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Case Report

Accessory carpal bone fracture repair by means of computer-assisted orthopaedic surgery in a Warmblood stallion

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Summary

A 10-year-old, 595 kg Irish Warmblood stallion used for showjumping was presented with a marked right forelimb lameness at walk. The horse sustained a dorsal plane fracture of the accessory carpal bone (ACB) when falling with both carpi in flexion. The fracture was repaired by means of computer-assisted orthopaedic surgery (CAOS) using two cortex screws placed in lag fashion. In a second CAOS procedure, a dorsoproximal fragment of the ACB was removed after further proximal displacement had become apparent. Both surgical procedures were facilitated by the application of a fibreglass cast to immobilise the carpus in extension and to allow for the placement of the patient tracker distant from the surgical site. One year after surgery, the horse had returned to full athletic activity. Neither the antebrachiocarpal joint nor the carpal sheath were distended. Control radiographs and standing cone beam computed tomography showed complete osseous union of the fracture and osteophyte formation on the caudal aspect of the radius and the proximal border of the ACB.

Introduction

Accessory carpal bone (ACB) fractures can occur in any horse or breed but are most common in horses that race over fences (Dyson, 1990; Ruggles, 2019). They are often the consequence of ACB compression between the third metacarpal bone and the radius when the horse falls with the carpus in flexion. They can also be caused by direct external trauma or by excessive tension forces exerted by the palmar ligamentous attachment during carpal loading, causing a so-called bowstring effect or leading to avulsion fractures (Barr et al., 1990; Mackay-Smith et al., 1972; McIlwraith, 2020; Ross, 2011; Ruggles, 2019). Most fractures are complete and run in a dorsal plane, palmar to the groove for the tendon of the ulnaris lateralis muscle (Barr et al., 1990; Minshall & Wright, 2014).

Conservative treatment of dorsal plane fractures of the ACB, consisting of rest and external coaptation, may return some horses to athletic soundness (Barr et al., 1990; Dyson, 1990) and is therefore recommended by some authors (Barr et al., 1990; Dyson, 1990; Easley & Schneider, 1981; McIlwraith, 2020; Rijkenhuizen & Németh, 1994; Ruggles, 2019). However, healing is usually prolonged and does not result in complete bone union (Barr et al., 1990; Dyson, 1990; McIlwraith, 2020; Ruggles, 2019). Displacement of the fracture fragments can cause secondary damage to the carpal sheath and soft tissue structures contained within the sheath, such as tearing of the deep digital flexor tendon (Minshall & Wright, 2014) and carpal tunnel syndrome (Radue, 1981) if dorsal plane fractures of the ACB are treated conservatively.

As surgical treatment of dorsal plane ACB fractures has the potential for faster return to soundness (Easley & Schneider, 1981) and healing with minimal callus formation, it is generally the recommended treatment for athletic horses (Ruggles, 2019). Comminution and displacement of fracture fragments may limit surgical treatment options to excision of articular fragments involving the antebrachiocarpal joint (Munroe & Cauvin, 1997) and/or to carpal sheath tenoscopy for the debridement of torn tendinous tissues and the fracture gap by removing small fragments and smoothing protuberant fracture edges (Minshall & Wright, 2014).

Fracture repair of the ACB by internal fixation is a challenging procedure because the discoid and flat shape of the ACB leaves little room for technical errors. Furthermore, the carpal sheath and the tendons contained within it, as well as substantial ligamentous (accessorio-quartal and accessorio-metacarpal ligaments) and tendinous structures (tendons of the flexor carpi ulnaris and ulnaris lateralis muscle) attaching to the palmar aspect of the ACB limit direct surgical access. Techniques described for the repair of simple dorsal plane ACB fractures include fixation with cortex screws placed in lag fashion under fluoroscopic guidance or under radiographic control aided by an aiming device (Easley & Schneider, 1981; Rijkenhuizen & Németh, 1994) and the application of small plates to the lateral aspect of the ACB (Ruggles, 2019). Generally, high surgical precision and appropriate case selection are mandatory if osteosynthesis is elected to treat dorsal plane ACB fractures.

