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Experimental evaluation of cortical screw placement in lag fashion into the distal phalanx in standing horses

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ABSTRACT

The objectives of this *in vivo* experimental study were to evaluate the feasibility of cortical screw insertion into the intact distal phalanx in standing sedated horses and to document potential post-operative complications. One cortical screw was randomly inserted in lag fashion into each distal phalanx in 9 horses. The second surgery on the contralateral limbs was performed 2–3 weeks after the first operation, when a 4.5-mm cortical screw was inserted in lag fashion into the distal phalanx of sedated horses following perineural analgesia. Following surgery, the drill hole was filled with an antibiotic-soaked swab, which was changed every 48 h. The horses were euthanised 8 weeks after the second surgery. The hooves were disarticulated and evaluated macroscopically and by computed tomography. The surgery time was 13.9 ± 4.8 min (mean $\pm$ SD). Pain scores and lameness gradually decreased after 7 days. Solar canal penetration (SCP) was detected in 10 out of the 18 distal phalanges (55.5%). In 7 out of the 10 penetrations intraoperative bleeding was obvious. No postoperative infection was observed. Screw insertion into the distal phalanx was easily and quickly accomplished in standing horses, but its advantages in horses with sagittal fractures should be investigated further. SCP had no impact on postoperative lameness.

KEYWORDS

equine, distal phalanx, cortical screw, standing surgery

INTRODUCTION

Fractures of the equine distal phalanx can be classified into seven distinct types (Petterson, 1976; Bertone, 1996). Type III or mid-sagittal fractures of the pedal bone are considered a relatively rare condition in horses. In one study, sagittal fractures of the distal phalanx accounted for 12% of all distal phalanx fractures (Honnas et al., 1988), while they represented only 3% in another study (Bindler et al., 2015). In a case series, 2 out of 8 foals had type III fractures (Yovich et al., 1986). The surgical management of such injuries is rarely mentioned in the relevant publications (Fackelman, 1974; Rose et al., 1979; Scott et al., 1979; Yovich et al., 1982; Andritzky et al., 2005; Russell and Maclean, 2006; Kay et al., 2016). The diagnosis of sagittal fractures can be confirmed via radiography and/or computed tomography (Honnas et al., 1988; Rossol et al., 2008; Vandeweerd et al., 2009). The decision as to whether a clinician manages such a fracture conservatively or surgically, depends on objective and subjective variables (Petterson, 1976; Bertone, 1996). Currently there is no consensus among surgeons as to when to choose a surgical approach for type III fractures. In fact, only a single large multicentre study has been conducted, in which most of the type II and III cases were managed conservatively and only a dorsal plane P1 fracture underwent internal fixation (Rijkenhuizen et al., 2012). In general, many surgeons prefer a surgical approach under general anaesthesia for the management of type III distal phalangeal fractures (Yovich et al., 1982; Kay et al., 2016). The traditional approach is to insert one or two cortical screws into the pedal bone in lag fashion under radiographic control or

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through computer-assisted surgery under general anaesthesia (Andritzky et al., 2005). The overall success rates for conservative management and surgical techniques under general anaesthesia were both around 70% according to the results of one study (Rijkenhuizen et al., 2012). The main complications included implant infection, improper screw positioning and inadequate fracture stabilisation (Yovich et al., 1986; Honnas et al., 1988). Despite the generally accepted potential benefit of a standing approach for the management of other selected fractures in horses, to the best of the authors' knowledge this technique has not been described to date (Russell and Maclean, 2006). Therefore, the objective of this prospective experimental *in vivo* study was to describe the feasibility of a standing surgical approach to fixation of the distal phalanx and to document potential postoperative complications in healthy horses. The authors hypothesised that cortical screws could be implanted into the distal phalanx in standing horses with a shorter surgical time and minimal postoperative complications. There are no published data about the clinical relevance of solar canal penetration (SCP) following screw insertion into the distal phalanx. Our hypothesis was that SCP could damage structures within the solar canal (SC), thus increasing postoperative pain.

