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CLINICAL RESEARCH

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Use of a new aiming compression device and technique for the repair of navicular bone fractures in horses: A cadaveric study

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Abstract

Objective: To assess the use of a newly developed aiming compression device (ACD) for screw insertion in non-fractured navicular bones (NB) in cadavers.

Study design: Cadaveric study.

Sample population: A total of 10 cadaveric front limbs of adult horses.

Methods: Placement of a 3.5 mm cortical screw in non-fractured NB under radiographic guidance was performed in 10 cadaver limbs in a standing position. An ACD was used to stabilize the NB and to guide the drilling process. Preparation and surgical time as well as the number of radiographic images were noted. A postoperative scoring system was used to assess screw placement by cone beam computed tomography (CBCT) and gross examination by two evaluators.

Results: The total procedure time was 25–62 min (median 33.5). During the procedure, 11–21 radiographs (median 18.5) were taken. The postoperative gross examination revealed an excellent screw placement in nine NB and poor in one. This could not be reliably assessed with post-procedure CBCT.

Conclusion: The described technique achieves an excellent screw placement in 9/10 bones without disrupting the articular or flexural surface of the NB and with no protrusion of the screw head or tip, in a median procedure time of under 35 min.

Clinical significance: Adequate screw placement is paramount for NB fracture repair. The described approach under radiographic guidance allows adequate screw placement using the ACD to stabilize the NB by lateral to medial compression. This technique facilitates adequate screw placement within the NB without the use of advanced imaging techniques.

The results of this ex vivo study were presented at the 31st Annual Scientific Meeting of the European College of Veterinary Surgeons Scientific Meeting July 7–9, 2022, Porto, Portugal.

1 | INTRODUCTION

Fractures of the navicular bone (NB) occur rarely.[1,2] Avulsion fractures or "chip" fractures of the distal border of the NB at the origin of the distal impar ligament,[1–3] can be associated with navicular disease[4,5] and can also occur at the collateral suspensory ligament attachment.[2,5] Comminuted fractures are less common[6] and are associated with a very poor prognosis[1] perhaps due to the difficulties to achieve fracture reduction and stabilization. Horizontal fractures of the NB are only sporadically reported,[5,7] while the most common fracture type documented are lateral parasagittal fractures,[2,8,9] affecting the front limbs more often than the hind limbs.[6,9–11] The etiology of a parasagittal fracture is most likely traumatic,[9,11] but it has been proposed that underlying bone disease may also predispose to fracturing.[6,12]

Treatment options for NB fractures include screw fixation[9,13,14] or conservative management including box rest with or without external coaptation provided by a cast or orthopedic shoeing and heel elevation.[6,11,15] In addition, neurectomy as a salvage procedure has also been described.[6,11] The prognosis for non-surgical treatment of NB fractures is guarded to poor.[6,11] Screw fixation with interfragmentary compression in lag-screw fashion increases the prognosis for the return to athletic function up to about 80% of cases and it is currently considered the treatment of choice.[1]

However, due to the NB's anatomical size, shape and location within the hoof capsule, the surgical approach is technically challenging, and precise screw placement is essential.[9] Therefore, the use of a custom-made drill jig[9] or traditional C-clamp as an aiming device (AD)[13,14] has helped to follow the intended drill path for fracture fixation.

Recently, advanced three-dimensional (3D) imaging techniques and computer-assisted surgery (CAS) techniques have been described to assist with internal screw fixation in NB fractures.[16–19] In an ex vivo study and in horses with NB fractures, computed tomography (CT) was used to determine the AD placement on the hoof capsule.[17,18] In addition, CT was used to create an individual 3D printed drill guide in experimental studies.[20,21] A few reports compared the outcomes of the conventional surgical technique with CT or CAS techniques in cadavers.[16,20,21] These advanced techniques, however, are expensive and not widely available to equine hospitals.