Computer-assisted orthopaedic surgery (CAOS) improves the precision of implant insertion compared with conventional intraoperative techniques utilised in human and veterinary surgery (Andritzky et al., 2005; Cheng et al., 2012; Gygax et al., 2006; Peters et al., 2016; Rossol et al., 2008; Tian et al., 2011). Recently, the clinical use of CAOS has been described in equine surgery and for a broad spectrum of indications (Heer et al., 2020; de Preux, Klopfenstein Bregger, et al., 2020). However, its use for surgical procedures involving the equine carpus has not yet been reported.

This case report describes the successful surgical case management of a comminuted, dorsal plane ACB fracture in an adult Warmblood stallion by means of CAOS.

Case history

A 10-year-old, 595 kg Irish Warmblood stallion utilised for showjumping was presented with a marked right forelimb lameness at walk. On the day prior to hospital admission, the horse was observed falling with both carpi in flexion when galloping in a sand paddock leading to an acute onset of the described lameness.

Clinical findings and further investigation

The region palmar to the right carpus was warm and slightly swollen, but the carpal sheath was not distended. The horse clearly resented flexion of the right carpus. Radiographs of the carpus (lateromedial, dorsopalmar, dorsal 45° lateral-palmaromedial oblique and dorsal 45° medial-palmarolateral oblique projections) were performed. On the lateromedial projection, a complete, minimally displaced dorsal plane fracture in a zigzag pattern was present, with the dorsal fragment measuring approximately 30% of the ACB's dorsopalmar distance (**Fig 1a**). An additional incomplete fracture line was observed in the proximal aspect of the dorsal fragment.

Treatment

All surgical procedures and postoperative orthopaedic and radiological examinations were performed at the ISME Equine Clinic Bern, Vetsuisse Faculty of the University of Bern, Switzerland. Written informed consent was obtained from the owner prior to publication of case details.

Surgical repair with cortex screws placed in lag technique

The horse received benzylpenicillin sodium (30 000 IU/kg IV, Penicillin Natrium Streuli, Streuli Pharma AG), gentamicin sulfate (6.6 mg/kg IV, Pargenta-50, Dr E Graeub AG) and flunixin meglumine (1.1 mg/kg IV Vetaflumex, Provet AG) one hour prior to induction of general anaesthesia. Sedative premedication consisted of acepromazine (0.03 mg/kg IM, Prequillan, Fatro SpA) administered 20 minutes prior to induction, combined with romifidine (0.04 mg/kg IV, Sedivet, Boehringer Ingelheim) and levomethadone (0.05 mg/kg IV, L-Polamivet, MSD Animal Health GmbH) given 10 minutes prior to induction.

As soon as the horse reached an appropriate level of sedation, a fibreglass cast extending from the distal metacarpus to the proximal radius and incorporating a $10 \times 3 \times 2$ cm piece of hardwood on the medial aspect of the carpus was applied (**Fig 2a**). Once the fibreglass cast material had fully cured, general anaesthesia was induced with a combination of ketamine (2.5 mg/kg IV, Ketasol-100, Dr E Graeub AG) and diazepam (0.05 mg/kg IV, Valium, Roche Pharma AG) and was maintained with isoflurane. The anaesthetised horse was placed in the right lateral recumbency. A window overlying the ACB of approximately 10 cm^2 in area was created in the cast using an oscillating cast saw (**Fig 2b**). Two self-tapping, threaded, 3.2 mm pins were placed in the piece of hardwood incorporated in the cast and served to tightly anchor the patient tracker (Medtronic Navigation) equipped with infrared reflective spheres to the medial aspect of the cast (**Fig 2c**). This was followed by aseptic preparation of the surgical field and draping.

