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Application of locking compression plates as type 1 external fixators to treat unilateral mandibular fractures in four equids and one dromedary

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[Correction added on 08 December 2021, after first online publication: Figures 1-6 has been replaced with the correct version.]

Abstract

Objectives: To describe a novel fixation of open, unstable, unilateral mandibular fractures applying a locking compression plate as an external skeletal fixator (ESF-LCP).

Animals: Four horses and one dromedary.

Study design: Short case series.

Methods: Animals presented with unstable, open, unilateral fractures of the mandible. Fracture fixation was performed under general anesthesia. A 4.5/5.5 narrow LCP was applied externally above the level of the skin and combined with intraoral tension band wiring.

Results: Fracture fixation was achieved successfully using an ESF-LCP. Minimal tissue manipulation was required during application and removal of the construct. The ESF-LCPs provided adequate access to the wounds at the fracture site, were well tolerated, and did not interfere with any objects in the animals' environment. Mild drainage at the screw-skin interface developed in all cases, requiring early implant removal due to surgical site infection in one case. The use of longer plates was associated with superficial pressure necrosis of the skin in the masseter area in two cases. Implants were removed after 3 to 12 weeks, and the long-term functional outcome after 11 to 41 (median 13) months was good in all cases.

Conclusion: Stabilization of mandibular fractures with ESF-LCP led to good outcomes in this case series. The use of longer plates positioned more caudally and in a ventrolateral position seemed associated with surgical site infection and pressure necrosis of the skin.

Clinical significance: Use of a locking compression plate as an external skeletal fixator seems to offer a viable alternative to treat unilateral mandibular fractures, especially when these are open and/or infected.

1 | INTRODUCTION

Mandibular fractures are common in horses and camels and are usually caused by traumatic incidents. Most are open to the oral cavity and they are often associated with a skin wound at the site where the traumatic impact occurred.[1,2]

Unilateral, stable, and minimally displaced fractures can often be treated conservatively.[3] Surgical treatment for unilateral fractures is indicated if they are unstable, comminuted, or result in malocclusion. Various surgical techniques are described[2,4–10] of which internal fixation using plates and screws in combination with intraoral wiring is the most stable.[11] The current concept for surgical fixation of unilateral unstable or comminuted fractures of the horizontal ramus of the mandible in large animals is based on intraoral tension band wiring combined with the application of a locking compression plate (LCP) at the ventral, ventro-lateral, or lateral aspect of the bone.[2,12] Surgical site infection related to soft-tissue injury and contamination is a common sequela following internal fixation of open mandibular fractures.[4,5,9,12,13]

Alternatively, an external skeletal fixator (ESF) may be used to stabilize open or infected fractures of the mandible. With external fixation, closed reduction of the fracture can be achieved with little tissue manipulation, and foreign material at the fracture site is minimized. Additional advantages include access to wounds that are typically present and the ease of implant removal.[5,9] Recently a polyaxial pedicle screw external fixator was evaluated biomechanically and clinically in three cases of mandibular fractures in horses.[7,10]

Locking compression plates are principally designed for internal fixation. The rigid engagement of the locking-head screws (LHS) in the threaded portion of the combi-hole allows for the LCP to be positioned at a chosen distance from the bone. The biomechanical properties of LCP external skeletal fixators (ESF-LCP) have been investigated for the use in human surgery where ESF-LCP constructs are mainly used for treatment of open tibial fractures.[14,15–17] The ESF-LCP shows decreased stiffness compared to internal LCP fracture fixation but the advantages of external fixation justify its application in selected cases.[18]

As far as the authors are aware, this is the first case series detailing the successful modification of the LCP system to be used as a type I external skeletal fixator for stabilization of mandibular fractures in large animals.

2 | MATERIAL AND METHODS

2.1 | Demographics

One 4 year old female dromedary (case 1), an 18 year old warmblood stallion (case 2), a 24 year old Appaloosa gelding (case 3), a 1 day old warmblood filly (case 4), and a 4 year old pony stallion (case 5) were admitted with mandibular fractures for surgical fixation of mandibular fractures at the equine clinic, Freie Universität Berlin (Table 1). The dromedary was used for breeding, cases 2 and 5 were used for pleasure riding and breeding, and case 3 was retired.

2.2 | Preoperative findings

Fractures were caused either by a fall (case 1), a kick from another horse (cases 2, 3 and 5), or a crush injury inflicted by the dam (case 4). Fractures were acute and presented within 24 hours following injury except for case 3, which was initially managed conservatively for 1 month. Case 3 was referred due to inability to take in solid food with associated weight loss caused by persistent fracture instability.

Clinical examination identified a skin wound in cases 1, 2, and 3, and a mucosal lesion to the oral cavity in cases 4 and 5 (Table 1). Fractures were unstable on palpation with a degree of soft tissue swelling, particularly marked in case 5. Digital radiography or CT examination revealed simple fractures in cases 1 (Figure 1A), 2 (Figure 2A), and 4 (Figure 4A), and comminuted fractures in cases 3 (Figure 3A) and 5 (Figure 5A,B) (Table 1). All fractures were displaced (mild displacement in cases 2 and 5) and involved the horizontal ramus of the mandible, with the additional involvement of the vertical ramus in case 3. The fracture of the vertical ramus was not displaced and was stable on palpation. The incisive bone and maxilla were also fractured bilaterally in case 2. In case 5 the teeth 406 and 408-11 were fractured. Prior to surgery all animals were able to ingest only soft food.

