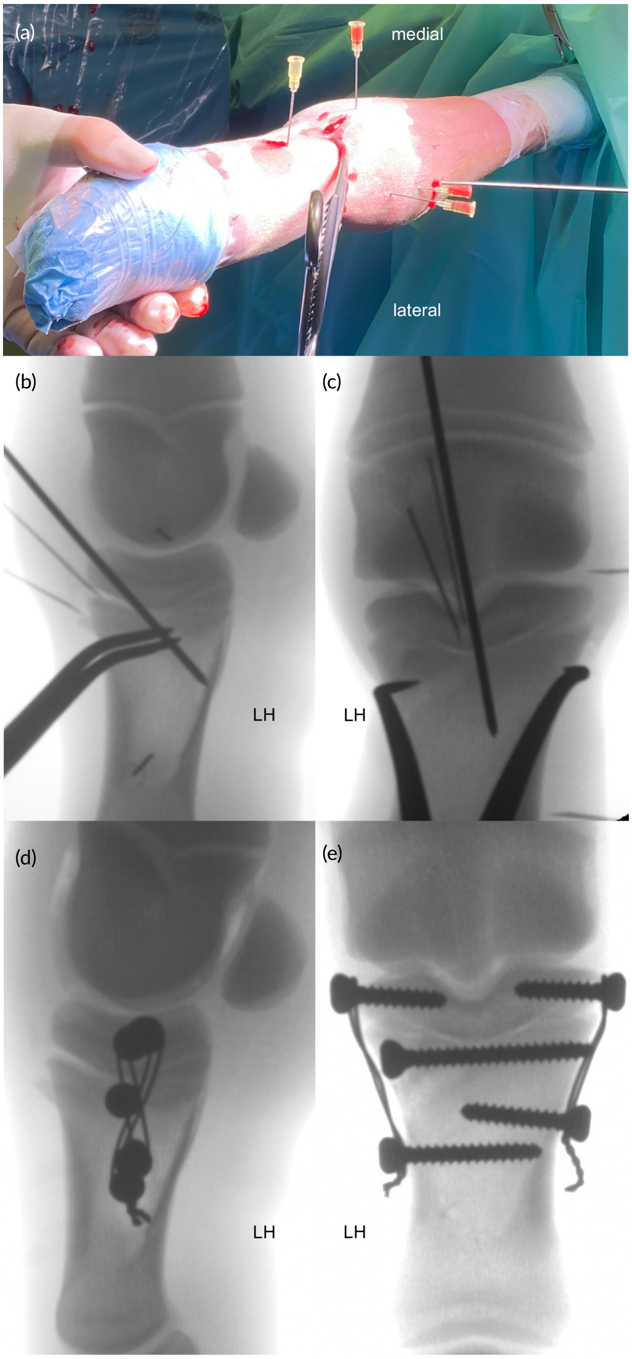

FIGURE 2 (a) Intraoperative image of the initial surgery with pointed reduction forceps and Steinmann pin used for temporary stabilisation of the left hind Salter-Harris type-II fracture in a 2-day-old Warmblood foal. Two needles were inserted dorsally to outline the P1 proximal physis. The proximal needle on the medial side marks the joint space and the distal needle is at the position for the distal medial screw. Lateromedial (b) and dorsoplantar (c) fluoroscopic projections showing the first surgical steps. The Steinmann pin was inserted into the first phalanx across the fracture plane in a dorsoproximal–plantarodistal direction. Lateromedial (d) and dorsoplantar (e) projections at the end of initial surgery, showing the fracture repair. A 4.5 mm cortical screw and wire (1.2 mm) repair was positioned on the lateral and medial aspect of the proximal phalanx, respectively. A 4.5 mm lag-screw was inserted in a lateromedial direction to engage the vertical fracture line associated with the metaphyseal part of the fracture.

