

Evaluation of factors associated with surgical site infection in equine proximal interphalangeal joint arthrodesis: 54 cases (2010–2019)

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Abstract

Background: The frequency of surgical site infection (SSI) following orthopaedic implant placement in horses has been reported but not compared with respect to specific antibiotic protocols administered.

Objectives: To determine factors associated with SSI in horses undergoing proximal interphalangeal joint (PIPJ) arthrodesis including perioperative antibiotic protocols.

Methods: Records were evaluated (2010–2019), and horses undergoing PIPJ arthrodesis were identified. Patient signalment, supervising surgeon, reason for surgery, limb, implants placed, anaesthetic time, duration casting/coaptation postoperatively, antibiotic regimen and incidence/onset SSI were recorded. Bayesian and frequentist logistic regressions were used to estimate the contribution of covariates to infection occurrence.

Results: Fifty-four PIPJ arthrodeses were performed. SSI occurred in 2/54 (3.7%) on day 15,30. Arthrodesis was performed most commonly for osteoarthritis (33/54, 61.1%), fracture (11/54, 20.4%), and subluxation (5/54, 9.3%). Perioperative systemic antibiotics were administered 1–3 days (15/54, 27.8%) or > 3 days (39/54, 72.2%). Antibiotic protocols included cefazolin/gentamicin (20/54, 37%), cefazolin/gentamicin/doxycycline (14/54, 25.9%) and potassium penicillin/gentamicin (10/54, 18.5%). Regional limb perfusion was performed preoperatively 31/54 (57.4%) and postoperatively 7/54 (13%). Survival to dismissal was 98.1% (53/54 horses) with one horse euthanized due to support limb laminitis. No association was identified between antibiotic selection or duration (1–3 vs. > 3 days), pre-operative regional antibiotic perfusion, intraoperative antibiotic lavage or anaesthetic time (< or > 3 h) and SSI; however, modelling was complicated by quasi-complete or complete separation of the data. Bayesian analysis (but not frequentist analysis) indicated an association between post-operative regional antibiotic perfusion and SSI. Limitations include the retrospective nature of data collection and the low rate of infection overall.

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Conclusions: The prevalence of SSI in this population was lower than that in previous reports of equine orthopaedic internal fixation. There was no difference in SSI rate in cases administered systemic antibiotics for 1–3 days or >3 days, or for those horses that did or did not receive preoperative regional antibiotic perfusion.

KEYWORDS

antibiotics, arthrodesis, horse, pastern, proximal interphalangeal

1 | INTRODUCTION

Surgical site infection (SSI) represents the primary cause of mortality after equine orthopaedic procedures including internal fixation (Stockle et al., 2018). Curtiss et al. reported that horses that developed SSI were 12 times less likely to survive hospital dismissal than horses without SSI (Curtiss et al., 2019). Treatment of infection increases the cost of care and can result in reduced functional and cosmetic concerns in the operated limb (Weese, 2008). The prevalence of SSI in equine orthopaedic procedures has been reported to occur in 10–28% of cases (Ahern et al., 2010; Curtiss et al., 2019; Knox & Watkins, 2006; Macdonald et al., 1994; McCormick & Watkins, 2017; Sakai et al., 2018). Factors previously associated with an increased risk of development of infection in equine musculoskeletal procedures include placement of implants, surgical duration (procedures > 3 h [Ahern et al., 2010] or 90 min [Macdonald et al., 1994], fracture configuration (open vs. closed), method of repair (open reduction), female sex and operated locations distal on the limb (Ahern et al., 2010; Curtiss et al., 2019; Macdonald et al., 1994; Richardson & Ahern, 2011). Increased risk of SSI was associated with internal fixation for carpal arthrodesis, fetlock arthrodesis, radial fracture, humeral fracture and femoral fracture when compared to other locations (Curtiss et al., 2019). A protective role for local antibiotic administration by regional limb perfusion (RLP) or prolonged systemic antibiotic administration has not been reported (Curtiss et al., 2019).

Proximal interphalangeal joint (PIPJ) arthrodesis is performed in horses with instability or osteoarthritis of the PIPJ, fracture of the second phalanx and less commonly for flexural deformities, phalangeal deviations in foals, osteochondritis dissecans or subchondral cystic lesions (Adams et al., 1995; Caron et al., 1990; Colahan et al., 1981; Martin et al., 1984; Rick et al., 1986; Schneider et al., 1978; Steenhaut et al., 1985; Watkins, 1996; Whitehair et al., 1992). Multiple surgical techniques for PIPJ arthrodesis have been described, including trans-articular screws placed in lag fashion, plate-screw combinations and chemically induced or laser-facilitated ankylosis (Caston et al., 2013; Herthel et al., 2016; Knox & Watkins, 2006; Levine & Richardson, 2007; Maclellan et al., 2001; McCormick & Watkins, 2017; Sakai et al., 2018; Schaer et al., 2001; Schneider et al., 1993; Watts et al., 2010). The selection of orthopaedic implants used in PIPJ arthrodesis has reportedly evolved over time, with trans-articular screws employed most commonly in the 1990s, dynamic compression plates (DCP) and limited contact-dynamic compression plates (LC-DCP) used more frequently in the 2000s, and locking compression plate technology becoming

available and gaining frequency of use in equine practice after 2010 with purported benefits of increased biomechanical strength compared to previous devices (Levine & Richardson, 2007; Sakai et al., 2018). Retrospective evaluations of equine patients undergoing PIPJ with orthopaedic implant placement have reported SSI rates in 2/30 (6.6%) (McCormick & Watkins, 2017), 3/30 (10%) (Hicks et al., 2021), 6/53 (11.3%) (Knox & Watkins, 2006), and 5/29 (17.2%) (Sakai et al., 2018) cases. The outcome for athletic performance following PIPJ arthrodesis was reduced in horses operated on for osteoarthritis vs. other causes (Herthel et al., 2016). The type of fixation did not affect the return to the intended level of performance, although the duration of casting was reduced in horses where a plate and screw combination was placed compared to screws alone (Herthel et al., 2016; Schaer et al., 2001). However, factors associated with the development of infection have not been investigated specifically and compared between perioperative techniques, specifically with regard to antibiotic protocols for PIPJ arthrodesis.