Neither the traditional ADs nor the advanced techniques offer the possibility to stabilize NB fragments during the fracture repair. The idea of developing an AD that would allow compression to both sides of the NB thereby stabilizing the bone fragments during drill hole preparation originated because it was considered helpful in minimizing the chances of transfragment displacement during hole preparation.

The objective of this study was to assess a screw placement technique under radiographic guidance of non-fractured NB with the aid of a customized aiming compression device (ACD) and cannulated instrumentation, which allows guidance while stabilizing the NB by lateral to medial compression during the drilling process. We hypothesized that precise screw placement within the narrow anatomical margins of the NB can be achieved with the described technique and ACD.

2 | MATERIALS AND METHODS

2.1 | Specimens

A total of 10 forelimbs from adult horses of various breeds and sizes and disarticulated at the carpometacarpal joint were collected at the slaughterhouse and stored in a −20°C freezer. The age and sex were unknown. The cadaver limbs were defrosted at room temperature for 48 h prior to performing this study. After thawing, the shoes were removed, and the hooves were trimmed by an experienced farrier to obtain a good lateral to medial balance. The hoof sole of the disarticulated limbs was manually brought to the ground by putting vertical pressure on the limb until the complete sole was in contact with the ground and a physiologic fetlock angle was achieved. To stabilize the distal phalanx in this position, the flexor tendons and the suspensory ligament were secured by a cable wire to the metacarpal bone. In addition, an elastic tension band connected the dorsal aspect of the toe to the holding system to maintain a physiologic extension of the distal phalanx. All extremities were positioned in a specially designed device (Strohm Hufbeschlagartikel GmbH, Düsseldorf, Germany) to allow recreation of a standing horse posture on a plastic block (Podoblock B.V. Tynaarlo, Netherlands) for elevation of the foot (Figure 1).

2.2 | Aiming compression device (ACD)

The newly designed ACD is an adaptation of an existing commercialized AD (IMEX Veterinary Inc., Texas) where the ends were modified with one end being a fixed conical sharp shape and the other one a conical sharp adjusting sleeve (Figure 2). This allows interchanging of different diameters sleeve guides for the insertion of a guiding k-wire and cannulated drill bits.

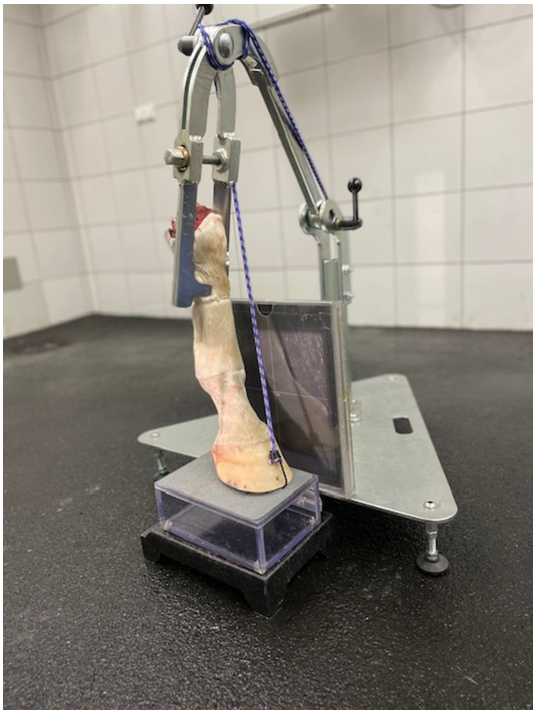

FIGURE 1 Cadaver specimen fixed in the stand positioned for surgical procedure.

FIGURE 2 Modified aiming device (AD), with two exchangeable adapters: First for pin insertion, 1.6 mm inner diameter, second for inserting the cannulated drill bit, inner diameter 2.75 mm.