Clinical outcome and follow-up

Upon follow-up examination 4 weeks after implant removal, the foal presented without lameness at the walk and trot. Mild swelling of the left hind fetlock was still present. As the digital hyperextension had improved, the hoof shoe with extension was removed, and the mare and foal were turned out onto a small pasture.

Radiographic examination 7 weeks after implant removal confirmed complete closure of the physis and fusion of the associated fracture lines with no sign of axial deviation or osteoarthritis of the metatarsophalangeal joint (Figure 5). The periarticular swelling had decreased, and flexion and extension of the joint was possible without restriction. Mare and foal were turned out with their herd.

During the examination 19 months after implant removal, the filly had remained sound and showed physiological fetlock range of motion. Whilst there was no obvious hindlimb asymmetry of motion and stride, shortening of the left hind P1 was visible when compared to the contralateral side. Radiographic examination did not identify evidence for progressing fetlock osteoarthritis despite the presence of an osteochondral fragment on the lateral aspect of the joint and a cystic-like lesion (CLL) in the medial proximal sesamoid bone (Video S1 and Figure 6).

DISCUSSION

This report describes the management of implant instability and infection following fracture repair in a Salter-Harris type-II fracture of the proximal P1 physis in a foal by utilising a minimally invasive alternative approach for screw positioning.

Postoperative implant-associated infection is the most frequent indication for implant removal in the horse (Auer, 2019; Donati et al., 2021; Ruggles, 2020). However, little information is available considering the procedure in cases where the fracture is still unstable. Alternative methods for fixation including transfixation pin casting and implant replacement in other locations with and without debridement of osteomyelitic bone are described (Goodrich, 2020; Ortved & Richardson, 2021). However, to the best of the authors' knowledge, a detailed description of an alternative approach for internal stabilisation of a proximal P1 physeal fracture following implant infection is not available in the current literature.

Internal fixation has several advantages compared to the application of external skeletal fixators, which is why it was preferred (Auer, 2015; Levine & Aitken, 2017; Richardson, 2020; Van Spijk et al., 2015). Some authors recommend maintaining the implants in place and treating the infection locally and systemically with antimicrobial drugs until sufficient fracture stability is achieved (Ortved & Richardson, 2021). However, Ruggles (2020) describes the risk of irreversible damage of adjacent synovial structures due

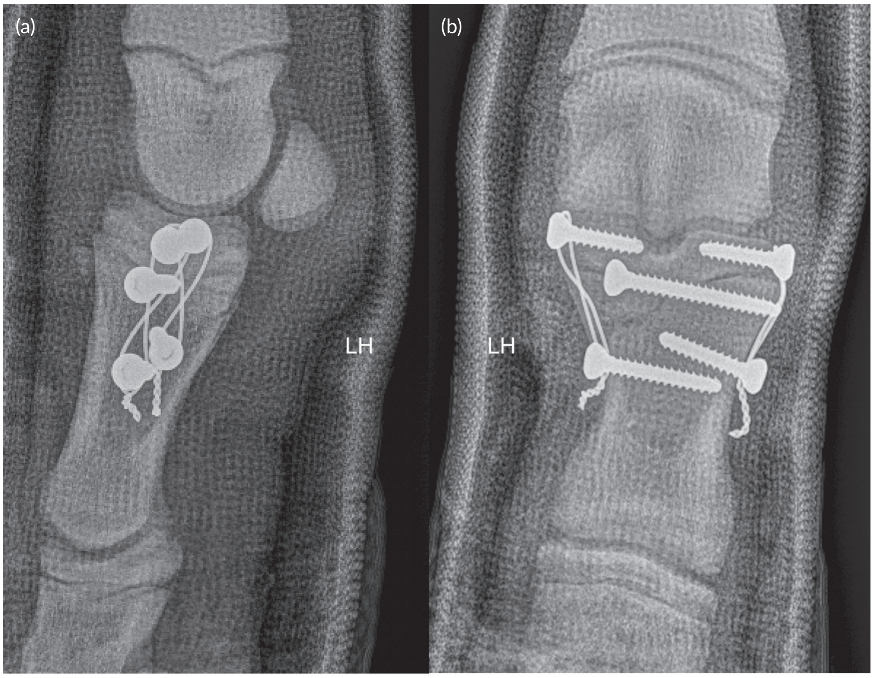

FIGURE 3 Lateromedial (a) and dorsoplantar (b) radiographs obtained 3 days after repair of a Salter-Harris type-II fracture in a 5-day-old Warmblood foal with distal-limb cast in place. Note the medial axis deviation on the dorsoplantar projection showing fracture displacement in a mediolateral direction.