While infection rates are moderately high in surgeries involving orthopaedic implants compared to other commonly performed procedures, the use of antibiotics locally or for extended periods of time postoperatively has not been demonstrated to have a direct beneficial effect on reducing SSI risk and furthermore may precipitate negative side effects such as imbalance of intestinal microflora. However, the selection of specific antibiotic regimens and duration of administration have not been compared with respect to complications such as SSI. The increasing incidence of antibiotic resistance in equine practice (Herdan et al., 2012; Loncarac et al., 2014; Theelin et al., 2014; Malardo et al., 2013; van den Eede et al., 2009, 2012) and the desire to minimize risks associated with antibiotic administration have prompted the evaluation of antibiotic protocols in many aspects of equine practice. Therefore, the objective of this study was to examine factors associated with SSI in horses undergoing PIPJ arthrodesis. We hypothesized that the development of infection would not be affected by the perioperative antibiotic protocol administered and that prolonged administration of systemic intravenous antibiotics past 72 h postoperatively would provide no additional benefit in minimizing the risk of SSI.

2 | MATERIALS AND METHODS

2.1 | Study design and data retrieval

Medical records (2010–2019, inclusive) of all horses presenting to the Surgery Service at Colorado State University Veterinary

Teaching Hospital were retrospectively reviewed. Horses that underwent PIPJ arthrodesis were identified and included. Data retrieved from medical records included patient signalment, weight, primary supervising surgeon, limb(s) operated, orthopaedic implants placed, closure technique, total anaesthetic duration, cast placement (yes/no), casting duration, number of cast changes and additional external coaptation postoperatively, perioperative antibiotic selection, duration and route of administration (systemic, regional perfusion, local intraoperative lavage), development of SSI, time postoperatively at which infection was recognized, treatment for infection if performed and duration of hospitalization. Data were recorded via computer-based spreadsheet (Microsoft Office Excel, Microsoft Corporation, Redmond, Washington, USA) and subsequently transferred to a statistical program (R version 4.1.2, R Foundation, Vienna, Austria) for analysis.

The criteria used to determine whether SSI had developed were at least two of the following: identification of a positive bacterial culture from the surgical site if submitted, presence of a draining tract from the surgical site with clinical observation of change in comfort level, radiographic or ultrasonographic evidence of infection and/or development of a fever ($>101.5^{\circ}\text{F}$) that could not be otherwise explained, as previously described (Ahern et al., 2010; Curtiss et al., 2019).

2.2 | Perioperative protocols

Preoperatively, all horses underwent preoperative radiographic imaging, including a minimum of a standard four-view radiographic series of the affected limb (dorsopalmar or dorsoplantar, lateromedial, 45° dorsomedial-palmarolateral or plantarolateral oblique, 45° dorsolateral-palmaromedial or plantaromedial oblique). Nonsteroidal anti-inflammatories (NSAIDs) (phenylbutazone 4.4 mg/kg IV) and tetanus toxoid (if indicated) were administered. Preoperative antibiotic protocols were selected at the discretion of the senior surgeon and consisted of either potassium penicillin (22,000 U/kg, IV, every 6 h) or cefazolin (11 mg/kg, IV, every 12 h) given in combination with gentamicin (6.6 mg/kg, IV, every 24 h), and followed in some cases by trimethoprim sulfamethoxazole (30 mg/kg PO, every 12 h), doxycycline (10 mg/kg PO, every 12 h) or minocycline (4 mg/kg PO, every 12 h). In one horse, doxycycline alone was administered preoperatively. General anaesthesia was induced and maintained per protocols determined by the senior board-certified anaesthesiologist.

For surgery, horses were positioned in lateral recumbency with the affected limb up. The operated limb was clipped circumferentially from the coronary band to the level of the proximal metacarpus or metatarsus and aseptically prepared using chlorhexidine gluconate (chlorhexidine gluconate, 4%, VetOne, MWI, Boise, Idaho, USA) followed by normal saline. An Esmarch bandage was placed to minimize intraoperative haemorrhage. A standard approach to the PIPJ was performed as previously described (Lischer & Auer, 2019). Briefly, an inverted 'T-shaped' incision was made over the dorsal aspect of the PIPJ. An inverted V-shaped incision was made through the long digital extensor tendon and extended to enter the PIP joint capsule. The PIP joint was disarticulated following transection of the medial and lateral collateral ligaments and

dorsal joint capsule. The articular cartilage was removed from the PIPJ in all cases using a curette, and osteostixis was performed with a 2.5-mm drill bit. Either a DCP, LC-DCP or locking compression plate (LCP) plate with two trans-articular screws placed in lag fashion, two LCP plates or two trans-articular screws were used as previously described (Herthel et al., 2016; Hicks et al., 2021; Sakai et al., 2018). All plates were contoured to provide plate-to-bone contact as needed.