Image acquisition and preoperative preparation of navigated instruments were performed as previously described (de Preux, Klopfenstein Bregger, et al., 2020). Briefly, a mobile cone beam CT (CBCT) unit (O-arm, Medtronic Navigation) coupled with a surgical navigation system (StealthStationS7, Medtronic Navigation) was utilised for 3D imaging. The acquired CBCT data set was automatically exported to the StealthStationS7. Quality control was performed on the CBCT images to ensure they met adequate standards. The exact fracture plane orientation was assessed by a board-certified radiologist and the operating surgeon. Corridors for two cortex screws to be

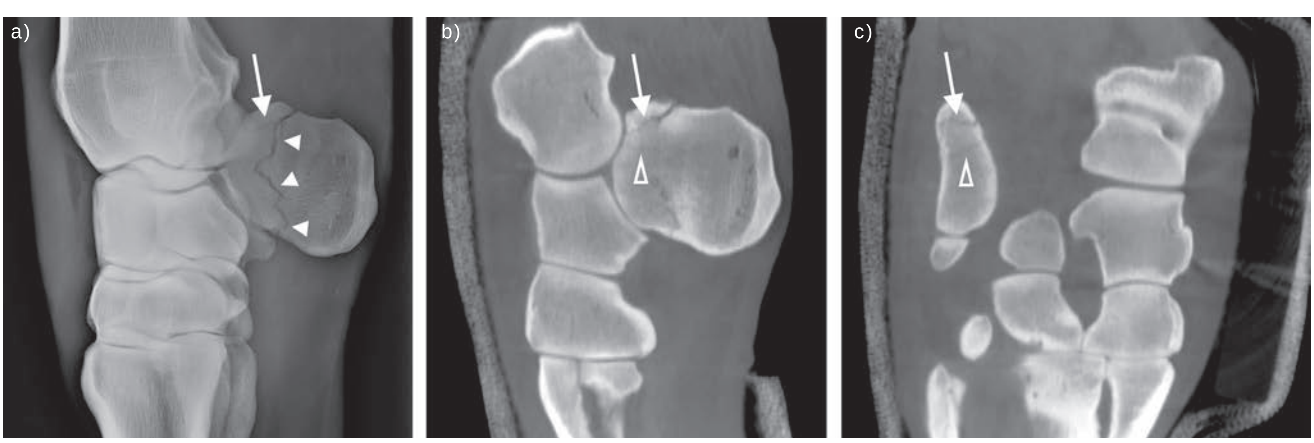

Fig 1: Lateromedial radiograph (a) of the right carpus showing a zigzag shaped, complete and mildly comminuted fracture (arrowheads) in the dorsal third of the accessory carpal bone (ACB), with minimal palmar displacement. An additional thin radiolucent line (arrow), originating from the main fracture, is present in the proximal fourth of the dorsal fragment, suspected to represent an incomplete fracture. (b) Sagittal and dorsal reconstructed images from an immediate preoperative CBCT under general anaesthesia show this last described fracture line in A (arrow) is complete and intra-articular. In addition, a second, intra-articular fracture line (open arrowhead), with a transverse orientation is present in the proximal half of the dorsal fragment.

***Fig 2:** Photographs of the preoperatively placed fibreglass cast utilised to facilitate the computer-assisted surgical repair of the accessory carpal bone (ACB) fracture. (a) The cast was placed prior to induction and with the horse standing to ensure immobilisation of the carpus in a fully extended position. Note: a piece of hardwood has been incorporated to allow the placement of the patient tracker. (b) Fenestration of the cast over the palmar aspect of the carpus to allow for surgical access to the ACB. (c) Intraoperative photograph showing the patient tracker anchored to the cast with two 3.2 mm pins. The operating surgeon utilises the navigated pointer to determine the appropriate site for placing the skin incisions. The patient tracker and the pointer are both equipped with light-reflecting spheres, which are detected by an infrared optical digitiser and camera array (not shown).*

placed in lag fashion and perpendicular to the fracture line were planned with the navigation software (Spine and Trauma, Medtronic Navigation). Following patient registration and calibration of the surgical drill, drilling was performed under navigation.