2.3 | Surgical treatment and intraoperative findings

Anti-inflammatory (flunixin meglumine 1.1 mg/kg IV) and antimicrobial medication (amoxicillin 15 mg/kg IV (dromedary); amoxicillin 15 mg/kg IV and gentamicin 6.6 mg/kg IV (adult horses); ceftiofur 4.4 mg/kg IM (foal)) were administered preoperatively. For premedication, adult horses received xylazine (1.1 mg/kg IV) and butorphanol (0.05 mg/kg IV), and for induction of general anesthesia diazepam (0.02 mg/kg IV) and ketamine (2.2 mg/kg IV). The foal was premedicated with diazepam (0.05 mg/kg IV) and butorphanol (0.05 mg/kg IV), and general anesthesia was induced with ketamine (2.2 mg/kg IV). The dromedary received xylazine (0.2 mg/kg IV) for premedication, midazolam (0.05 mg/kg IV), and ketamine (2.2 mg/kg IV) for

TABLE 1 Case details of five large animals presented with unstable mandibular fractures treated with external application of a locking compression plate

Case	Signalment	Fracture configuration	Implants	Complications in addition to mild drainage at the screw-skin interface	Plate removal (weeks post operation)	Outcome/*Long-term follow up (months)*
1	Dromedary mare, 4 years	Open, acute, simple, oblique, unstable, displaced, left diastema	Ventrolateral, 10-hole 7 × 5.0 LHS Two 3.5 cortical screws across the fracture in lag fashion ITBW	Screw contact to tooth roots 306/7/8, Fistula, Sequestrum	12	Wounds healed after implant and sequestrum removal resolution of drainage Used for breeding *33*
2	Warmblood, stallion, 18 years	Open, acute, simple oblique, unstable, mildly displaced, left diastema, bilateral fracture nasal process of the incisive bone and maxilla	Ventrolateral, 10-hole 8 × 5.0 LHS, ITBW ITBW between 106, 206 and incisors	Hypergranulation	12	Resolution of drainage Used for riding *41*
3	Appaloosa gelding, 24 years	Open, chronic, oblique, unstable, displaced, right diastema, osteolysis, callus formation, multiple fracture lines caudal horizontal and vertical ramus	Ventral, 12-hole 10 × 5.0 LHS ITBW	No adequate reduction, Hypergranulation	12	Resolution of drainage Retired *11*
4	Warmblood, mare, 1 day	Open, acute, simple oblique, unstable, displaced, originating between 706 and 707 to ventral at the level of 708	Ventrolateral, 12-hole 5 × 5.0 LHS	Hypergranulation pressure necrosis of the skin	3	Wounds healed 1 week after implant removal resolution of drainage Not in training yet (yearling) *11*
5	Pony, stallion, 4 years	Open, acute, oblique, unstable, mildly displaced, right mandible, from interdental space, involving mesial root of the 406, comminution at the ventral aspect; from ventral through the medial aspect of the mandibula, involving 408-410 exiting between 410 and 411	Ventrolateral, 16-hole 8 × 5.0 LHS ITBW	Screw contact to tooth root 409, pressure necrosis of the skin, abscess, fistula, Infection of the tooth root 406	3, ITBW left in place for 12 weeks	Resolution of infection after tooth removal (406) resolution of drainage Mineralization of the distal pulp 409 Used for riding and breeding *13*

Abbreviations: ITBW, intraoral tension band wiring; LHS, locking-head screws.

induction of general anesthesia. Anesthetized animals were intubated orotracheally (horses and dromedary) or via nasotracheal intubation (foal). General anesthesia was maintained with isoflurane (minimum alveolar concentration 1.0) and was balanced with xylazine in adult horses (0.8 mg/kg/h IV). Horses were positioned in dorsal recumbency and the dromedary was placed in the cush position with the head tilted to the right. Following routine skin preparation, wounds were debrided and enlarged as necessary to remove contamination, loose bone fragments, or infected tissue. The fracture site was lavaged with sterile saline and fracture reduction was performed with pointed reduction forceps without further enlargement of the surgical incision.

Narrow 4.5/5.5 LCPs were used in combination with 5.0 LHS for fracture fixation in all cases. The plate length varied as required for the individual case with a 10-hole 4.5/5.0 narrow LCP used in cases 1 (Figure 1B) and 2 (Figure 2B-D), a 12-hole LCP used in case 3 (Figure 3C) and 4 (Figure 4B,C) and a 16-hole LCP in case 5 (Figure 5C,D) (Table 1). Plates were bent to fit the contour of the mandible and positioned with respect to the location of the associated wound and fracture configuration. The plates were positioned on the ventral side of the mandibula in case 3 and ventrolateral in all other cases. A distance of approximately 3 to 4 mm between the skin and the LCP was maintained by placing the flat side of a scalpel handle between plate and skin (Figure 6). The LHS were inserted through stab incisions. At least 3 screws were inserted on each side of the fracture, except in the foal (case 4), because there was only room for 2 screws rostrally (Figure 4). Radiographic guidance for fracture reduction, plate contouring, and implant placement was used in cases 3, 4, and 5.