MATERIALS AND METHODS

Animals

Nine horses free of any radiological disorders in the phalanges of the front feet, but culled for other reasons, were included in the study. None of the horses were lame or had any visible orthopaedic disorders. The horses were between 4 and 9 years of age (mean $\pm$ SD: 5.8 ± 1.7). There were 6 geldings, 2 intact males and one mare. The breed distribution was as follows: 7 Hungarian Half-blood, 1 Fjord and 1 Lipizzaner. In full compliance with the Act on Animal Experiments, this study was evaluated and approved by the Ethics Committee of Szent István University, Hungary (PEI/

001/3501-8/2014). The horses underwent routine physical and lameness examination prior to enrolment into the study.

Procedures and preparation

Both front limbs of all horses were subjected to surgery. The contralateral distal phalanx of the same horse was operated on after having a minimum 7-day lameness-free period at walk and trot on the operated limb. A total of 18 procedures were performed. One day before surgery the affected hoof was trimmed, thoroughly cleaned, washed with Betadine soap, and placed into a 2% Betadine solution (Egis) poultice bandage. Immediately before preparing the hoof capsule for surgery, the optimal position of the screw was determined by taking several lateromedial radiographs with a digital radiographic equipment (Fujifilm FDR D-EVO II C24i) and identifying the correct position on either side of the hoof capsule with round metal markers 4 mm in diameter. The exact location of the correctly positioned markers was then marked with drill holes (4 mm in diameter and 2 mm in depth) on either side of the hoof wall. The markers were set up for positioning the screw midway between the joint surface and the SC near the palmar cortex (Bindler et al., 2015). For the procedure, horses were sedated with a combination of 0.01 mg/kg detomidine (Orion Pharma) and 0.01 mg/kg butorphanol (Animedica GmbH) intravenously. The distal limb was anaesthetised via abaxial sesamoid blocks with 4 mL of 5 mg/mL bupivacaine (Reciphaem) in the first four hooves and via a low 4-point block in the further 14 limbs. The distal limb was clipped and prepared aseptically distal to the fetlock joint. The contralateral limb was covered with a sterile surgical drape. The horses were positioned with both of their front feet on a 10 cm high wooden block (Fig. 1). Phenylbutazone (2.2 mg/kg) and amoxicillin-clavulanic acid (Norbrook) was administered 1 h prior to the surgery.

Screw placement

As a first step, a hole 8.5 mm in diameter was drilled through the hoof capsule using the predetermined marker

Fig. 1. Intraoperative bleeding after solar canal penetration

point on the hoof wall until the corium was reached. After vigorously flushing the drilled hole through the hoof capsule with physiological saline, a 4.5-mm glide hole was drilled into the bone perpendicular to the imaginary fracture line (Fig. 2). Before drilling the glide hole up to the imaginary fracture line, the position of the drill bit with the drill sleeve was checked by lateromedial radiography. The screw length was estimated using previous studies (Bindler et al., 2015) and was checked by taking an oblique radiograph. In each case the screw was placed across the full width of the distal phalanx. Screw insertion was carried out using the AO principles of fracture fixation (Fig. 3). Following placement of the screw, the hole in the hoof capsule was filled up with a gauze sponge impregnated with gentamicin (Eurovet Animal Health B.V.), followed by application of a sterile bandage to the distal limb with a waterproof cover on the solar surface.

Postoperative follow-up

During the 4-week follow-up, the horses were kept on stall rest. After the first week, hand walking was started for 5–10 min daily. Bandages were changed every other day for 3

weeks. Horses received a combination of gentamicin (6.6 mg/kg IV) once daily and amoxicillin–clavulanic acid at a dose of 8.5 mg/kg intramuscularly once a day, and phenylbutazone 2.2 mg/kg per os for 5 days. The beddings of horses were checked and cleaned four times a day. The horses underwent clinical and lameness examination by two independent observers and pain scoring daily for 2 weeks by another senior clinician, then every other day for another 2 weeks. Lameness scores were graded according to the AAEP lameness scale (Fackelman, 1974; AAEP, 1991) (Table 1). The time needed for horny scar tissue to cover the corium wound was also recorded. A multimodal, composite pain scoring, with a range from 0 to 39 points was used. The 13 parameters included heart rate, respiratory rate, rectal temperature, gastrointestinal borborygmi, interactive behaviour, response to surgical site palpation, general appearance, evidence of sweating, kicking at the abdomen, frequency of pawing, appetite, posture and head movement as described in detail elsewhere (Bussieres et al., 2008) (Table 2). All horses were euthanised two months after the second surgical procedure, using embutramide and mebezonium iodide (Intervet International B.V.).