The CBCT images confirmed the presence of a nondisplaced dorsal plane fracture of the ACB. Moderate comminution with a larger, i.e. 16 × 10 × 7 mm fragment was present at the dorsoproximal aspect of the ACB, involving the articulation with the distal radius (**Fig 1b**). An additional thin fracture line with a transverse orientation was observed in the dorsal fragment, just distal to the previously described dorsoproximal fragment (**Fig 1b** and **c**). Given the lack of displacement and the interdigitation of the fragments, the surgeons hoped to stabilise these fragments *in situ* with the planned lag screw repair. With the aid of the navigated pointer (sharp pointer, Medtronic Navigation), the appropriate positions for the skin incisions were determined. For each cortex screw, a 1.5 cm longitudinal incision was made through the skin reaching the palmar surface of the ACB, followed by drilling a 2.5 mm pilot hole. Drill orientation and penetration depth were closely monitored on the screen of the StealthStation navigation (**Fig 3**). After ensuring the correct placement and orientation of the pilot holes by acquisition of an intraoperative CBCT scan, they were enlarged for the placement of a 4.5 mm cortex screw (48 mm in length) proximally and a 3.5 mm cortex screw (50 mm in length) distally. The proximal pilot hole was over-drilled with a navigated 4.5 mm drill bit to create the glide hole and then a navigated 3.2 mm drill bit to create the thread hole of appropriate width and depth. For the distal screw, the glide hole was prepared with a navigated 3.5 mm drill bit following the pilot hole to the level of the fracture gap. The choice of a 3.5 mm cortex screw distally was dictated by the proximity of the medial and lateral cortices of the ACB to the drill tract of the pilot hole and the concern about fragment displacement into the carpal sheath after potential violation of the medial cortex if a larger implant was utilised. After countersinking, screw length measurement and tapping, the two cortex screws were placed in lag fashion and tightened with the maximal strength achieved by holding the screwdriver with thumb, index and middle finger. An intraoperative control CBCT confirmed precise placement of the screws and satisfactory reduction of the fracture (**Fig 4a**). Skin incisions were closed with simple interrupted sutures by using nonabsorbable 2-0 monofilament suture material (Prolene, Ethicon, Johnson & Johnson). The patient tracker and its anchoring 3.2 mm pins were removed. The rectangular piece of fibreglass cast material corresponding to the window created to gain surgical access was replaced in its original position and secured with adhesive bandage material (Isoelast, IVF Hartmann AG).

A closed castration via an inguinal approach, double ligature of the spermatic cord, and primary skin closure was performed following the fracture repair under the same general anaesthesia. This was elected by the owners to facilitate the rehabilitation phase. The total surgery and anaesthesia times were 110 and 175 minutes, respectively. An additional bolus of romifidine (0.02 mg/kg IV, Sedivet, Boehringer Ingelheim) was administrated prior to recovery