2.3 | Surgical procedure

The first step of the procedure was to mark the location of the NB within the hoof capsule. A metallic ring and a metallic ball were placed laterally and medially respectively on each side of the hoof and secured with radiolucent modeling-clay. Under radiographic guidance with lateromedial (LM) and horizontal dorsopalmar (DP) radiographic views both markers were readjusted until they were aligned in a straight line with the NB, and the ball was seen within the inside margins of the ring. Once the entry points were identified, a 4 mm hole was drilled on the lateral and medial sides through the hoof wall and the collateral cartilage until the lateral or medial aspect of the NB was reached. After radiographic confirmation, the holes were enlarged with an 8 mm drill bit trough the hoof wall, passing the ungula cartilage, stopping in close proximity to the NB under radiographic control to allow placement of the conical sharp ends of the ACD in close contact to the NB from lateral to medial and confirmed on LM and DP radiographs. The device was then firmly locked in position while compressing both ends by sliding the adjustable part of the ACD.

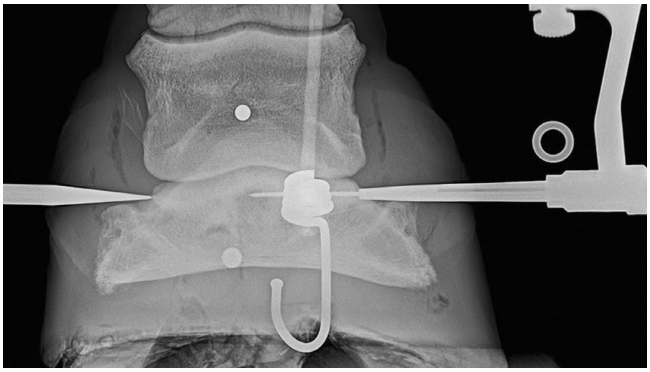

FIGURE 3 Radiographic image of the aiming compression device (ACD) in place while inserting of the k-wire.

The recorded preparation time started when the extremity was positioned and ended when the fixation of the ACD to the navicular bone was completed.

Once the ACD was positioned correctly, a 1.5 mm k-wire was inserted into the entire length of the NB via a custom-made conical sleeve (inner diameter [ID] 1.6 mm) for the k-wire to create a secure guiding path for the intended position of the screw (Figure 3). After exchanging the conical sleeve of the ACD (ID 2.75 mm), with the k-wire in place, a cannulated 2.7 mm drill bit was fitted over the k-wire and a 2.7 mm path was created along the transverse axis of the NB. The path was tapped with a 3.5 mm tap and a 3.5 mm cortical screw was inserted. The length of the screw was determined by measuring the length of the NB on horizontal DP radiographs. For correcting the magnification effect, the measurement was divided through the factor 1.1 and a screw 4 mm shorter than the corrected length was chosen according to the recommendations of the AO vet reference.[22] The magnification factor was calculated with the use of a metallic marker with a known length placed on the plate.

Along the procedure, all steps were monitored with radiography. Two radiographic units to obtain LM and DP views were used with a setting of 64 kV and 1.6 mAs to expedite the process and to maintain radiographic views as identical as possible.

FIGURE 4 Picture of the gross examination of the isolated navicular bones (NB).

The time measured between insertion of the k-wire and completed insertion of the screw was recorded as surgical time.

2.4 | Cone beam computed tomographic imaging

After placing the screw all limbs underwent a CT examination with a cone beam unit (O-arm, Metronic Japan Co., Ltd., Tokyo, Japan). While scanning, the limbs were placed with their dorsal aspect uppermost. The setting was 120 kV, 16 mA, and 64 mAs. All images were stored in a PACS and evaluated in a multiplane reconstruction with a DICOM viewing program (RadiAnt DICOM Viewer, Medixant, Poznań, Poland) in transverse, sagittal and dorsal images as well as in a 3D reconstruction.

2.5 | Gross examination

Post-surgery, two observers evaluated the accuracy of the screw placement in gross examination by consensus (Figure 4). Therefore, limbs were disarticulated at the distal interphalangeal joint and then boiled for 3 h. The hoof capsule was detached, and the NB extracted. Following this step, the NB was boiled for another hour to ease the removing of the remaining soft tissue and fibrocartilage adhered to the bone. Gross examination was performed with special emphasis to the articular and flexor surface, as well as to screw head placement and exit of the screw at the contralateral side of the bone.