The transected ends of the extensor tendon were opposed with absorbable sutures using a combination of simple interrupted and continuous patterns. The skin was closed using a combination of simple interrupted cruciate and tension-relieving suture patterns (near-far-far-near). The surgical site was bandaged using kerlix AMD (Kerlix AMD, Covidien, Dublin, Ireland) and elastikon (Elastikon, Johnson & Johnson, New Brunswick, New Jersey, USA) and the operated limb was placed in a cast. The duration of casting and additional external coaptation were at the discretion of the senior surgeon. Following recovery from general anaesthesia, the contralateral limb was placed in a supportive boot (Soft-ride Inc., Vermillion, Ohio, USA) or support shoe (NANRIC Inc., Lawrenceburg, Kentucky, USA).

Postoperatively, all horses were administered nonsteroidal anti-inflammatories (phenylbutazone 2.2 mg/kg IV or PO, every 12 h) for at least 5 days following surgery with duration depending on patient discomfort and at the discretion of the senior surgeon. Intravenous antibiotics (either cefazolin or potassium penicillin in combination with gentamicin as described above) were continued postoperatively for a total of 3–7 days, followed by oral antibiotics in some cases, as described above.

Postoperative radiographs were typically performed 24 h following surgery, at the time of first cast change or removal, and at approximately 3–4 months postoperatively prior to increasing exercise to document implant position and progression of arthrodesis and/or fracture healing. Skin sutures were aseptically prepared in a routine fashion and removed at the time of first cast change, recommended at approximately 2–3 weeks postoperatively. Additional casting, bandage casting, splinting and bandaging were performed depending on clinician preference, the appearance of postoperative radiographic fusion and the apparent comfort level of the horse. Gradual return to exercise was recommended over the first 3–4 months postoperatively, with stall rest, initially and increased hand-walking based on the apparent comfort level, the appearance of postoperative radiographs and clinician preference.

2.3 | Statistical analysis

The following variables were coded as binary predictors (Y or N) for modelling: The presence of post-operative infection, the use of antibiotics for < 3 days post-operatively, the use of oral antibiotics post-operatively, performance of antibiotic RLP pre- or post-operatively, and duration of anaesthesia > 3 h. The sex of horses and affected limbs were included, and age in years was maintained as a linear predictor. Due to quasi-complete and complete separation of the data, penalized logistic regression (R package *logistf* (Heinze et al., 2020) was used for

TABLE 1 Diagnostics and posterior summary statistics of the parameters included in the final model

Parameter	<i>n_{eff}</i>	Rhat	Mean	MCSE	SD	2.5%	97.5%
(Intercept)	2190	1	-3.4	0	1.7	-7	-0.6
Duration of antibiotic use < 3 days	1911	1	-2.2	0.1	2.4	-7.3	1.9
Regional limb perfusion post-operatively	1500	1	4.5	0.1	1.9	1.1	8.8
Duration of anaesthesia > 3 h	1921	1	-2.4	0	2	-6.6	1.2
Mean PPD	4354	1	0.1	0	0	0	0.1
log-posterior	1358	1	-11.9	0	1.5	-15.5	-10.1

Abbreviations: MSCE, Monte Carlo standard error; *n_{eff}*, effective sample size; PPD, posterior predictive distribution; SD, standard deviation.

initial statistical modelling. No combination of variables or individual variables allowed for model convergence, and no variables were found to have an odds ratio significantly different from 1 either alone or in combination. Due to convergence issues, Bayesian analysis was utilized in an attempt to model the data more efficiently.

Further analysis of the models was performed using Bayesian logistic regression (*stan-glm*) via the R package *rstanarm* (Goodrich et al, 2020). The final model was arrived at by omitting individual predictors from the model containing all predictors and examining the change in expected log predictive density via leave-one-out sampling (*elpdloo*) (R package *loo*) (Vehtari et al, 2017, 2020). The final model included the use of antibiotics for less than or equal to 3 days, the use of post-operative regional antibiotic perfusion and the duration of anaesthesia (classified as less than or greater than 3 h). Diagnostics and summary statistics for the final model are summarized in Table 1. Statistical analysis was performed using R version 4.1.2 ("Bird Hippie") (R Core Team, 2021).

3 | RESULTS

3.1 | Signalment and rationale for surgery

During the time frame examined, 54 horses were identified to have undergone PIPJ arthrodesis. Breeds presented were predominantly stock-type horses (Quarter horses (*n* = 31), Paints (*n* = 6) and Appaloosas (*n* = 3)) and also included Arabians (*n* = 4), Warmbloods (*n* = 3), mixed breeds (*n* = 3), Saddlebreds (*n* = 2), Morgans (*n* = 1) and Missouri Fox Trotters (*n* = 1), which is representative of the case population at this institution. There were 33 geldings, 16 mares and 5 stallions. The mean age at the time of surgery was 8.4 years (median 8 years, range 0.75–20). The mean weight of horses was 488 kg (median 500, range 281–620 kg).

Reasons for performing surgery were primarily osteoarthritis (*n* = 33), followed by fracture (*n* = 11), subluxation (*n* = 5), osseous cyst-like lesion (*n* = 2), osteoarthritis with osseous cyst-like lesion (*n* = 2) and severed lateral collateral ligament (*n* = 1). The distribution of limbs operated on was relatively even between the fore- and hindlimbs and left to right (LF *n* = 13, RF *n* = 14, LH *n* = 13, RH *n* = 14). Only a single limb was operated on in every case. The data are summarized in Table 2.