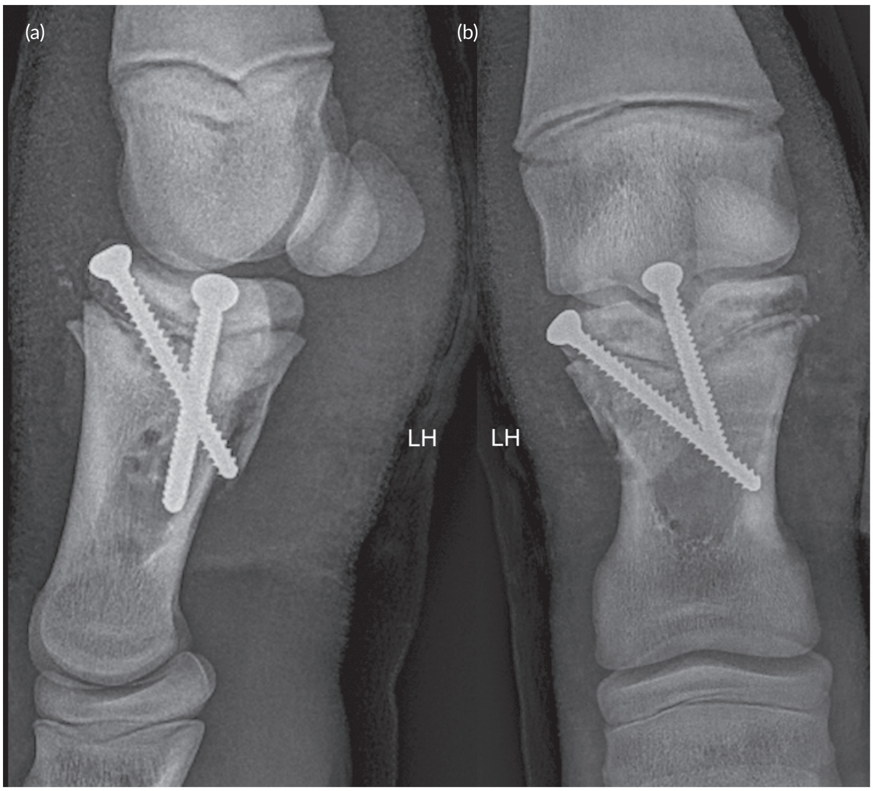

FIGURE 4 Revision surgery: Lateromedial (a) and dorsoplantar (b) radiograph of left hind Salter-Harris fracture type-II in a 12-day-old Warmblood foal following implant infection and revision surgery. Two 4.5 mm transphyseal screws were inserted in lag-fashion, one in a proximolateral–distomedial and one in dorsoproximal–plantarodistal direction. Note the close position to the articular surface of both screw heads.