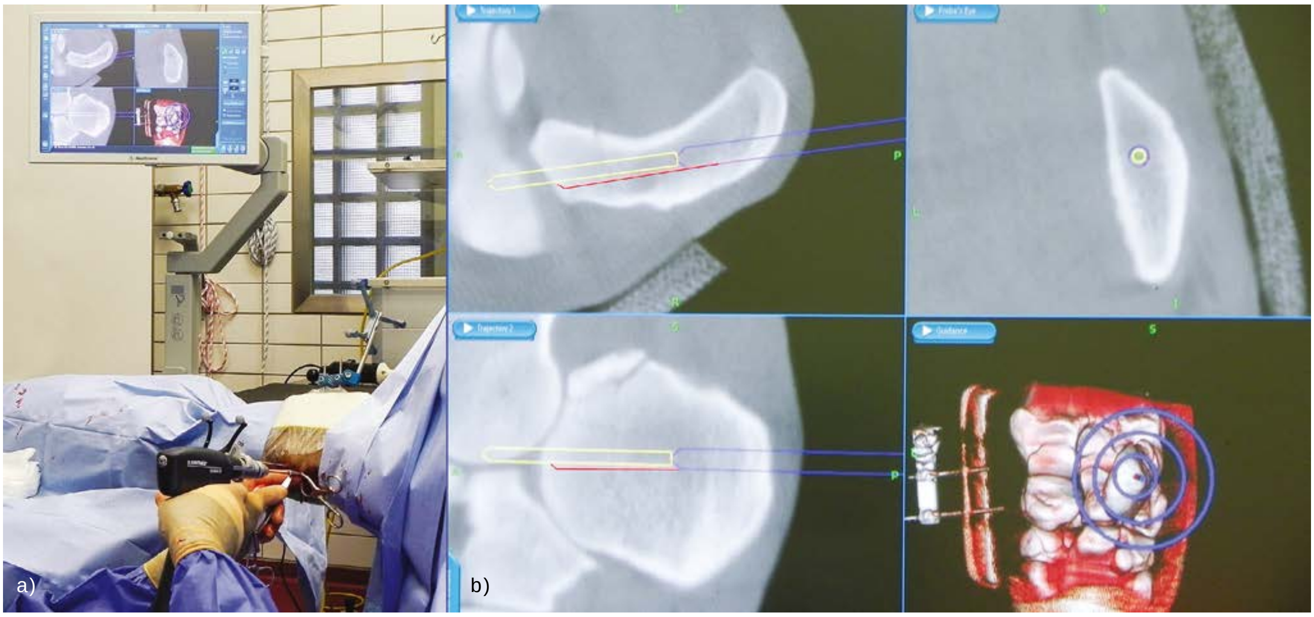

***Fig 3:** Computer-assisted, navigated drilling for the repair of an accessory carpal bone (ACB) fracture. (a) Intraoperative photograph depicting the drilling procedure. The drill orientation and penetration depth are monitored on the screen of the navigation system. (b) Close-up view of the screen. The ACB is projected in three planes (top left, transverse; bottom left, sagittal; top right, dorsal). The red cylinder, partially obscured by the virtual drill bit (blue cylinder), represents the planned screw position. The drill bit has penetrated the near cortex but has not yet passed the fracture line. The projection of the drill bit (yellow cylinder) and a target-grid (bottom right) are utilised for navigation.*

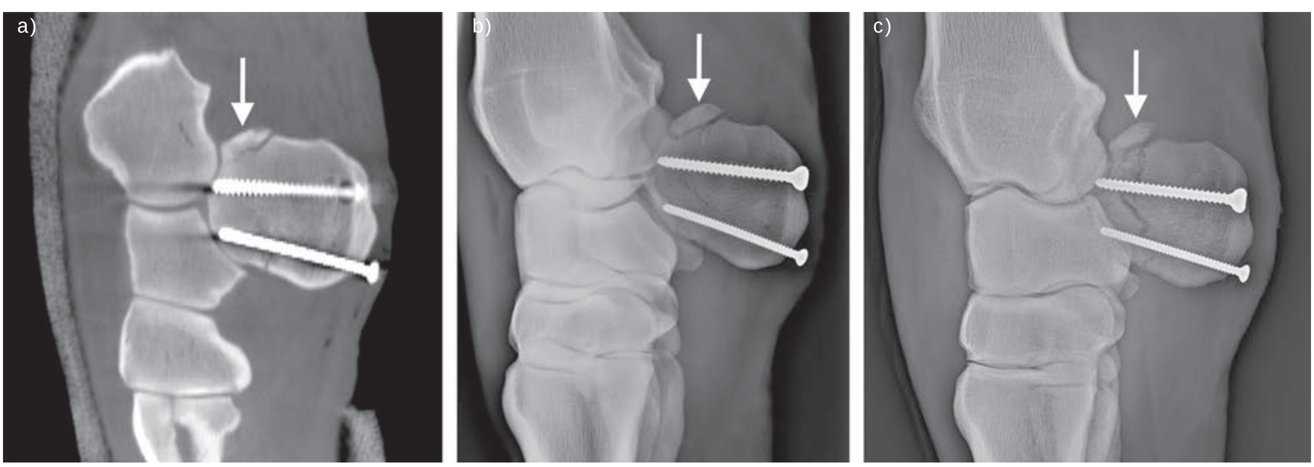

***Fig 4:** Sagittal reconstructed CBCT image and lateromedial radiographs of the carpus made at the end of the surgery (a) and 4 days (b) and 39 days (c) postoperatively, respectively. Note the gradual increase in proximal displacement of the dorsoproximal fragment (arrow). The widening of the main fracture gap in image C represents a normal stage of fracture healing. No signs of implant failure were observed. Note the streak artefacts in the distal radius and intermediate carpal bone due to the presence of metallic implants in the accessory carpal bone.*

from general anaesthesia. The horse was placed on a padded mattress with the casted limb uppermost and protracted, and assistance with head and tail ropes was provided in order to facilitate recovery. The horse showed only slight ataxia during recovery and stood uneventfully on its second attempt.