3.2 | Details of surgical procedure

Surgical procedures were performed by seven senior clinicians who performed 20, 13, 10, 5, 4, 1, and 1 procedures. Fourteen house officers assisted in arthrodesis procedures and postoperative management of cases. Orthopaedic implants selected were most commonly 3-hole 4.5 mm narrow LCP with two abaxial trans-articular screws (*n* = 35), followed by 3-hole DCP with two abaxial trans-articular screws (*n* = 10), two 3-hole 4.5 mm narrow LCPs (*n* = 7), 4-hole LC-DCP with two abaxial transarticular screws (*n* = 1) or two trans-articular screws alone (*n* = 1). The total anaesthetic time was on average 192 min (median 195 min, range 105–315 min). Computed tomography scanning was performed under the same general anaesthetic event in one case.

3.3 | Antibiotic protocols

Nine combinations of antibiotics and 21 different regimens with differing drug selections and durations of administration were implemented in the 54 operated cases. Antibiotic selections included cefazolin/gentamicin (*n* = 20), cefazolin/gentamicin/doxycycline (*n* = 14), potassium penicillin/gentamicin (*n* = 10), potassium penicillin/gentamicin/doxycycline (*n* = 3), potassium penicillin/gentamicin/trimethoprim sulfamethoxazole (*n* = 2), cefazolin/gentamicin/trimethoprim sulfamethoxazole (*n* = 2), cefazolin/gentamicin/doxycycline/trimethoprim sulfamethazole (*n* = 1), cefazolin/gentamicin/minocycline (*n* = 1) or doxycycline alone (*n* = 1). The three most common protocols prescribed included intravenous administration for 3 days (*n* = 19), intravenous administration for 5 days (*n* = 4) and intravenous administration for 5 days followed by oral administration for 5 days (*n* = 4). Drugs and durations of administration varied from intravenous use alone for 2–8 days, oral (PO) antibiotic administration (duration unrecorded in a single case) or intravenous administration for 1–7 days followed by oral antibiotic administration for 5–104 days.

RLP was performed preoperatively in 31/54 (57.4%) cases and post-operatively in 7/54 (13.0%) cases. In cases where postoperative RLP was performed, perfusions were administered four times (*n* = 4), three times (*n* = 1), two times (*n* = 1) or ten times (*n* = 1). Antibiotics and doses administered in regional perfusions were most commonly amikacin

TABLE 2 Patient characteristics

Variable	Study horses (n = 54)
Age (years)	Mean 8; range 0.8–20
Sex	Gelding (33) Mare (16) Stallion (5)
Body weight (kg)	Mean 488; range 281–620
Breed	Quarter Horse (31) Paint (6) Arabian (4) Appaloosa (3) Warmblood (3) Mixed Breed (3) Saddlebred (2) Morgan (1) Missouri Fox Trotter (1)
Diagnosis	Osteoarthritis PIPJ (32) P2 Fracture (11) Subluxation PIPJ (5) Osseous cystlike lesion P2 (2) Osteoarthritis with cyst-like lesion P2 (2) Severed lateral collateral ligament PIPJ (1) Chronic fracture with osteoarthritis PIPJ (1)
Limb	LF (13) RF (14) LH (13) RH (14)
Implants	3-hole LCP (35) 3-hole DCP (10) two 3-hole LCP (7) 4-hole LCDCP (1) 2 screws (1)
Duration Anaesthesia (hours)	Mean 3.2; Range 1.75 to 5.25
Duration Cast (days)	Mean 25; Range 14 to 67
Duration Hospitalization (days)	Median 7; Range 3 to 117
Complications	Gastrointestinal (colic/diarrhea) (20) Cast sores (15) Surgical site pain (6) Facial nerve paralysis (5) Corneal ulcer (2) Support limb laminitis (2) Swelling proximal to cast (2) Fever of unknown origin (1)

Abbreviations: LCP, locking compression plate; DCP, dynamic compression plate, LCDCP, limited contact dynamic compression plate.; LF, left forelimb; LH, left hindlimb; P2, second phalanx; PIPJ, proximal interphalangeal joint; RF, right forelimb; RH, right hindlimb.

TABLE 3 Antibiotic dosing strategies

Variable	Study horses (n = 54)
Systemic selection	cefazolin gentamicin (20) cefazolin, gentamicin, doxycycline (14) potassium penicillin, gentamicin (10) potassium penicillin, gentamicin, doxycycline (3) potassium penicillin, gentamicin, trimethoprim sulfamethoxazole (2) cefazolin, gentamicin, trimethoprim sulfamethoxazole (2) doxycycline (1) cefazolin, gentamicin, doxycycline, trimethoprim sulfamethoxazole (1) cefazolin, gentamicin, minocycline (1)
Duration (days)	>3 (39) ≤ 3 (15)
Route of administration	IV only (31) IV and PO (23)
Regional limb perfusion	Preoperative (31) Postoperative (7)
Intraoperative lavage	yes (52) no (2)

Abbreviations: IV, intravenous; PO, per os.

sulfate 2 g ($n = 12$) or amikacin sulfate 1 g ($n = 9$), followed by amikacin 3 g ($n = 1$), amikacin 1 g/timentin 1 g ($n = 2$), amikacin 1 g/timentin 2 g ($n = 2$) and amikacin 1 g/timentin 3 g ($n = 2$). Doses were not specified in the medical record in two cases (amikacin in one case, and amikacin/timentin in the second case). Intraoperative lavage with antibiotic infused (neomycin, polymyxin B, ampicillin) sterile saline was performed in 52/54 (96.3%) cases. The data are summarized in Figure 1 and Table 3.

3.4 | Surgical site infection rate

SSI was diagnosed in 2/54 (3.7%) cases, which were identified at days 15 and 30 postoperatively. Bayesian analysis indicated that a short course of antibiotics (< 3 days) and a longer duration of anaesthesia (> 3 h) could be associated with a decrease in the incidence of SSI (although the confidence intervals for the odds ratio both include 1, indicating a wide margin of error and lack of significance), while the performance of post-operative regional antibiotic perfusion was associated with an increase in the risk of SSI. The associated odds ratios are summarized in Supplemental Document 1.