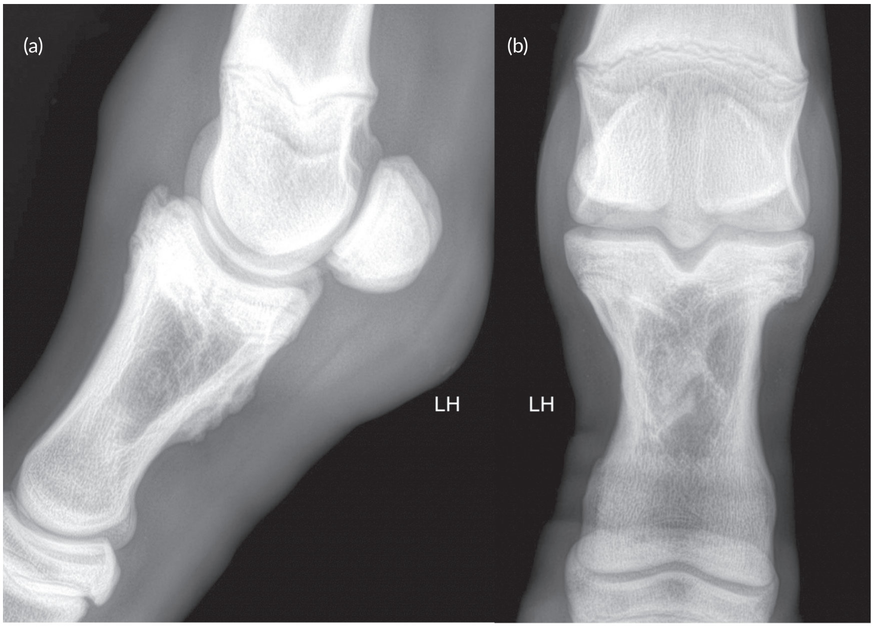

FIGURE 5 Lateromedial (a) and dorsoplantar (b) radiograph following left hind Salter-Harris type-II fracture repair, 7 weeks after implant removal showing complete fracture healing without signs of osteoarthritis. There is evidence for closure of the physis with smooth dorsoproximal and plantarolateral P1 periosteal proliferation.

to implant-induced osteomyelitis. Because of the combination of instability and infection, it was decided to remove the implants early to avoid possible damage to the metatarsophalangeal joint as well as the development of physitis and further axial deviation of the fracture.

Sufficient fracture stabilisation was achieved using two 4.5 mm cortical screws only. Size and position of the screws as well as external coaptation were crucial for the postoperative stability of the construct. Whilst screw insertion in lag-fashion through the metaphyseal spike has been already described, reports of transphyseal fixation of a Salter-Harris fracture in dorsoproximal–plantarodistal direction are not currently available (Klopfenstein Bregger et al., 2016; Richardson & Ortved, 2019). Van Spijk et al. (2015) reported a more stable fixation of P1 Salter-Harris type-II fractures using two locking compression plates. Since all recently described types of fixation require implant positioning on the lateral or dorsal side of P1, they are disadvantageous in case of local infection. The tension side of P1 and therefore the optimal site for fracture fixation would be on the palmar/plantar aspect of the bone. However, the anatomical conditions make the approach very difficult here (Auer, 2015; Markel & Richardson, 1985).

The current recommendation for patient positioning during repair of a Salter-Harris type-II fracture is to place the metaphyseal spike upwards to ease fracture reduction (Richardson, 2020). However, in the present case, a superficial cast sore was located on the medial aspect of the limb. For better intraoperative visualisation of the injury and placement of the implants as far away from the skin defect as possible, left lateral recumbency was initially preferred in this particular case. As the wound was draining when revision surgery was attempted, the foal was placed in right lateral recumbency for the second surgery, to avoid inadvertent contamination of the surgical site.

The minimally invasive nature of the described alternative method of fixation appears to be an advantage compared with previously described techniques in case of local infection (Auer, 2015; Markel & Richardson, 1985; Van Spijk et al., 2015). The authors suspect that a limitation may be that the stability provided by two screws only might not be sufficient for fracture fixation in older foals with a bodyweight >100 kg.

The currently recommended coaptation period following internal fixation of a Salter-Harris type-II fracture in foals ranges from 3 days to 2 weeks (Klopfenstein Bregger et al., 2016; Richardson, 2020; Van Spijk et al., 2015). In the present report, the cast was kept for 4 weeks, resulting in digital hyperextension and cast sores. The prolonged cast application was deemed necessary in this case as the revised repair appeared significantly weaker than the initial repair as well as previously described methods for fixation (Klopfenstein Bregger et al., 2016; Richardson, 2020; Van Spijk et al., 2015).