A 1.2 mm stainless steel cerclage wire was used for tension band wiring between the premolars and incisors using the Obwegeser technique as described elsewere.[4,8] In the foal (case 4) application of a tension band was not possible as the incisors and premolars had not yet erupted. The additional fracture of the incisive bone was treated with intraoral tension band wiring in case 2. Adequate anatomic reduction was achieved radiographically in all cases except case 3 and 4 (Figures 1-5).

The open fracture sites were left to heal for secondary intention. Recovery from general anesthesia was unassisted and uneventful in all cases.

2.4 | Postoperative management

Antimicrobial therapy was continued for up to 10 days and flunixin meglumine (1.1 mg/kg orally, twice daily) was given for 6 days. Case 2 and 5 additionally received omeprazole (1 mg/kg orally, once daily) for 2 weeks, and case 4 sucralfate (10 mg/kg three times a day) for 10 days.

The skin wounds and the open fracture sites could be accessed easily (Figure 7) and were cleaned twice a day with polyhexanide solution. Postoperative medication and wound care was not possible for the dromedary due to uncooperative behavior.

The adult subjects were able to consume their usual diet including concentrates and roughage and the foal was able to nurse without difficulty within 24 h following surgery.

Cases were discharged from the hospital at a mean time of 11 days postsurgery (1 to 21 days). After hospital discharge, clinical and radiographic follow-up examination was continued until implant removal was performed by the referring veterinarian or at the clinic.

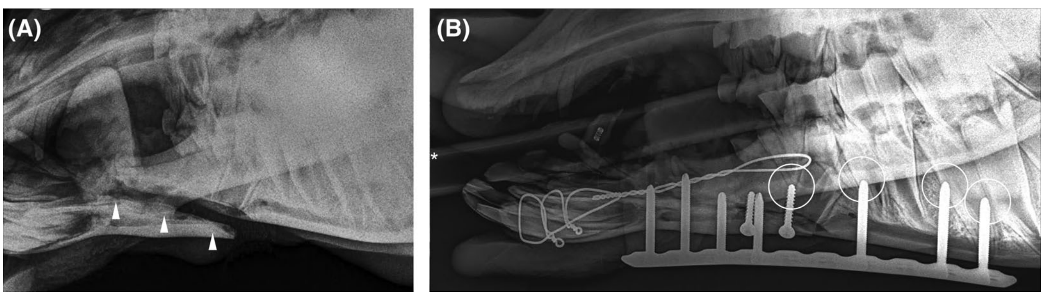

FIGURE 1 Case 1 (A) Preoperative (right ventral–left dorsal oblique) projection of the mandibula of a 4 year old female dromedary. A simple, oblique, displaced fracture in the left diastema is observed (arrowheads). (B) immediate postoperative (right ventral–left dorsal oblique) radiograph. A 10-hole narrow locking compression plate (LCP) with 7 × 5.0 mm locking head screws was positioned at the ventrolateral aspect of the right mandible. An intraoral wire was placed between 306 and the incisors. Two 3.5 cortical screws were placed across the fracture in lag fashion. Note that there was contact of screws with the tooth roots 306/7/8 (circles). There is an orotracheal tube in place (star)