2.6 | Evaluation of screw placement

Post-surgery, two observers evaluated the accuracy of the screw placement on CBCT images as well as in gross examination by consensus. A previously described scoring system by Gygax et al.[16] was used as follows: screw length (1 adequate, 2 too long, 3 too short), position of the screw head (1 well positioned, 2 too inserted, 3 protruding), screw condition (1 straight, 2 bent), and screw position within the NB (1 contact to the proximal margin, 2 contact to the distal margin of the bone, 3 contact to the articular surface, 4 contact to the flexor surface). The outcome was determined by summation of scores. A final score of 3 was considered excellent, as final score of 4–8 was considered a moderate outcome, and a poor outcome was defined with a final score of 9–12 or if the position of the screw within the bone was scored 2–4.

2.7 | Statistical analysis

Descriptive statistical analyses were performed using IBM SPSS Statistics 28. The data were evaluated for normality, by Shapiro–Wilk test and Kolmogorov–Smirnov test as well as visual evaluation of histograms. p-values of <.05 were considered statistically significant. The non-parametric data are reported as median with the range.

3 | RESULTS

3.1 | Specimens

The limbs of seven Warmblood horses, one Islandic horse, one Haflinger and one Thoroughbred were used for this study. In the study, seven right forelimbs and three left forelimbs were included. It was unknown whether the horses were lame prior to euthanasia. Specimen number 10 revealed a large cystic lesion in the center of the distal sesamoid bone with an approximate diameter of 8 mm, which was in contact with the flexor cortex.

3.2 | Surgical procedure

Preparation time took a median of 22 min (range 11–52 min) while surgical time, took a 14.5 min (10–23 min). The total time needed for the whole procedure was 33.5 min (25–62 min). In total, 18.5 radiographs (11–21) were taken during the procedure, with the most images (11) (5–15 images) obtained during the preparation stage. Repositioning of the ACD required recreation of the drill hole through the hoof wall and was necessary in specimens two, four, and six. A single attempt to insert the threaded k-wire was carried out in six specimens while a second attempt was performed in the remaining four cases. The only complication seen during all surgical procedures occurred in specimen seven in which the k-wire for guidance broke (Figure 5). The mean screw length used in all specimens was 55 mm. Further details of each case can be found in Table 1.

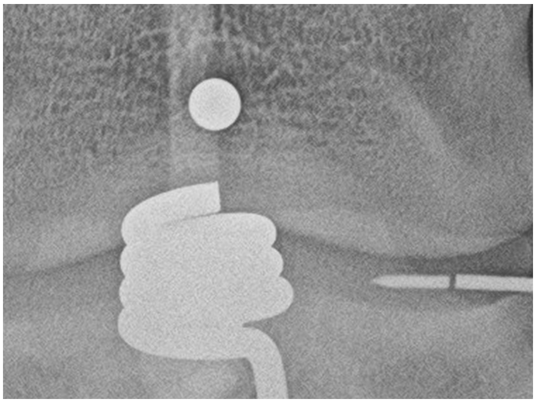

FIGURE 5 Radiographic image of the broken k-wire in specimen No. 7.

3.3 | Evaluation of screw placement

CBCT evaluation showed excellent screw placement in six NB, moderate placement in one NB and poor placement in three NB. The scores assessed on images acquired with a CBCT are shown in Table 2. On the contrary, gross examination findings revealed that nine of the screws were inserted in the center of the navicular

TABLE 1 Details of the surgery.

No	Preparation time (min)	Surgical time (min)	Repositioning of ACD	Radiographs (in total)	Screw length (mm)
1	11	17	0	11	60
2	36	23	1	18	45
3	19	11	2	17	50
4	38	17	1	21	60
5	26	16	0	19	50
6	52	10	2	20	60
7	12	16	0	18	55
8	20	13	1	21	55
9	24	10	0	20	55
10	15	10	0	17	60

Abbreviation: ACD, aiming compression device.