Two different combinations of senior surgeons and house officers were involved in each of the two cases that resulted in infection postoperatively. Original perioperative antibiotic protocols consisted of potassium penicillin/gentamicin for 3 days or cefazolin gentamicin

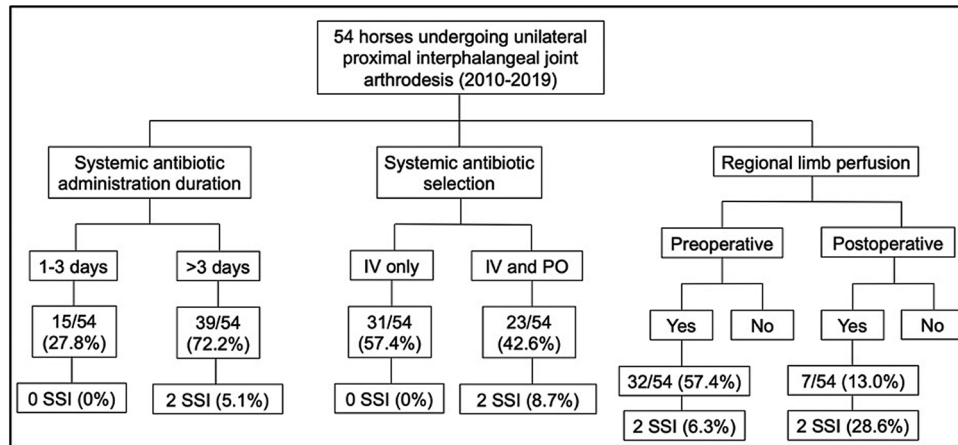


FIGURE 1 Flow diagram illustrating the number of horses undergoing PIPJ arthrodesis that received various antibiotic protocols that resulted in infection postoperatively. Over the time period evaluated, 54 arthrodeses were performed, resulting in two cases of SSI (3.7% of limbs and procedures). Antibiotic selection, duration (1–3 vs. 3 days) and use of pre- or post-operative RLPs were not associated with an increased risk of developing SSI

for 7 days. In both cases, a 3-hole narrow 4.5 mm LCP plate with abaxial trans-articular screws was placed. Reasons for the operation were an open comminuted second phalangeal fracture in one case or osteoarthritis in the second case. Once identified, the infection was treated with prolonged oral antibiotic therapy, regional perfusions and local dressings. In the first horse, a 12-year-old Arabian gelding presenting for osteoarthritis, treatment consisted of trimethoprim sulfamethoxazole for five additional days, RLPs postoperatively ($n = 4$) and topical therapy with vinegar for *Pseudomonas* infection. The infection was successfully resolved with medical management and implant removal was not necessary. In the second horse, a three-year-old Quarter Horse gelding presenting for open comminuted second phalangeal fracture, postoperative treatment consisted of prolonged oral antibiotic therapy (trimethoprim sulfamethoxazole 104 days, RLPs every 36–48 h for a total of 10 perfusions and local surgical site preparation (Figure 2). Clinical signs of infection improved and the horse survived dismissal from the hospital although dismissal instructions indicated that implant removal would likely be necessary and recheck examination and radiographs were recommended; however, the patient was lost to further follow-up and whether implants were in fact removed could not be ascertained retrospectively. Aerobic/anaerobic culture and sensitivity were submitted in the first case, which yielded growth of *Pseudomonas*, *Cronobacter*, and *Aerococcus* spp. Culture and sensitivity were not performed in the second case, but the infection was suspected based on the presence of lameness, incisional discharge, and clinical response to antimicrobial therapy.

3.5 | Complications and outcomes

Forty-five horses experienced complications related to the procedure, the majority of which (42/45) were considered mild and responded favourably to medical management. Complications pre-

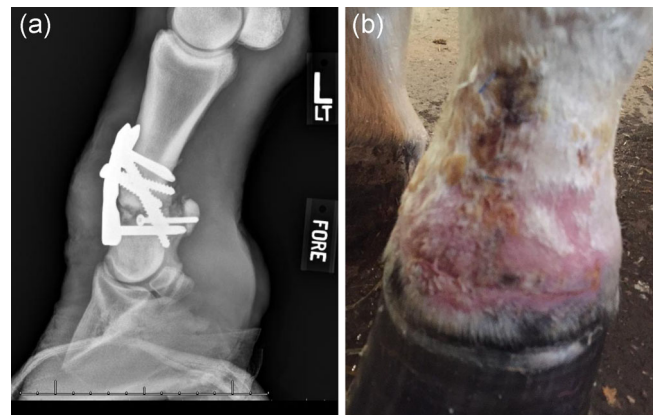


FIGURE 2 Lateral postoperative radiograph of the pastern of the left forelimb (a) and photograph (b) of a three-year-old Quarter Horse gelding who presented for open comminuted second phalangeal fracture and subsequently developed SSI

dominantly gastrointestinal included colic/decreased manure output/diarrhea ($n = 20$), cast sores ($n = 16$), postoperative pain associated with the surgical site requiring additional treatment ($n = 6$), facial nerve paralysis ($n = 6$), corneal ulceration ($n = 2$), support limb laminitis ($n = 2$), swelling proximal to the cast ($n = 2$), fever of unknown origin ($n = 1$), plate screw breakage ($n = 1$) and implant discomfort necessitating removal ($n = 1$). One horse was euthanized 93 days postoperatively for support limb laminitis following arthrodesis for biaxial eminence fracture of the left hind second phalanx. An additional horse was managed with prolonged casting for an additional 4 weeks following breakage of the distal plate screw, and subsequent development of lameness was noted at 63 days postoperatively. In a third horse, implants were removed at day 144 postoperatively due to persistent lameness attributed to suspected impingement on the deep digital flexor tendon, which improved following implant removal.