Fig. 2. Drilling the third phalanx in standing position

Fig. 3. A. Solar canal penetration in lateromedial position. B. Screw position in a dorso-palmar radiograph. The screw is located dorsal to the solar canal

Postmortem examination

The distal limbs were disarticulated at the metacarpophalangeal joint and were scanned with a computed tomographic unit (GE CT, single-slice helical CT) using 1 mm slice thickness. Dorsal, horizontal and sagittal plane CT slides were evaluated for any signs of osteophyte/enthesophyte formation or bony changes around the screws by two independent observers (SZM, DB). Screw angle was measured on the dorsal plane CT scans. Screws had to be parallel to the line drawn across the distal aspects of the distal phalanx. Within 2 grades of difference to the line drawn across the joint surface of the third phalanx (P3), they were accepted as 'parallel'. Hooves were cut in a dorsal plane to evaluate the screw thread–bone interface for any signs of septic osteitis and penetration of the SC by the screw as described before (Bindler et al., 2015) (Fig. 4).

Statistical analysis

Descriptive data were expressed as mean $\pm$ SD. Pain and lameness scores over time were analysed by one-way repeated measures ANOVA. Comparisons between individual limbs were made by 2-sample *t*-test or Mann–Whitney U test. Correlation was determined by linear regression analysis. Comparisons of categorical variables were performed with Chi-square test or Fisher's exact test. $P < 0.05$ was considered significant in all tests.

RESULTS

Procedure time, screw lengths and intraoperative bleeding

The surgery time was 13.9 ± 4.5 min with a range of 8–25 min from the onset of drilling the hoof wall to the placement of bandages. The screw lengths used were 56 mm (7/18), 58 mm (6/18), and 60 mm (5/18). Marked intraoperative

haemorrhage was noted in 7 feet. The parallelism of screws relative to the articular surface of the distal interphalangeal joint was less common in the SCP group ($P = 0.029$) (Table 3).

Lameness and pain score

The mean pain scores and the results of statistical comparison are presented in Table 1. Mean lameness scores after the first and the second surgery and statistical comparisons are presented in Tables 2 and 3, respectively. Except for two cases, all horses were free of lameness in walk and trot following the first 7 days after each surgery. In the first case a hoof abscess was diagnosed 3 weeks after the first operation on the ipsilateral limb without any association with the screw. The horse became sound following curettage and

Table 1. Mean lameness grades for the 9 horses following the first procedure

Day 0	Day 1	Day 7	Day 14	Day 28	<i>P</i> value
0	1.44	1.11	0.33	0.33	0.0006

Table 2. Mean lameness grades for the 9 horses following the second procedure

Day 0	Day 1	Day 7	Day 14	Day 28	<i>P</i> value
0	1.66	1.33	0.44	0.22	0.0005

Table 3. Frequency of marked haemorrhage in the group where screws were placed parallel versus non-parallel to the joint surface

	Marked haemorrhage	No marked haemorrhage	<i>P</i> value
Parallel	4	9	0.029
Non-parallel	5	0

Fig. 4. Postmortem examination: position of the screw proximal to the solar canal is visible. The hole on the lateral hoof wall grew down 5 mm from its original position in 4 weeks' time

treatment of the abscess. Another horse was lame for 6 weeks following the first surgery; lameness was localised to the hoof by diagnostic anaesthesia, and the horse became sound only in the 7th postoperative week.

Complications

By radiological examination 2 months after surgery no radiographic signs of infection or screw lysis were detected in any of the 18 feet. The 8.5-mm drill-hole became covered with scarified horn tissue on the inside 3–4 weeks following surgery. From that time point no bandages were applied.

Postmortem CT and macroscopic findings

By evaluation of the CT images, neither of the two independent observers saw any new bone formation around the screws or remodelling of the distal phalanx. Twelve of the 18 screws were inserted parallel to the line drawn across the distal aspects of P3 (a deviation by 0–2° was accepted as 'parallel'). In 6 hooves a larger deviation (2–4°) was detected (Table 3). In 10 out of 18 hooves SCP was observed by macroscopic evaluation of hooves cut in the dorsal plane. In all (7) cases where excessive intraoperative bleeding was observed, SCP was present.