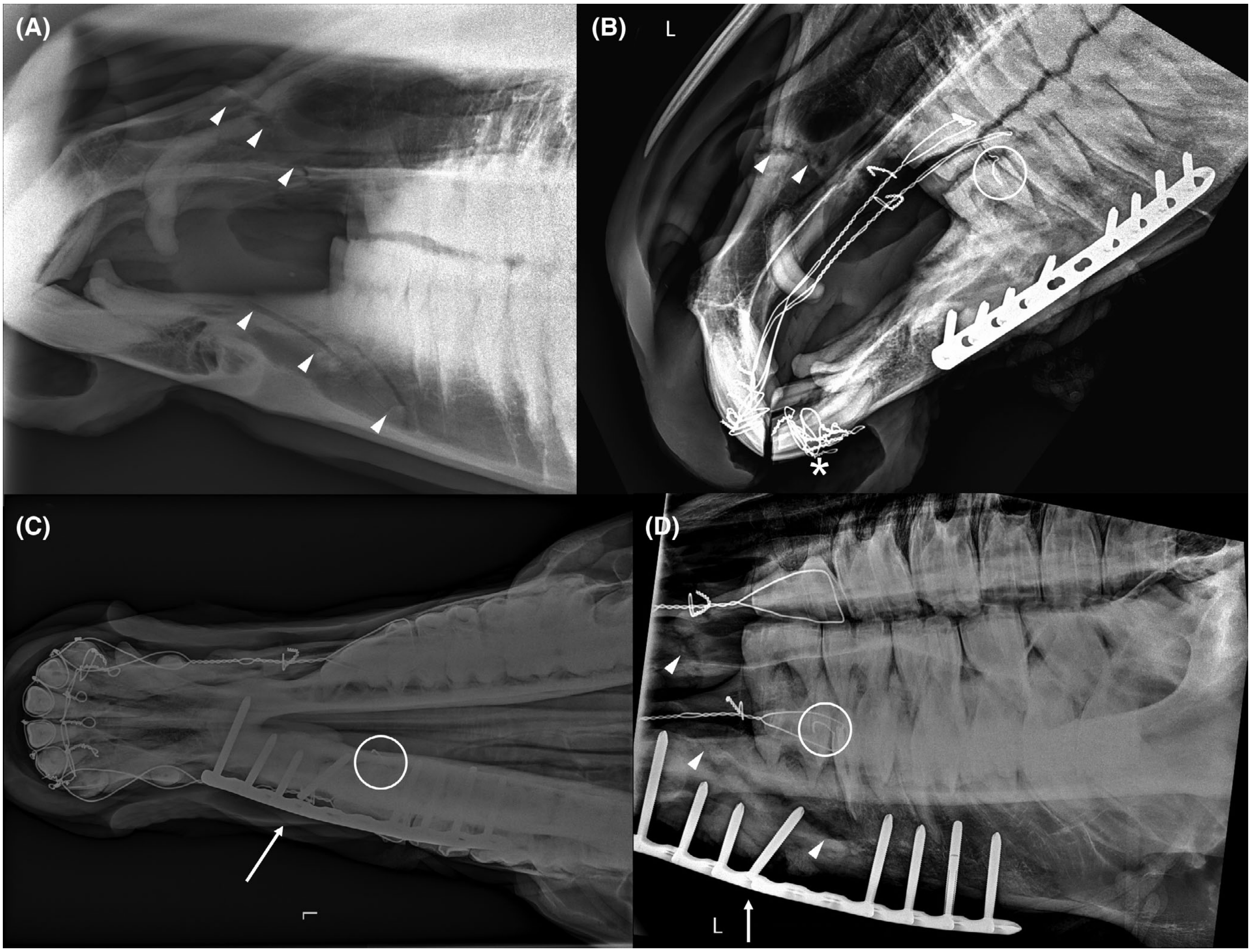

FIGURE 2 Case 2 (A) Preoperative latero-lateral radiograph of an 18 year old warmblood stallion, presented with an acute, unstable, open fracture of the left mandible. There is a simple oblique, mildly displaced fracture of the left diastema. A bilateral fracture of the incisive bone and maxilla is also shown. Fractures are identified by arrowheads. (B) laterolateral, (C) dorsoventral, and (D) right ventral to left dorsal oblique projection obtained 3 months postoperatively. A 10-hole, narrow locking compression plate with 8 locking head screws (LHS) is positioned at the ventrolateral aspect of the left mandible. Intraoral tension band wires were initially placed between 106, 206, and 306 and the upper and lower incisors respectively. Note, that the LHS just rostral to the fracture line is broken (C, D, arrow). The intraoral cerclage wire between the 306 and the lower incisors is broken. The wire is still in place at the lower incisors (B, star), remains from the 306 and diastema have already been removed except for a small piece of cerclage wire at the distal and lingual site of 306 (B-D circle). Even though screw contact to tooth roots was suspected, it could be ruled out by combination of laterolateral and oblique projections (B, D). Advanced remodeling is evident at the fracture site (D, arrowheads)

3 | RESULTS

Interference by the ESF-LCP with objects in the animals' environment was not observed and not reported. Postoperative complications prior to plate removal included mild drainage at the screw-skin interface, which developed on days 6-10 postsurgery in all cases, and hypergranulation tissue at the screw-skin interface and towards the rostral aspect of the plate in cases 2 (Figure 7), 3, and 4. Four screws were in direct contact with the premolar and first molar teeth in case 1 (Figure 1B), and one with the distal root of 409 in case 5 (Figure 5C,D). In case 1, radiographic examination after 12 weeks identified a sequestrum at the fracture site associated with a fistula. A loose fragment was removed under general anesthesia along with the plate.

In case 2 the LHS just rostral to the fracture line and the intraoral cerclage wire on the left hemimandible were broken after 3 months (Figure 2C,D). There was no evidence of plate loosening.

In the newborn foal (case 4) and in case 5 the LCP induced superficial pressure necrosis of the skin and subcutaneous tissue at the level of the masseter muscle.