3.6 | Postoperative care

Nonsteroidal anti-inflammatories (phenylbutazone 2.2 mg/kg by mouth every 12 h) were continued for at least 5 days postoperatively and varied at the discretion of the senior clinician. Additional treatments were performed for perceived postoperative discomfort on the operated limb including butorphanol 0.01–0.03 mg/kg intramuscularly ($n = 4$ cases), fentanyl 100 $\mu\text{g/h}$ patch ($n = 1$) and topical diclofenac for soft tissue swelling proximal to the cast ($n = 2$). Acupuncture was performed for the development of facial nerve paralysis following recovery from general anaesthesia ($n = 4$). Cryotherapy of the contralateral limb was performed for the treatment of support limb laminitis ($n = 2$). Topical triple antibiotic ointment was applied for the development of superficial corneal ulceration sustained during recovery ($n = 2$).

A distal limb cast was placed in all cases to support the arthrodesis and maintained for a mean of 24 days (median 21 days, range 14–67) until the first cast change or removal. Horses were discharged in casts and returned for cast removal on an outpatient basis in most cases, with the typical recommendation for time to initial removal of the cast to be 14–21 days postoperatively. Sutures were removed at the first cast change, following radiography. Five horses had casts placed for additional time points after the first cast removal, ranging from one to four additional casting sessions prior to transitioning to a bandage cast or splint. Following the removal of the cast, horses were either transitioned to a splint for 2–3 weeks followed by a bandage for 2–3 weeks ($n = 13$), bandage cast for 2–3 weeks followed by splint followed by bandage ($n = 11$), bandage alone for up to 4 weeks ($n = 9$), bandage cast for 2–3 weeks followed by bandage ($n = 6$), bandage cast followed by bivalved cast followed by splint followed by bandage ($n = 3$) or bivalved cast followed by bandaging ($n = 3$) in the 35 cases for which further follow-up past initial cast change was available. Horses were hospitalized for a median of 7 days (mean 12 days, range 3–117). Prolonged hospitalization in some cases was influenced by management of complications and owner convenience to pick up patients postoperatively.

4 | DISCUSSION

This study described the rate of SSI in equine PIPJ arthrodesis and the relative risk for development of infection with various systemic and local antibiotic protocols. The prevalence of SSI in this population (3.7%) was lower than previous reports in equine orthopaedic internal fixation (10–28%; Ahern et al., 2010; Curtiss et al., 2019; Macdonald et al., 1994) or PIPJ arthrodesis specifically (6.6–17.2%; Hicks et al., 2021; Knox & Watkins, 2006; McCormick and Watkins, 2017; Sakai et al., 2018). There was no difference in SSI rate in cases administered systemic antibiotics for 1–3 days or > 3 days, or for those horses that did or did not receive regional antibiotic perfusion in this population, although Bayesian odds ratios indicate that a shorter course (< 3 days) of antibiotics may be associated with a decrease in the odds of a postoperative SSI. The interpretation of this decrease may be made in sev-

eral ways. One is that a shorter course of antibiotic administration (< 3 days) is as good or better than a longer course of antibiotic administration at preventing SSI. Another is that cases that were deemed 'at risk' for post-operative SSI were routinely treated for a longer period of time and that some of these cases did indeed develop an SSI. As there is no way to retrospectively determine the basis for decisions made at the time of surgery, both of these remain valid, with the former supporting the initial hypothesis that an extended duration of antibiotic treatment would not provide any additional benefit in the prevention of SSI.

There was no association found in either analysis between the antibiotic protocol selected, sex, anaesthetic duration or surgeon with the development of infection. These findings differ from previous reports where females and prolonged anaesthetic duration > 90 min or 3 h were identified as risk factors for the development of infection (Ahern et al., 2010; Curtiss et al., 2019; Macdonald et al., 1994; Richardson & Ahern, 2011). As this study was performed in a single referral clinic, other factors that may affect the risk of SSI such as intraoperative protocols for asepsis were maintained relatively consistently between clinicians and surgeries and may play a role in the overall low rate of SSI observed.

The perioperative antibiotic protocols used were highly variable between cases and clinicians, illustrating the lack of therapeutic guidelines available to equine surgeons performing orthopaedic implant procedures. The most commonly used protocols prescribed included parenteral administration alone for 3 or 5 days, or parenteral administration for 5 days followed by an additional 5 days of oral antibiotics. Antibiotic protocols reported previously for PIPJ arthrodesis also varied widely between institutions, with combinations of aminoglycosides and β -lactams commonly administered (Ahern et al. 2010), although the duration of parenteral antibiotics was not specifically stated in some cases or was continued until lameness improved (Sakai et al. 2018). In one study describing the use of LCPs in PIPJ arthrodesis, 5 days of parenteral antibiotics followed by oral doxycycline until cast removal was reported (Hicks et al. 2021). Ahern et al. reported no difference between postoperative infection rate or survival to dismissal with regard to antimicrobial regimen administered (Ahern et al. 2010), although horses that developed SSIs were on average administered antibiotics for longer periods of time (21.8 vs. 4.5 days) and were 7.25 times less likely to be dismissed from the hospital compared to those with uninfected repairs (Ahern et al. 2010). This paper expands on previous work by Ahern et al. to specifically compare outcomes with regard to antibiotic protocols (selection and duration) used, while maintaining other factors such as the procedure (PIPJ arthrodesis), surgical technique and facilities relatively consistent over an extended time frame. The findings reported here are in concordance with Ahern et al. and do not support an additional benefit to parenteral antibiotic therapy past the first 3 days or prolonged oral antimicrobial therapy postoperatively in preventing SSI. Higher postoperative SSI rates for PIPJ arthrodesis reported in other studies may be related to other factors, such as intraoperative practices including the presence of additional personnel in the operating room to perform radiographs, as has been previously described (Sakai et al., 2018). These data may be useful to equine surgeons in examining their own practice's

complications rates, intraoperative protocols and medication administration practices.