TABLE 2 Score and outcome of the cone beam computed tomography (CBCT) evaluation of the screw placement.

No	Screw length	Screw head	Screw condition	Screw position	Sum	Outcome
1	1	1	1	4	7	Poor
2	1	2	1	0	4	Moderate
3	1	1	1	0	3	Excellent
4	1	1	1	0	3	Excellent
5	2	1	1	3	7	Poor
6	1	1	1	0	3	Excellent
7	1	1	1	4	7	Poor
8	1	1	1	0	3	Excellent
9	1	1	1	0	3	Excellent
10	1	1	1	0	3	Excellent

TABLE 3 Score and outcome of the gross examination of the screw placement.

No	Screw length	Screw head	Screw condition	Screw position	Sum	Outcome
1	1	1	1	0	3	Excellent
2	1	1	1	0	3	Excellent
3	1	1	1	0	3	Excellent
4	1	1	1	0	3	Excellent
5	2	1	1	3	7	Poor
6	1	1	1	0	3	Excellent
7	1	1	1	0	3	Excellent
8	1	1	1	0	3	Excellent
9	1	1	1	0	3	Excellent
10	1	1	1	0	3	Excellent

bone in a position considered excellent and in one specimen we found the screw to have penetrated the dorsal articular surface of the NB thus considered poor. In addition, the screw was protruding approximately 2 mm on the contralateral end of the NB and was thereby considered as too long. Details on the gross examination score can be found in Table 3.

4 | DISCUSSION

We describe a technique for placing a 3.5 mm neutral cortical screw across the NB from lateral to medial using a custom-made modification of an existing AD, which allows stabilizing the NB during screw placement obtaining an excellent placement in 90% of the specimens. The procedure needs radiographic monitoring and the use of two radiographic generators proved to be ideal to speed the process, but it was considered not essential. The technique described also involves the use of threaded k-wires as guides and cannulated drill bits to prepare a secure and precise screw path. This equipment is not standard in osteosynthesis kits but is widely available and easy to acquire at a small cost. The described ACD allows screw placement in a standing position with an average completion time of under 35 min.

Slippage off the hoof capsule of a conventional AD has been previously described.[21] This complication did not occur with the ACD in the current study. This problem is prevented because both sides of the ACD are inserted through the hoof wall, firmly until they reach the wings of the NB at its widest point, thus providing two anchoring points. In addition, the possibility of the drill bit sliding off the edge of the navicular bone while preparing the hole in the cis cortex, due to its curved contour[1,16] is reduced with the ACD and further the k-wire over which the cannulated drill bit is inserted gives additional guidance and stability. If this provides sufficient stability of the bone fragments in a scenario with a fractured NB will have to be investigated in another study.

The use of this ACD requires the creation of two holes through the hoof wall until the NB is reached which is not required with the previously described techniques. Therefore, the possibility of having a complication such as a surgical site infection logically would also increase. However, this will have to be evaluated in clinical cases. The use of broad-spectrum perioperative antibiotics by regional perfusion may contribute to reduce such complication in a clinical setting.

Insufficient fracture line reduction, which might result in a step formation, poor internal compression, insufficient stabilization and inability to neutralize rotational forces are described complications of navicular fracture repair.[9] The reported residual gap after internal screw fixation with a classical AD varied from 0.9 to 1.2 mm in three horses.[18] Non-calcified fibrous healing is frequently observed after NB fracture[12] and although, an ossification healing tissue seems not to be necessary for return to soundness.[9,15] Our modification of the AD would allow compression of both NB sides, avoiding displacement of the trans fragment during surgical fixation and potentially facilitating fragment reduction and bone stabilization during drilling. However, in this study, we used specimens with non-fractured NB, so these theoretical advantages of the ACD for fracture gap reduction and stabilization of the fragments remain unproven. An additional study should be performed in cadavers with artificially fractured navicular bones to prove such theory.