The transphyseal screw placement during the fastest growth phase caused shortening of the affected P1 in the present case (Figure 6 and Video S1) (Auer, 2015; Fretz et al., 1984; Klopfenstein Bregger et al., 2016). There was however no difference in the total length of the hindlimbs or related movement asymmetry evident 19 months following implant removal (Video S1). Most likely the longitudinal growth was compensated by other growth plates along the limb (Fretz et al., 1984; Watkins, 2006).

The osteochondral fragment observed in the affected metatarsophalangeal joint 19 months postoperatively was potentially related to the inadvertent intraarticular placement of the lateral screw head (Figures 4 and 6). Whilst there was no evidence for progressing

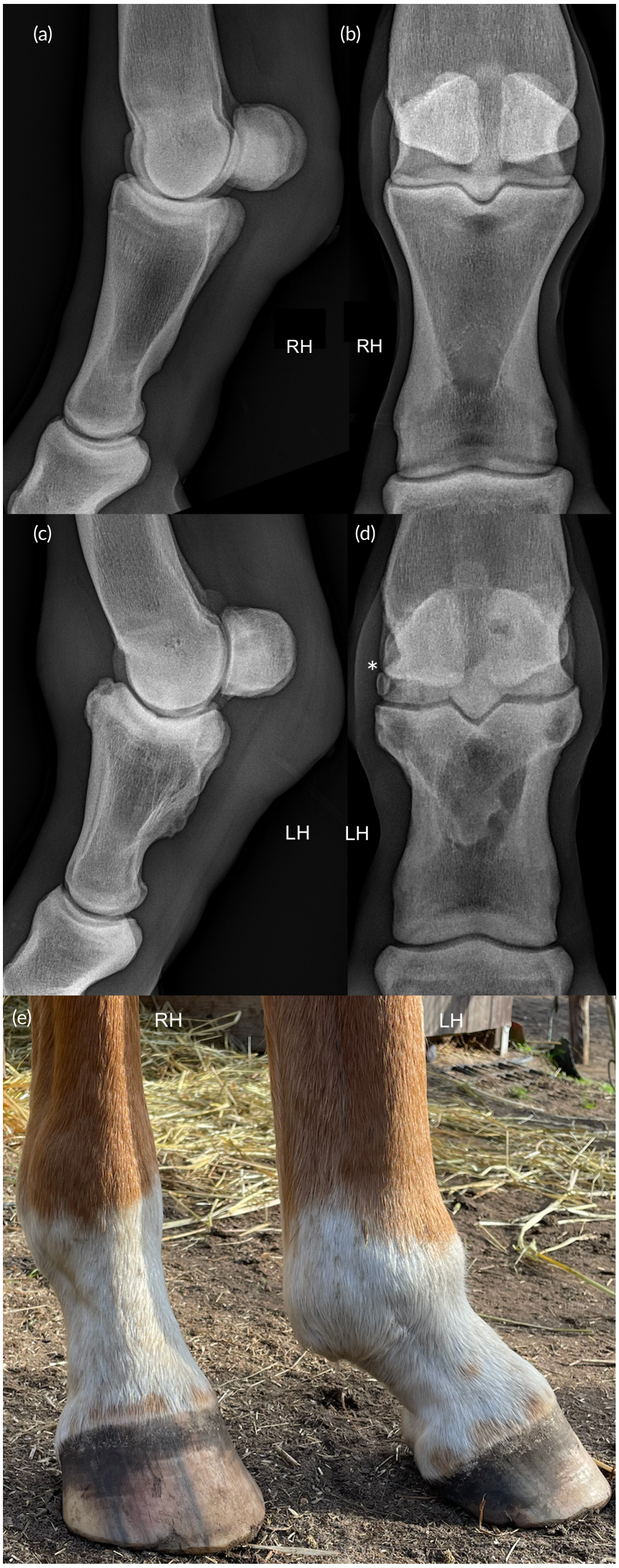

FIGURE 6 Lateromedial and dorsoplantar radiographs of right hind (a, b) and left hind fetlock region (c, d) following left hind Salter-Harris type-II fracture repair, 19 months after implant removal. Note the small osteochondral fragment (asterisk) at the level of the lateral metatarsal condylar fossa and the cyst-like lesion in the medial proximal sesamoid bone. A shortening of the left hind P1 as well as mild chronic soft tissue thickening compared to right hind is evident on radiographs and on the photograph taken at the same time (e).

osteoarthritis at this point, subsequent complications associated with this fragment cannot be ruled out and surgical removal may be considered.

Additionally, a CLL was evident on the axial aspect of the medial proximal sesamoid bone in the affected fetlock 19 months postoperatively (Figure 6). Possible causes include locally compromised blood supply due to the initial trauma, local cartilage damage, a defect in the subchondral bone or an undetected fissure in the medial proximal sesamoid bone (Del Chicca et al., 2008; Olstad et al., 2015; Ray et al., 1996). Implant infection after the initial surgery and prolonged inflammation in the fetlock region may also promote CLL formation (Ray et al., 1996; von Rechenberg et al., 2001). Since there was no functional limitation in the affected fetlock at the time of examination, the lesion was considered to be a coincidental finding at the time of examination (Howard et al., 1995; Trotter & McIlwraith, 1981).