The implementation of local antimicrobial therapy via RLP preoperatively prior to the placement of orthopaedic implants was not identified as a factor associated with reduced risk for the development of SSI in this study. However, the use of regional perfusions postoperatively was observed in both cases where SSI developed and was therefore associated with increased odds of SSI, presumably due to increased frequency of the use in cases perceived to have a higher risk of SSI development or following the development of SSI, similar to previous reports (Curtiss et al., 2019). The extremely large confidence interval for the odds ratio (3.039–6392.058) indicates some degree of model misspecification, and these numbers should be interpreted with caution, but the model was significantly degraded in its ability to predict outcomes without this factor and so it was included in the final model. Despite the increased frequency of use of antimicrobial regional limb perfusion (A-RLP) in equine practice and a large number of studies investigating side effects and drug pharmacokinetics indicating relative safety with its use, there remains a lack of evidence that A-RLP makes a difference in prophylaxis or treatment of equine orthopaedic infections (Rubio-Martinez, 2021). However, greater evidence for efficacy in human medicine has reported improved outcomes in people treated for diabetic and ischaemic nonhealing pedal ulcers (Agarwal et al., 2005; Seidel et al., 1994), infected total knee arthroplasty (Lazzarini et al., 2003) and chronic osteomyelitis (Finsterbush & Weinberg, 1972). The clinical benefits of A-RLP may be difficult to confirm in equine practice due to the lack of standardization or determination of the optimal methods for the A-RLP technique in equine practice in terms of drugs used, volume and concentration of perfusate, dosing interval, type, method and duration of application of the tourniquet and whether the procedure should be performed standing or under general anaesthesia (Biasutti et al., 2021). This was supported by the findings of this study where six different drug selection and dosing protocols were used for A-RLP in cases where data were available. Future studies to standardize the technique are indicated to fully investigate the potential benefit of RLP in equine orthopaedic procedures (Biasutti et al., 2021).

Aerobic/anaerobic bacterial culture and sensitivity were submitted in one case of SSI in this series, which yielded positive results for *Pseudomonas*, *Cronobacter* and *Aerococcus* spp. Previous studies reporting on equine SSI rates have frequently identified *Staphylococcus* spp. (Ahern et al., 2010; Hicks et al., 2021; Knox & Watkins, 2006; Sakai et al., 2018) associated with infections following orthopaedic implant placement, as well as *Enterobacter* (Ahern et al., 2010; Knox & Watkins, 2006), *Streptococcus* (Knox & Watkins, 2006), *Pseudomonas* (Ahern et al., 2010; Hicks et al., 2021; Knox and & Watkins, 2006) and *Corynebacterium* (Sakai et al., 2018). Ahern et al. reported a relatively equal distribution of Gram-positive and negative bacterial isolates with *Enterobacter* and *Staphylococcus* being the most commonly cultured Gram-negative and positive isolates, respectively (Ahern et al., 2010). Positive bacterial culture was previously associated with a lower rate of survival to hospital dismissal when compared to horses without infection (Ahern et al., 2010). However, there was no significant difference in the rate of dismissal between horses with different bacterial culture types (Gram-

positive vs. negative) or horses with mixed bacterial cultures (Ahern et al., 2010). These findings were not supported in this study, with both horses identified to develop SSI successfully resolving the infection and surviving to dismissal. The removal of implants was not performed in either case. Furthermore, although culture and sensitivity were only submitted in a single case in this series, serial cultures of suspected SSI are recommended to document trends in multidrug resistance as well as response to treatment.

The most common method of fixation in horses undergoing PIPJ arthrodesis in this case population over the time frame evaluated was the placement of two trans-articular cortical screws in lag fashion with an axial, 3-hole, 4.5-mm narrow locking compression plate. A temporal shift in implant selection was noted over time, with the complete shift to the use of LCP plates in later years of study collection due to *ex vivo* studies demonstrating LCP constructs to have comparable or superior mechanical properties with stiffer resultant constructs compared to DCP or LC-DCP (Ahern et al., 2010; Sod et al., 2011) in combination with favourable clinical reports of outcomes, including reduced time cast postoperatively (Herthel et al., 2016; Hicks et al., 2021; Levine & Richardson, 2007; Sakai et al., 2018). Implant failure or implant-associated discomfort necessitating removal occurred in two horses in this study. In one case, distal plate locking screw breakage identified at day 63 and associated lameness was managed conservatively with prolonged casting for an additional 4 weeks resulting in improvement in comfort. Although plate-bone contact was considered appropriate in this case, the long working length of the screw may have contributed to breakage. In the second case, implant-associated discomfort may have represented delayed infection or irritation to the surrounding soft tissues including the deep digital flexor tendon resulting in lameness. The surgical removal of all implants under general anaesthesia was performed on day 144 postoperatively. Lameness improved rapidly following the removal, and therefore soft tissue impingement was thought to be the more likely cause; however, delayed SSI could not be ruled out as culture and sensitivity were not performed. Radiographic images of both cases in which implant-associated discomfort occurred are presented in Figure 3. These findings are similar to one previous study examining outcomes following LCP placement for PIPJ arthrodesis, where implant removal was performed in 2/30 cases due to infection, although no incidences of implant failure were reported (Hicks et al., 2021).