In addition to inadequate reduction of fracture, other intraoperative complications include breakage of a drill bit and splitting of the fragment.[7,9,21] Breakage of the drill bit is considered as a severe complication, as a second placement of a drill path will be difficult and removal of the broken fragment from the hoof capsule is very challenging.[21]

In this study, the only complication we had was a broken k-wire and another wire had to be inserted, which was not found to be difficult due to its small size.

The readjustment of the ACD required recreation of the drill holes into the hoof wall in three specimens and could potentially increase the risk of postoperative complications such as infection. In addition, it significantly increased the preparation time and required more radiographs for the intraoperative control. It has been previously reported that the most time-consuming part of the surgery is loosening or resecuring and readjusting the AD.[21] The overall duration of a previous surgical technique with a drill jig in live horses was reported to be between 1.5 and 2 h.[9] In other cadaveric studies, the surgical repair time with an AD was 20.7 ± 4.8 min[21] and 27.36 ± 4.20 min[16] which is a comparable to the current study. Overall, the preparation of the correct placement of ACD was the most time-consuming part and was also where the largest number of radiographs were necessary to determine the correct location on the hoof capsule. We found that to start the hoof hole with a smaller drill bit and then using a bigger drill bit leads to a more precise execution of this process. A cone-shaped drill bit can also be investigated to ensure a more optimal hole preparation, because it offers a precise centred enlargement of the drill hole.

When using interfragmentary compression to repair navicular fractures, countersinking is generally advised. For the objectives of our study, explicit countersinking was not necessary as a neutral screw was inserted. Other authors have described the use of a drill bit for that purpose.[1,9,19] The proposal of the current study was to assess screw placement and not the biomechanical interrelations. The positioning of the screw head was found to be adequate during gross examination. However, no mechanical suggestions for the need to countersink can be made for lag screw fixation repair in clinical cases.

Gross examination was considered the gold standard for the evaluation of screw placement, which evaluated a better outcome than with CBCT postoperative exanimation. CBCT images showed metal artifacts, which may have affected appropriate assessment of screw placement. To the author's knowledge, there is no artifact reduction software for CBCT available to negotiate this problem. Evaluation with conventional CT without or with such a software could have been advantageous and may lead to a more precise evaluation. One study also found discrepancies in the postoperative evaluation between gross examination, radiographs, and C-arm imaging.[16] During that study it was not possible to judge the screw placement itself with the fluoroscopy but the drill path, because the authors found that the evaluation of screw bending and protruding of the screw was not possible with the C-arm.[16]

The use of a 3.5 mm screw is considered adequate due to the small size of the NB,[9,19] but screw breakage has also been reported[7] and in an ex vivo study the biomechanical stiffness was 28% greater with a 4.5 mm screw compared to and 3.5 mm cortical screw.[23] A 4.5 mm screw with a screw head size of 8 mm was considered too large for an average size Thoroughbred or Warmblood horse.[19] As a compromise, the use of 4 mm cortical screws has been contemplated by other authors to reduce risk of breakage.[7,19] This could be considered, although a 4 mm osteosynthesis kit is not wildly available in equine hospitals. In our cases, we found the 3.5 mm to be of adequate size. The one poorly placed screw happened in the smallest of our specimens from an islandic horse, which also had a marked curvature of the bone. Thus, screw malpositioning in a small NB is considered more likely. Therefore, using a 2.7 mm screw could have been advantageous, because in the midbody width the narrowest side of the NB measured only 5.4 mm. Whether a 2.7 mm screw provides enough stability for the fracture repair in a clinical case remains unknown. To date it is not known which part of the NB is most likely penetrated in clinical cases. However, it has been suggested that the most likely side of penetration would be the articular surface because of its anatomical conformation, followed by the flexor cortex.[20] In our case the articular side was affected.