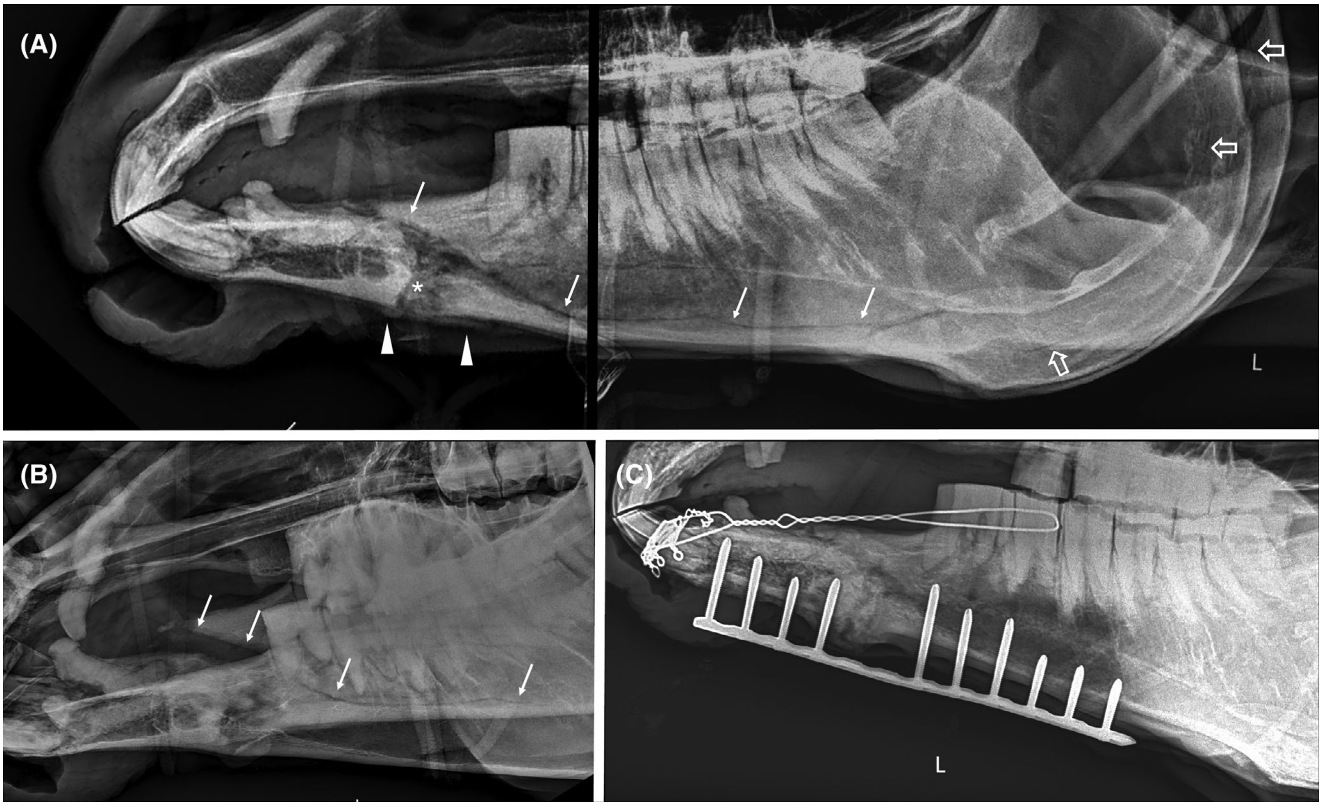

FIGURE 3 Case 3 (A) Two latero-lateral and (B) right ventral-left dorsal oblique radiograph centered on the right mandible of a 24 year old Appaloosa gelding presented with open chronic mandibular fracture of 4 weeks' duration. Note the oblique, displaced fracture at the level of the right diastema propagating in the horizontal ramus (arrows) with associated osteolysis (star) and callus formation (arrowheads). Multiple fracture lines are additionally evident in the caudal horizontal and vertical ramus of the right mandible (blank arrows). (C) Latero-lateral radiograph obtained 3 months postoperatively. A 12-hole narrow locking compression plate (LCP) with 10 × 5.0 mm locking-head screws was positioned at the ventral aspect of the right mandible with an intraoral cerclage wire (1.2 mm) placed between the incisors and the third premolar teeth. Advanced remodeling and callus formation are evident at the fracture site

In case 5 the plate was removed early because of the pressure necrosis described above and as an abscess had formed in the intermandibular region in association with the fracture site 3 weeks after surgery. The abscess was drained subsequently, and the intraoral wire was left in place 12 weeks after surgery. In this horse a fistula associated with the fractured mesial root of the first premolar tooth (406) was detected 7 weeks after plate removal. The fistula was initially debrided and lavaged. As soon as radiology evidenced sufficient fracture healing 2 months later, the tooth 406 was removed via intraoral extraction.

Implants were removed 3-12 weeks following surgery in sedated horses or under general anesthesia in case 1, as the dromedary was too uncooperative to attempt implant removal with sedation only. The external application of the LCP facilitated easy access to all screw heads and LHS were removed using a handheld screwdriver without difficulty. Radiographically there was advanced remodeling and evidence of mineralized callus at the fracture site in all cases.

Long-term follow up after implant removal was obtained via telephone questionnaire at the time of writing this case series. Owners and/or referring veterinarians were asked about food intake, body condition, signs of inflammation at the fracture site, bone deformities, dental problems, and level of exercise. They were also asked to compare performance before and after fixation.

Long-term follow-up information was available for a period of 11 to 41 (median 13) months after hospital discharge (Table 1).

All cases were reported by the owners as having normal food intake and chewing motion. All animals performed as intended.

Clinical consequences from contact between screws and teeth in cases 1 and 5 did not arise during the time until long-term follow-up information was received. A control CT examination of case 5 was performed 13 months postoperatively. The apical aspect of the distal pulp of the 409 was filled with hyperattenuating material consistent with mineralization (Figure 8).