DISCUSSION

To the best of the authors' knowledge, this is the first study evaluating the clinical outcome and complications of screw insertion into the distal phalanx through the hoof capsule on live horses. Our study has brought three new results. The first novel information is that surgery can be performed more easily and quickly in the standing horse with less complications than described previously with the conventional procedure performed in general anaesthesia. The second novel finding is that SCP is not always associated with excessive bleeding, while marked intraoperative bleeding always occurs in conjunction with SCP. The third novel result is that SCP does not cause increased pain compared with hooves without SCP.

The time of screw insertion was 13.9 ± 4.5 min in our cases, in contrast with previous studies on cadaveric limbs, where conventional screw placement took 16–28 min (Andritzky et al., 2005). No iatrogenic damage to the surrounding soft tissues or joints was noted during the final assessment of hooves in our study. In contrast, iatrogenic damage had previously been reported in another study, where in 2 out of 8 cases penetration or a fissure formation into the coffin joint occurred (Andritzky et al., 2005). Septic inflammation causing septic pedal osteitis is another frequently described complication following lag screw fixation of distal phalangeal fractures (Rose et al., 1979). In a more recent multicentre study successful screw fixation was achieved in 7 out of 9 cases in type III distal phalangeal fractures; however, further information is not given about the reason for failure in the remaining two (Rijkenhuizen et al., 2012). In our study septic complications did not occur

in any of the 18 hooves. We hypothesise that frequent changes of the antibiotic-impregnated swabs and hoof bandages decreased the risk of septic complications in our cases. To the best of the authors' knowledge this specific postoperative regimen has not been described previously. Prior to and during surgery, it was the authors' subjective impression that SCP was predicted by excessive bleeding. This study demonstrated that, while marked intraoperative bleeding always occurred in conjunction with SCP, a lack of bleeding did not necessarily indicate that SCP had not occurred. It was a generally accepted statement that the surgeon must avoid penetration of the SC (Rossol et al., 2008); however, the clinical relevance of this impression was not known. We compared the clinical outcome of the SCP group (10 cases) with hooves in which the SC had not been penetrated (8 cases). Out of the 7 cases where pronounced haemorrhage was noted, only 3 horses had mild to moderate lameness. Based on the results of our experimental study with a limited number of cases ($n = 18$), SCP does not appear to result in increased incidence of lameness or other long-term complications in comparison to horses in which SCP did not occur. On the other hand, it should be mentioned that in one case in which SCP and excessive bleeding were present, lameness persisted for 6 weeks following screw insertion. With the help of perineural analgesia lameness was localised to the hoof. The exact cause of lameness in this case remained unclear. During post-mortem evaluation of this hoof no signs of screw loosening or septic inflammation were detected. During the first four screw placements abaxial sesamoid blocks were used. In two out of these four cases the horses reacted with movement during drilling. Changing our regional anaesthesia protocol to a low 4-point block eliminated such reactions during the following 14 operations. The CT scans revealed that in 12 feet the screws were placed parallel to the horizontal axis of the distal interphalangeal joint, while in 6 cases a mild deviation (2–5°) was found. Computer-assisted surgery is more accurate than the conventional technique to insert screws in the distal phalanx and would result in improved clinical success; however, the technique is expensive and not readily accessible in many clinics. Provided that the hoof is balanced relative to the axis of the distal interphalangeal joint, in the authors' opinion, screw insertion parallel to this axis is easier in the standing, weight-bearing horse as compared to conventional screw insertion in general anaesthesia.

The study presented in this paper has several limitations. Our model was not a real type III fracture model, as we did not have a fracture in the distal phalanx. In real fractures, abaxial motion of the fractured pieces in the weight-bearing limb could further influence appropriate anatomical reduction, which could not be investigated in this study. Our horses had only paddock exercise after surgery. A more regular exercise regimen could have influenced the outcome. Although 18 hooves are an acceptable number in a research project with live horses, as SCP only occurred in 10 cases, it is difficult to draw conclusions as to the effects of this complication in clinical patients. This study is the first description of cortical screw insertion into the distal phalanx

in the standing horse. We found less complications compared to previous studies. This standing technique provides an alternative approach to screw placement in the distal phalanx. This approach may be technically simpler than the approach under general anaesthesia, especially if access to advanced imaging modalities is not available. SCP by the inserted screw did not increase the risk of post-operative pain and lameness in our study. Based on the results of this study, this technique should be further investigated in clinical cases.

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