Trauma to the growth plate in the fastest growth phase, the soft bone of the foal and positioning of the implant near the tension side are the most significant challenges in case of a proximal P1 Salter-Harris fracture (Auer, 2015; Markel & Richardson, 1985). As trauma to the physis should be avoided whenever possible, the described approach is not proposed as a first-line treatment for proximal P1 fractures in foals (Auer, 2015; Klopfenstein Bregger et al., 2016). It should be considered an alternative technique in case of previous complications with the standard methods of repair. The initial construct is less traumatic in relation to the physis, more stable and has been successful applied in case of Salter-Harris type-II fractures of the third metacarpal and metatarsal bones as well of P1 (Richardson, 2020; Richardson & Ortved, 2019).

CONCLUSIONS AND OUTLOOK

Instability associated with implant infection has historically been associated with a guarded prognosis for fracture healing and complete recovery (Goodrich, 2020; Richardson, 2020). Implant replacement following infection led to rapid fracture healing with few complications 10 weeks postoperatively in the described case. Nineteen months after implant removal, the filly showed no lameness or movement restrictions in the affected fetlock region. Implant positioning at an alternative location appears to be successful for the treatment of implant infection in unstable fractures. Evaluation of the described technique in other cases with similar fracture configuration of P1 as well as other bones would be of great interest.

AUTHOR CONTRIBUTIONS

A. Kalinovskiy, the main author, contribution to data collection, analysis and manuscript preparation. A. Ehrle contributed to manuscript preparation and data collection. E. Mueller, the second surgeon, contributed to data collection. C. Lischer, the first surgeon and senior author, contributed to the preparation of the manuscript. All authors gave their final approval to the manuscript.

ACKNOWLEDGEMENTS

The authors thank the referring veterinarian for sending the case. Open Access funding enabled and organized by Projekt DEAL.

CONFLICT OF INTEREST STATEMENT

None of the authors have any financial or personal relationships that could inappropriately influence or bias the content of this report.

FUNDING INFORMATION

No funding received.

ETHICS STATEMENT

This is a clinical case report. The consent of the owners was obtained.

ORCID

Andrey Kalinovskiy https://orcid.org/0000-0002-1320-3371
Anna Ehrle https://orcid.org/0000-0001-5338-6195

REFERENCES

Ahern, B.J., Richardson, D.W., Boston, R.C. & Schaer, T.P. (2010) Orthopedic infections in equine long bone fractures and arthrodeses treated by internal fixation: 192 cases (1990-2006). *Veterinary Surgery*, 39, 588–593.