Intravenous antimicrobial therapy initiated preoperatively was continued for a total of 3 days and anti-inflammatory treatments for a total of 5 days (phenylbutazone, initially 2.2mg/kg IV BID for 3 days, then per os for 2 days). Immediately following recovery from general anaesthesia, the cast was removed, and the limb was placed in a full-limb bandage with a fitted dorsal splint made out of fibreglass cast material and reaching up to the proximal antebrachium. Radiographs were acquired to assess the progression of fracture healing (**Fig 4a**). The limb remained immobilised in the splinted bandage for a total of 3 weeks, followed by another 3 weeks in a full-limb bandage without the splint. Skin sutures were removed 10 days after surgery, and the horse was discharged from the hospital 2 weeks after surgery. The owners were instructed to keep the horse rested in a box until control examination 4 weeks after hospital discharge and to have the bandage changed at regular intervals by their attending veterinarian.

Removal of dorsoproximal fragment

The horse was re-examined 6 weeks postoperatively. Surgical incisions had healed without complications, and the horse was sound at walk. Control radiographs were made and revealed no signs of implant failure (**Fig 4b**). The fracture gap was mildly widened when compared with the immediate postoperative phase, with evidence of fracture gap remodelling which was deemed to be normal. However, there was increased proximal displacement of the separate dorsoproximal ACB fragment compared with that of the previous examination. Therefore, it was decided to remove this fragment in order to reduce the risk of developing antebrachiocarpal osteoarthritis and/or excessive callus formation at that site.

Premedication, anaesthesia protocol, preparation of the horse for CAOS including the application of the fibreglass cast before inducing general anaesthesia and assisted recovery were performed as for the first surgical intervention. Since the fragment was deemed to be mainly extra-articular and difficult to reach by arthroscopy, its removal was performed through a navigated cut-down procedure guided by the navigated pointer. After acquisition of a control-CBCT to confirm appropriate removal of the fragment, the 2 cm longitudinal skin incision was closed with simple interrupted sutures and using nonabsorbable 2-0 monofilament suture material (Prolene, IVF Hartmann AG). The piece of fibreglass cast material corresponding to the window created to gain surgical access was replaced in its original position and secured with adhesive bandage material. The horse made an uneventful recovery from general anaesthesia assisted with head and tail ropes.

Antimicrobial therapy was limited to the immediate perioperative period, and anti-inflammatory therapy was discontinued after 3 days. The horse continued to bear weight normally after the surgery and was discharged from the hospital 2 days postoperatively with a dorsally splinted full-limb bandage. The owners and referring veterinarian were instructed to leave the splint bandage in place for 1 week and then protect the surgical site with a regular full-limb bandage for an additional week. The skin sutures were removed 10 days after surgery. Box rest was recommended for 3 weeks, followed by another 3 weeks of box rest with access to a small paddock. Four weeks after the second surgery, the owners started to perform daily passive mobilisation of the carpal region and manual lymph drainage following the instructions of an animal physiotherapist. In-hand walking was started 6 weeks postoperatively.

Outcome

Six months after osteosynthesis, the horse was performing light exercise under saddle with short sessions of trot and canter without lameness. Control radiographs showed partial bony union of the fracture (**Fig 5a**). Moderate signs of bone remodelling were present in the articular region of the distolateral aspect of the radius and at the proximal border of the ACB, adjacent to the previous ACB fracture (**Fig 5a**). Minimal osteophyte formation was observed at the dorsal aspect of the antebrachiocarpal joint. The horse was re-examined one year after osteosynthesis. At that time, the horse had returned to full athletic activity and regularly started in dressage competitions on a regional level. The decision to compete the horse in dressage rather than showjumping was made for reasons unrelated to the injury, as the owner had changed her focus to that discipline. Nonetheless, she was still regularly jumping the horse for pleasure and training purposes, and without notable differences to its performance prior to the accident. During this period, the horse had not shown any lameness and neither the antebrachiocarpal joint nor the carpal sheath were distended. This was confirmed by the veterinary follow-up examination performed at the ISME Equine Clinic Bern where the horse was found to be sound on a straight line and circle on hard and soft ground at walk, trot and canter. Passive flexion test of the right carpus was negative. Repeat radiographic examination and a standing CBCT revealed neither signs of implant failure nor loosening. Remodelling noticed during the last examination remained minimal, with neither signs of excessive callus formation nor progression of osteoarthritis present (**Fig 5b**).