The duration of postoperative coaptation until the first cast change was similar in this study (median 21 days, mean 24 days) to previous reports of a median of 14 days (Hicks et al., 2021; Knox & Watkins, 2006), 20 days (McCormick & Watkins, 2017), 20 days until first change with a second cast placed in 10/29 cases (Sakai et al., 2018), 27 days (MacLellan et al., 2001), and 35 days (Schaer et al., 2001). Subjectively, a trend in reduced time cast was observed over the time period evaluated in this study with increased implementation of the LCP construct as this plate became more widely used. The arthrodesis was supported with additional coaptation with either bandage cast, bivalved cast, splint or bandage for up to an additional three months postoperatively in 35 cases for which additional follow-up was available past initial cast removal. Additional coaptation was performed for more

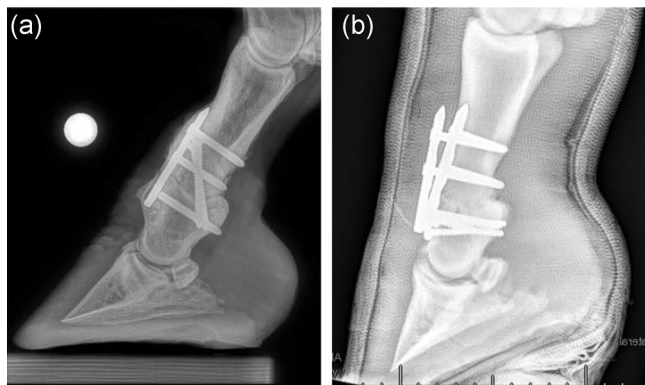


FIGURE 3 Radiographs of two cases with implant-associated discomfort postoperatively. (a) In Case 1, a 15-year old Arabian cross-gelding treated with pastern arthrodesis for osteoarthritis, distal plate locking screw breakage was identified at day 63 postoperatively and associated lameness was managed conservatively with prolonged casting for an additional 4 weeks resulting in improvement in comfort. (b) In Case 2, a 7-year-old Quarter Horse gelding treated for a second phalangeal fracture, implant-associated discomfort which may have represented delayed infection or irritation to the surrounding soft tissues including the deep digital flexor tendon resulting in lameness. Surgical removal of all implants under general anaesthesia was performed on day 144 postoperatively and lameness improved rapidly following the removal

prolonged periods in both cases in which infection was identified, with either a bivalved cast or bandage cast followed by splint followed by a bandage. Results of more recent work by Hicks et al. suggest that the placement of the LCP construct in PIPJ arthrodesis can safely allow for reduced casting times (median 14.5 days) due to the increased stability of the plate-screw construct and greater resistance to cyclic failure associated with unprotected weight-bearing in the early postoperative period, which may further reduce the incidence of complications such as cast sores in the early postoperative period (Hicks et al., 2021). The observation that both SSI events occurred following placement of an LCP construct should not be over-interpreted and was attributed to the increased frequency of use of LCP over DCP or LC-DCP temporally at that stage of the study time period.

Limitations of this study include the retrospective nature of data retrieval, a limited number of cases meeting inclusion criteria to enroll, and a low rate of SSI overall. It is possible that additional follow-up with owners would have allowed the detection of more complete information regarding the development of infection postoperatively. Outcomes for return to the previous level of athleticism long-term were not assessed in this study. The definition of SSI varies between studies and may represent a limitation in that some cases that resolved with conservative therapy under the care of referring veterinarians may not have been recorded. In the one case in this study where implants were removed due to persistent lameness and subsequently rapidly improved, the cause of lameness was thought more likely to be due to implant impingement on adjacent soft tissues; however, delayed SSI cannot be ruled out definitively as culture and sensitivity were not performed. The criteria used here to define 'SSI' have been previously

reported and used for retrospective designation of synovial infection, and all cases defined as SSI in this study met those criteria (Ahern et al., 2010; Curtiss et al., 2019). Finally, it is acknowledged that the relatively rare occurrence of infection necessitates caution in the extrapolation of conclusions to populations. These findings add to the body of the literature regarding the risk of SSI in equine patients undergoing internal fixation with orthopaedic implants, specifically with regard to perioperative antibiotic protocols.

In conclusion, the frequency of SSI in this population of horses undergoing PIPJ arthrodesis was lower than that in previous reports of internal fixation in equine patients and was not affected by the antibiotic protocol administered. There was no additional benefit to the administration of parenteral antibiotics for longer than 72 h postoperatively or the preoperative use of RLP in preventing SSI. These data may be useful to surgeons in evaluating their own postoperative infection rate with musculoskeletal procedures and in assessing factors associated with increased risk for SSI. Further evaluation of prophylactic local antibiotic administration is indicated.

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CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

ETHICS STATEMENT

The authors confirm that the ethical policies of the journal, as noted on the journal's author guidelines page, have been adhered to. No ethical approval was required as this manuscript represents a retrospective analysis of medical records.

AUTHOR CONTRIBUTIONS

Study conception and design: DH, LP, GG. Acquisition of data: LP, AD, GG. Data analysis and interpretation: GG, LP, DH. Drafting of the manuscript: AD, LP, GG. All authors contributed and approved the final manuscript.

DATA AVAILABILITY STATEMENT

The data that support these findings are available from the authors upon reasonable request.

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