The fistulae in case 1 and 5 had healed completely. During follow up of the foal (case 4) the referring veterinarian reported slight latero-lateral incongruence of the incisors 10 weeks post implant removal. Fourteen

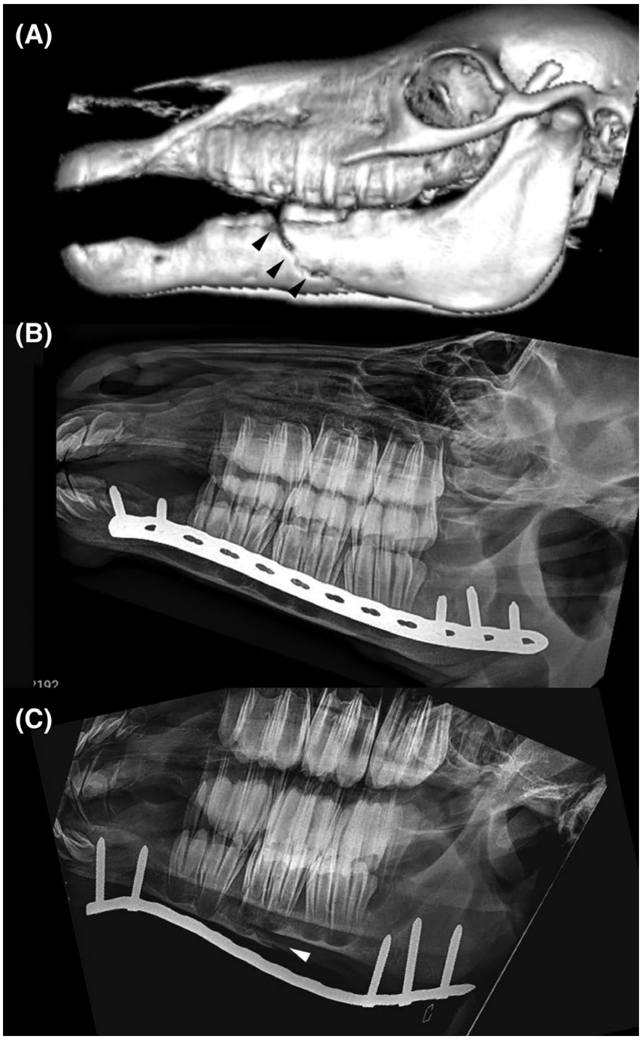

FIGURE 4 Case 4 (A) Preoperative, three-dimensional CT reconstruction of the left mandibula of a 1 day-old foal presented with an unstable fracture open to the oral cavity. There is a simple, oblique, displaced fracture originating between 706 and 707 to the ventral level of tooth 708 (black arrowheads). (B) Latero-lateral and (C) right ventral–left dorsal oblique radiograph obtained 1 week after surgery. A 12-hole narrow locking compression plate (LCP) with five 5.0 mm locking head screws is positioned at the ventrolateral aspect of the left mandible. The long plate was chosen to avoid the large reserve crowns and tooth roots of the premolars. Anatomic reduction was not achieved, and a step is visible on the ventral aspect of the mandibula (white arrowhead)

months later the yearling showed normal growth and development and the incongruence of the incisors had resolved without further intervention.

4 | DISCUSSION

This case series describes the successful stabilization of open and unstable unilateral fractures of the horizontal ramus of the mandible using a 4.5/5.0 ESF-LCP in large animals.

The slim configuration of the ESF-LCP presumably prevented the interference with objects in the animals' environment reported for other ESF constructs.[2,9] The LCP system is available in most equine referral hospitals nowadays and surgeons are familiar with its use.

Another major advantage of the approach described is the minimal tissue manipulation required during implant application and removal. Implant removal was performed standing, using only sedation in all equine cases in this study. Although other ESF constructs applied to treat mandibular fractures in horses can be removed standing,[5,7,9] general anesthesia was described for the removal of a conventional ESF in 8/14 cases in one report.[5]

In the current study, LCPs were applied on the ventral aspect of the mandible in one case and ventrolateral in four cases. In case 3 the fracture propagated caudally in the horizontal ramus of the mandibula and a ventral positioning of the plate was chosen to avoid placing LHS within the fracture line. Furthermore, the LHS were intended to act as position screws, providing additional stabilization. A ventrolateral placement was chosen because of the ventral wound in cases 1 and 2 to allow best access for wound care.

In cases 4 and 5 the fractures were open to the oral cavity and biomechanical considerations led to the choice of a ventrolateral position for the plate. The biomechanical impact of plate positioning for the fixation of biaxial interdental mandibular osteotomies was evaluated in an ex vivo model and identified a superior stiffness for ventrolateral LCPs when compared to ventral or ventrolateral DCPs.[19] In this ex vivo study, ventrolateral positioning of LCP was not compared to ventral positioning and constructs were tested without intraoral tension band wiring. For this reason, and because of the external application of the LCP in the present study, the biomechanical situations evaluated by Durket et al.[19] are not directly transferable to the cases described in this report. Ex vivo studies would be required to clarify biomechanical characteristics of the different positions for LCP-ESF. No obvious clinical disadvantages with either position were observed in the present report.

Despite the advantages of the technique described some complications were noted postoperatively.