Discussion

Lag screw fixation of ACB fractures in horses is considered a technically demanding procedure owing to the flat and slightly bent shape and size of the ACB (Ruggles, 2019). In the present case, owner expectation for continued athletic activity was the primary objective of pursuing treatment. Given the authors' experience with CAOS and because the fracture was only minimally displaced and mildly comminuted, internal fracture stabilisation by means of a minimally invasive, navigated lag screw repair was elected.

The use of CAOS improves surgical accuracy for implant placement in human and equine surgery (Andritzky et al., 2005; Cheng et al., 2012; Gygax et al., 2006; Peters et al., 2016; Rossol et al., 2008; Tian et al., 2011). Recently, the successful application of this surgical navigation system, developed for human surgery, has been reported on clinical cases for various equine orthopaedic surgical procedures (de Preux, Klopfenstein Bregger, et al., 2020). However, technical refinements for its application on equine cases are required prior to integration into routine clinical use (de Preux, Vidondo, et al., 2020). In CAOS, optical tracking systems rely on a patient tracker that is securely anchored to the relevant anatomical region and remains in an angle-stable connection with the target bone, thus not changing its orientation in relation to this target bone. Tracker fixation can be challenging when working on small or unstable fragments, as in the present ACB fracture, and the tracker itself may be obscuring the surgical field. Furthermore, in human orthopaedic surgery, the pins utilised for tracker fixation have reportedly contributed to complications such as injury of neurovascular structures, pin-track infection, or pinhole fractures (Bonutti et al., 2008; Hoke et al., 2011; Jung et al., 2011; Li et al., 2008; Sikorski & Blythe, 2005). To overcome those drawbacks, a purpose-built frame was developed for CAOS applications involving the distal extremities of horses and extending up to the level of the proximal metacarpal or metatarsal bones (de Preux, Vidondo, et al., 2020). The fibreglass cast utilised in this case report served the same

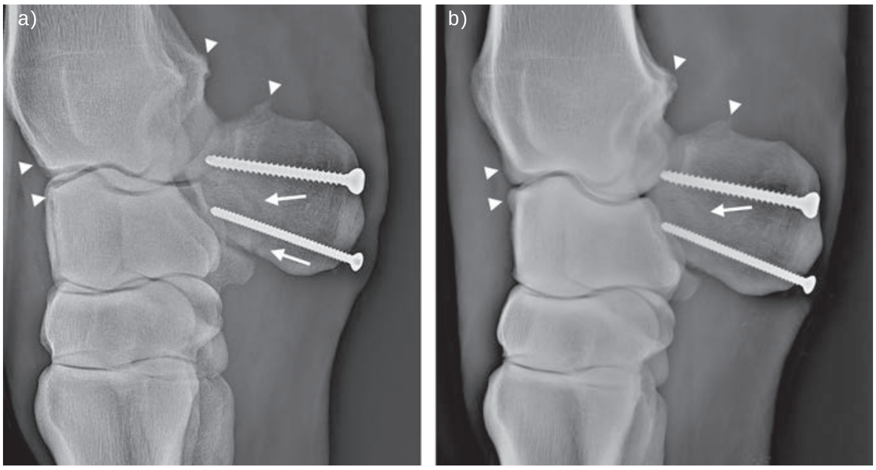

***Fig 5:** Lateromedial projections of the right carpus made 6 months (a) and 1 year (b) after the surgery, respectively, showing progressive fracture healing (arrows). The main fracture line is only slightly visible on the last control radiograph. Mild osteophyte formation (arrowheads) are present at the dorsal and palmar aspects of the antebrachiocarpal joint, but show smooth and rounded contours and minimal progression 1 year postoperatively.*