This study was performed in a simulated standing position. In live standing horses, movement of the NB within the hoof capsule due to horse movement or just swinging must be considered during screw insertion.[21,24] Previously, the surgical approach to a distal phalanx fracture in the standing horse was performed in an experimental study and was found to be adequate.[25] Application of our described technique in the standing horse must be evaluated in clinical cases. To create the medial drill path through the hoof might be impeded by the contralateral limb and should be taken in consideration.

This described surgical technique could be performed with only one radiographic unit but the use of two decreases the preparation and surgical time. In the recumbent patient, the use of a fluoroscope for acquiring a DP and LM views is also feasible. One publication reported a mean of 40 fluoroscopic images during surgery but decreased as experience with the technique increased.[21] Others reported to take at least seven radiographs, and usually 15–20 images are needed, from preparation to drill[9] which is consistent with our findings. A previous report finds it essential to obtain LM, DP oblique and proximopalmar-distopalmar (skyline) views.[9] We found two perpendicular views sufficient, but it is important to produce true LM projections and horizontal DP views with the central beam positioned on the NB. We consider that the oblique projection may be misleading during placement of the ACD and surgery due to image distortion that occurs in this radiographic projection.

More advanced imaging and surgical techniques like CT, CAS and the use of 3D-printed guides have been shown to be advantageous for screw placement in the navicular bone.[16–21] However, these are expensive, not widely available, and mostly require general anesthesia. CT imaging is known to be more accurate than radiographs for surgical procedures.[20] Despite that, the radiation exposure for the surgical team during intraoperative use must be considered with conventional radiography.

Recent publications document a better outcome with advanced 3D imaging techniques compared to the traditional approaches.[16,20] CAS showed in several studies to be superior to conventional surgical technique, but it did not accomplish 100% accuracy.[16,20,26] Regardless of these statements, the CAS technique achieved perfect placement in 50% of the NB, while conventional AD under fluoroscopy guidance could place the 3.5 mm screw perfectly in 25%.[16] In our study, applying the same post-operative criteria for the screw placement, an excellent placement was obtained in nine out of 10 NB. However, it has been shown that 4.5 mm screws can be placed in the majority of NB when using advanced imaging techniques, which shows that a higher placement accuracy can be achieved even when a smaller margin of error exists when using a larger screw.[17–19] In a study comparing the 3D printed drill guide with the conventional technique, no differences in the quality of the 3.5 mm screw placement could be detected and an excellent positioning was found in three cases in each group ($n = 3/8$).[21] Nevertheless, a comparison between the different methods is difficult.

The limitations of our study were the small sample size, and its design as a cadaveric study which avoids the challenges of a live animal application. We also used non-fractured navicular bones, which do not represent a true clinical setting in a patient. In this study, the focus was placed on the screw placement and a neutral screw was inserted. In clinical cases, interfragmentary compression by using the lag-screw principle during fracture repair is warranted. Therefore, the custom-made ACD has interchangeable conical sleeves for a 2.7 mm cannulated drill bit as well as for a cannulated 3.5 mm drill bit for preparation of the glide and pilot holes required for lag screw principle in clinical cases.

In conclusion, we show that the described technique allows a precise screw insertion in the NB of regular size horses. However, the perceived advantages of bone stabilization during screw placement will warrant further investigation in cadaver models and the technique overall, investigation in the live horse.

AUTHOR CONTRIBUTIONS

Pudert T, TA, FTA, DrMedVet and Cruz AM, LV, MVM, MSc, PhD, ACVS, ECVS, ACVSMR, MRCVS: Were responsible for the concept study, design modification of ACD, execution of the study and preparation of the manuscript. Pudert T, TA, FTA, DrMedVet: Performed the statistical analysis. Fries GF, TA and Lotz H, TA: Assisted during the preparation of the specimens, as well as prepared the cadaver extremities for gross examination. Both scored specimens in gross examination. Röcken M, TA, FTA, DrMedVet: Was responsible for intellectual support for the study, oversaw data collection and interpretation of these. All authors reviewed, edited, and gave final approval to the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare no financial or other conflicts related to the report.

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