On radiographs, screw contact with tooth roots was observed in cases 1 and 5. There were no clinical consequences reported at long-term follow up; however, during a control CT of case 5 apical mineralization of the distal pulp of the 409 was diagnosed. Similar images are described in horses with apical infections and they most

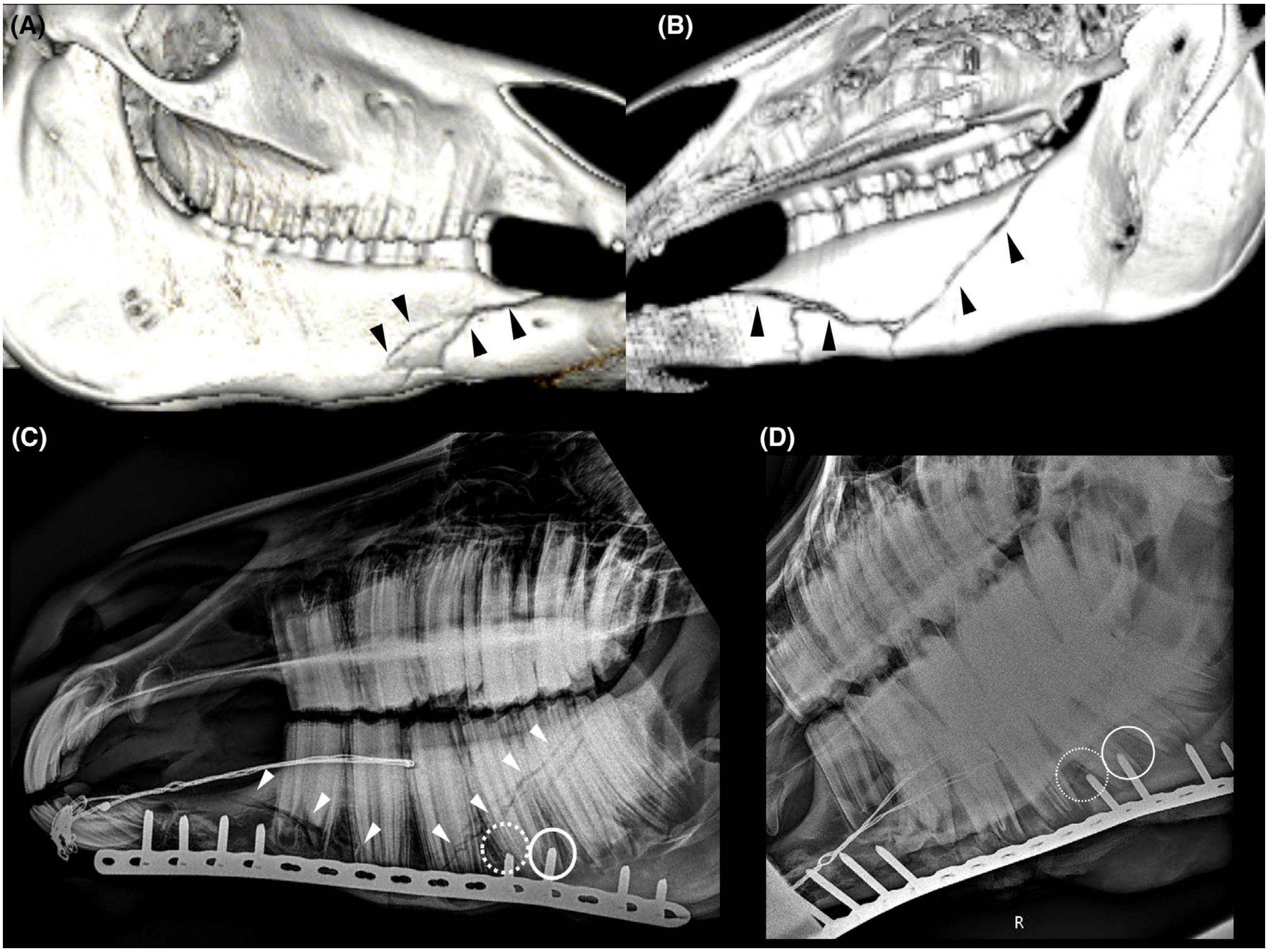

FIGURE 5 Case 5 (A) and (B) preoperative 3-dimensional CT reconstructions of the right mandible of a 4 year old pony stallion presented with an acute unstable fracture of the right mandible, open to the oral cavity. There is an oblique, mildly displaced, fracture in the right mandible, coursing from the interdental space ventrocaudal, involving the mesial root of the 406. There is comminution at the ventral aspect. From this area another fracture line at the medial aspect of the mandibula involves the roots of the teeth 408-410 and exits between 410 and 411. (C) lateromedial and (D) left ventral–right dorsal oblique radiographs 3 weeks postoperatively. A 16-hole narrow locking compression plate (LCP) with eight 5.0 mm locking head screws is positioned at the ventrolateral aspect of the right mandible. Intraoral wires are placed between 407 and the incisors. Fractures are identified by arrows. Note that there is contact between the third screw from caudal and the distal root of the 409 (C, D circle). Although suspected from the laterolateral radiograph, the fourth screw from caudal has no contact to the mesial tooth root of 409 (C, D dotted circle)

likely represent a reactive or reparative response of the dentinopulpar complex to an insult.[20] These changes could have been caused by the contact of the screw with the tooth root or the initial fracture of the tooth. Other teeth involved in the fracture did not develop mineralization of the pulps, making an iatrogenic etiology more likely. Further complications related to the trauma of the tooth roots induced by surgical implants may arise later. At the time of this writing, there is little information in the literature regarding the length of time to development of complications from injury to the pulp cavity in the horse.[21,22]

In case 5, implants were placed under radiographic control to prevent screw contact with the teeth, which was particularly challenging because of the long reserve crowns and tooth roots in this young horse. The interference of screws placed in the ventrolateral aspect of the mandible with tooth roots is a known risk.[2] Fluoroscopic control successfully prevented damage to tooth roots in a case series of complicated mandibular fractures repaired by open reduction and internal fixation with LCP.[12] In that case series, intraoperative imaging may have been facilitated by placing the plate on the ventral side of the bone, in most cases, reducing superimpositions.