purpose as the frame: it stabilised the carpus in extension and minimised significant movement of the antebrachiocarpal, middle carpal and carpometacarpal joints. By doing so, the cast provided an artificial extension of the ACB and allowed the surgeon to place the tracker distant from the surgical site whilst still achieving a satisfactory surgical accuracy in implant placement. In order to avoid any displacement of the ACB in relation to the tracker during the surgical procedure, the cast was only minimally padded with felt at its proximal and distal border. Importantly, the cast also protected the fracture from further displacement or comminution during induction and again protected the fracture repair from early failure during the recovery phase of general anaesthesia.

The main fracture line ran just dorsal to the groove of the ACB where the long tendon of the ulnaris lateralis muscle glides over the lateral aspect of the ACB to insert on the fourth metacarpal bone. This fracture configuration differs from those described in a recent case series where all fractures were found palmar to this groove (Minshall & Wright, 2014). This had important consequences for surgical planning, since only a thin bone fragment remained dorsally for the thread hole. Extreme precision was mandatory to avoid penetration of the antebrachiocarpal joint as well as the medial and lateral cortex of the ACB. The latter was also the deciding factor in the choice for a smaller diameter screw distally.

Looking at the surgical repair, it appears that the length of the distally implanted 3.5 mm screw is not appropriate and that this screw would not achieve compression due to the lack of contact between its head and the bone. However, it was the surgeons' intraoperative impression that the screw head was tightly seated within the dense ligamentous attachments over the palmar border of the ACB. It was feared that more aggressive tightening of the screw would lead to breakage of the thin dorsal fragment or to penetration of the screw tip into the antebrachiocarpal joint. Furthermore, it was deemed that the compression achieved with the proximal 4.5 mm cortex screw was sufficient to stabilise the fracture and that the distal 3.5 mm cortex screws acted mainly as a position screw, serving to prevent fragment rotation in the dorsal plane. Therefore, it was elected not to replace the screw with a shorter implant as this would have required further dissection of the ligamentous tissues covering the palmar surface of the ACB.

The decision regarding the removal of the dorsoproximal fragment of the ACB was postponed until 6 weeks after the initial surgery. At this time point, further proximal displacement of this fragment became evident, making primary bone healing and bony union unlikely. More importantly, osteoarthritis of the antebrachiocarpal joint was anticipated due to continued synovial irritation because of the unstable articular fragment (Higgins et al., 2010).

In conclusion, this is the first report of successful surgical case management of a comminuted dorsal plane ACB fracture by means of CAOS. Following internal lag screw fixation in the initial surgery, an unstable dorsoproximal fragment was removed in a second surgery. Complete bony union was documented more than 6 months after the initial surgery and the horse returned to full athletic activity. CAOS opens new perspectives for the repair of ACB fractures as it offers so-far unmatched real-time intraoperative orientation and millimetre-scale accuracy for precise drilling and surgical access through minimally invasive approaches. The fibreglass cast served as an extension of the surgical target structures and allowed for the placement of the patient tracker in a strategically advantageous position. Furthermore, the cast protected the fracture from further displacement or comminution during induction and the fracture repair from early failure during the recovery phase of general anaesthesia. Additional investigations are needed to refine the proposed approach for CAOS involving other carpal bone fractures and osseous lesions.

Authors' declaration of interests

No conflicts of interest have been declared.

Ethical animal research

No ethical review and approval is required for the publication of clinical cases in Switzerland.

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Authorship

Mathieu de Preux drafted and revised manuscript. Elke Van der Vekens performed clinical work and revised manuscript. Julien Racine drafted parts of the manuscript. Daphne Sangiorgio performed clinical work and provided follow-up data. Micaël David Klopfenstein Bregger and Hervé Paul Brünisholz performed clinical work and revised manuscript. Christoph Koch conceptualised the work, performed clinical treatment and revised manuscript. All authors the approved final article.

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