Auer, J.A. (2015) Physeal fractures of the proximal phalanx in foals. *Equine Veterinary Education*, 27, 183–187.

Auer, J.A. (2019) Principles of fracture treatment. In: Auer, J.A., Stick, J.A. & Kummerle, J.M. (Eds.) *Equine surgery*, 5rd edition. St. Louis: Elsevier, pp. 1277–1314.

Biasutti, S.A., Cox, E., Jeffcott, L.B. & Dart, A.J. (2021) A review of regional limb perfusion for distal limb infections in the horse. *Equine Veterinary Education*, 33, 263–277.

Borriello, G., Werner, E., Roe, F., Kim, A.M., Ehrlich, G.D. & Stewart, P.S. (2004) Oxygen limitation contributes to antibiotic tolerance of *Pseudomonas aeruginosa* in biofilms. *Antimicrobial Agents and Chemotherapy*, 48, 2659–2664.

Clegg, P.D. (2011) Osteomyelitis in the veterinary species. In: Percival, S., Knottenbelt, D. & Cochrane, C. (Eds.) *Biofilms and veterinary medicine*, 1st edition. Heidelberg: Springer, pp. 175–190.

Del Chicca, F., Kümmerle, J.M., Ossent, P., Nitzl, D., Fuerst, A. & Ohlerth, S. (2008) Use of computed tomography to evaluate a fracture associated with a subchondral pedal bone cyst in a horse. *Equine Veterinary Education*, 20, 515–519.

Dernell, W.S. (1999) Treatment of severe orthopedic infections. *Veterinary Clinics of North America: Small Animal Practice*, 29, 1261–1274.

Donati, B., Fürst, A.E., Del Chicca, F. & Jackson, M.A. (2021) Plate removal after internal fixation of limb fractures: a retrospective study of indications and complications in 48 horses. *Veterinary and Comparative Orthopaedics and Traumatology*, 34, 59–67.

Fretz, P.B., Cymbaluk, N.F. & Pharr, J.W. (1984) Quantitative analysis of long-bone growth in the horse. *American Journal of Veterinary Research*, 45, 1602–1609.

Goodrich, L.R. (2020) Osteomyelitis. In: Nixon, A.J. (Ed.) *Equine fracture repair*, 2nd edition. Hoboken, New Jersey: Wiley-Blackwell, pp. 851–873.

Howard, R.D., McIlwraith, C.W. & Trotter, G.W. (1995) Arthroscopic surgery for subchondral cystic lesions of the medial femoral condyle in horses: 41 cases (1988-1991). *Journal of American Veterinary Medical Association*, 206, 842–850.

Klopfenstein Bregger, M.D., Fürst, A.E., Kircher, P.R., Kluge, K. & Kummer, M. (2016) Salter-Harris type II metacarpal and metatarsal fracture in three foals. Treatment by minimally-invasive lag screw osteosynthesis combined with external coaptation. *Veterinary and Comparative Orthopaedics and Traumatology*, 29, 239–245.

Levine, D.G. & Aitken, M.R. (2017) Physeal fractures in foals. *Veterinary Clinics of North America: Equine Practice*, 33, 417–430.

Lischer, C. & Mählmann, K. (2022) Post-operative complications. In: Wright, I.M. (Ed.) *Fractures in the horse*, 1st edition. Hoboken, NJ: John Wiley & Sons, pp. 283–309.

MacDonald, D.G., Morley, P.S., Bailey, J.V., Barber, S.M. & Fretz, P.B. (1994) An examination of the occurrence of surgical wound infection following equine orthopaedic surgery (1981-1990). *Equine Veterinary Journal*, 26, 323–326.

Markel, M.D. (2020) Bone grafts and bone substitutes. In: Nixon, A.J. (Ed.) *Equine fracture repair*, 2nd edition. Hoboken, New Jersey: Wiley-Blackwell, pp. 163–172.

Markel, M.D. & Richardson, D.W. (1985) Noncomminuted fractures of the proximal phalanx in 69 horses. *Journal of the American Veterinary Medical Association*, 186, 573–579.

Newman, J.C., Prange, T., Jennings, S., Barlow, B.M. & Davis, J.L. (2013) Pharmacokinetics of tobramycin following intravenous, intramuscular, and intra-articular administration in healthy horses. *Journal of Veterinary Pharmacology and Therapeutics*, 36, 532–541.

Nunamaker, D.M. (2020) Orthopedic implant failure. In: Nixon, A.J. (Ed.) *Equine fracture repair*, 2nd edition. Hoboken, New Jersey: Wiley-Blackwell, pp. 831–834.

Olstad, K., Ekman, S. & Carlson, C.S. (2015) An update on the pathogenesis of osteochondrosis. *Veterinary Pathology*, 52, 785–802.

Ortved, K.F. & Richardson, D.W. (2021) Complications of equine orthopedic surgery. In: Rubio-Martinez, L.M. & Hendrickson, D.A. (Eds.) *Complications in equine surgery*, 1st edition. Hoboken, New Jersey: Wiley-Blackwell, pp. 629–666.

Ray, C.S., Baxter, G.M., McIlwraith, C.W., Trotter, G.W., Powers, B.E., Park, R.D. et al. (1996) Development of subchondral cystic lesions after articular cartilage and subchondral bone damage in young horses. *Equine Veterinary Journal*, 28, 225–232.

Richardson, D.W. (2020) Fractures of the proximal phalanx. In: Nixon, A.J. (Ed.) *Equine fracture repair*, 2nd edition. Hoboken, New Jersey: Wiley-Blackwell, pp. 295–319.

Richardson, W.D. & Ortved, K.F. (2019) Third metacarpal and metatarsal bones. In: Auer, J.A., Stick, J.A. & Kummerle, J.M. (Eds.) *Equine surgery*, 5th edition. St. Louis: Elsevier, pp. 1618–1635.

Ruggles, A.J. (2020) Implant removal. In: Nixon, A.J. (Ed.) *Equine fracture repair*, 2nd edition. Hoboken, New Jersey: Wiley-Blackwell, pp. 823–830.

Stoodley, P., Kathju, S., Hu, F.Z., Erdos, G., Levenson, J.E., Mehta, N. et al. (2005) Molecular and imaging techniques for bacterial biofilms in joint arthroplasty infections. *Clinical Orthopaedics and Related Research*, 437, 31–40.

Trotter, G.W. & McIlwraith, C.W. (1981) Osteochondritis dissecans and subchondral cystic lesions and their relationship to osteochondrosis in the horse. *Journal of Equine Veterinary Science*, 1, 157–162.

Van Spijk, J.N., Fürst, A.E., Del Chicca, F., Ringer, S.K. & Jackson, M.A. (2015) Minimally-invasive plate osteosynthesis of a salter-Harris type 2 fracture of the proximal phalanx in a filly. *Equine Veterinary Education*, 27, 179–182.

von Rechenberg, B., Leutenegger, C., Zlinsky, K., McIlwraith, C.W., Akens, M.K. & Auer, J.A. (2001) Upregulation of mRNA of interleukin-1 and -6 in subchondral cystic lesions of four horses. *Equine Veterinary Journal*, 33, 143–149.

Watkins, J.P. (2006) Etiology, diagnosis, and treatment of long bone fractures in foals. *Clinical Techniques in Equine Practice*, 5, 296–308.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Kalinovskiy, A., Ehrle, A., Müller, E. & Lischer, C. (2023) Alternative approach for fracture fixation following implant infection in a Salter-Harris type-II fracture of the proximal phalanx in a Warmblood foal. *Equine Veterinary Education*, 35, e641–e649. Available from: https://doi.org/10.1111/eve.13822