The need to insert LHS at a 90° angle to the ESF-LCP makes avoidance of tooth roots challenging. Other fixation methods allow placement of screws at variable

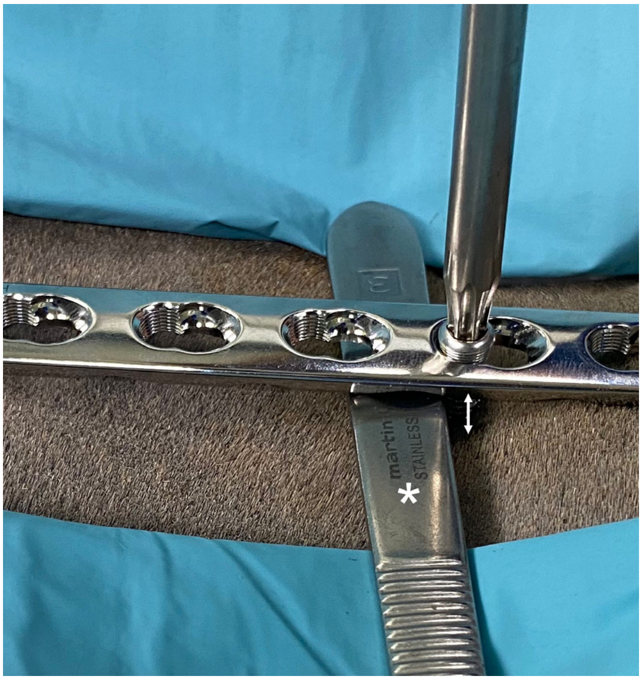

FIGURE 6 Application of the locking compression plate used as an external skeletal fixator (ESF-LCP) (simulation). The flat surface of a size 3 scalpel handle (star) was placed between the skin and LCP during screw placement to maintain a distance of approximately 3 to 4 mm to the soft tissues (2-sided arrow)

FIGURE 7 A 10-hole external skeletal fixator locking compression plate (ESF-LCP) on the ventrolateral left mandible of an 18 year old warmblood stallion (case 2), 2 weeks postoperatively. The ESF-LCP allows good access to the skin wound (arrowhead) associated with the open mandibular fracture. There is mild exuberant granulation at the screw-skin interface close to the fracture site (arrow)

angles. For internal fixation with LCP, LHS were combined with cortical screws.[12] Recently a pedicle screw external fixation device was evaluated biomechanically and in three clinical cases, and no interference of implants with tooth roots was reported.[7,10] A type I ESF construct using 5.5 mm cortical screws connected with a polymethyl methacrylate bar has also been described for stabilization of mandibular fractures.[5] Another option to avoid contact of implants to tooth roots in mandibular fracture fixation would be the pinless external fixator, although it is not produced any more.[9]

The initial trauma and contamination most likely led to sequestrum formation in case 1 and abscessation and tooth-root infection of 406 in case 5. Surgical site infection following surgical repair of equine mandibular fractures is a common complication, as most fractures are open to the skin and/or oral cavity.[4,5,9,12,13]

The cases in this report were all described as having drainage at the screw-skin interface. After repair of mandibula fractures in the equids, drainage from the clamp insertion sites was observed in 4 of 9 cases treated with the pinless external fixator,[9] and infection associated with the implants, involving the surrounding bone, was reported for 2 of 3 cases treated with the polyaxial pedicle screw external fixator.[7] In contrast, for human open and closed tibial fractures stabilized with ESF-LCPs, superficial screw tract infection was described in 7.1% of cases.[18] A clean environment and the option for bandaging are possible reasons for this difference between species and fracture sites.

Another complication arose in two cases where the application of long LCPs was elected to bridge the fracture gap, and pressure necrosis of the skin occurred at the caudal aspect of the plate. Initial swelling and compression of the skin during neck flexion may promote this complication. In one horse treated with the polyaxial pedicle screw external fixator, a similar problem was noted at the rostral end of the construct, and the rod was shortened to address this concern.[7] To prevent excessive pressure in the area of the masseter the ESF-LCP could be applied further ventral to avoid the masseter muscle; more intensive plate contouring could be performed, and a larger distance could be chosen between the plate and skin. Alternatively, internal fixation of caudal fracture configurations could be elected. Finally, using the shortest plate possible may prevent this complication: In case 4 a 12-hole plate was chosen due to the fracture localization extending to the ventral aspect of 708 and to avoid the large reserve crowns and tooth roots of the deciduous premolars. However, an 11-hole plate with 2 LHS caudal to the fracture site may have been sufficient to stabilize the fracture. Placement of at least two pins on either side of the fracture is recommended if a type I ESF is used in unilateral mandibular fractures of the horizontal ramus.[2] For

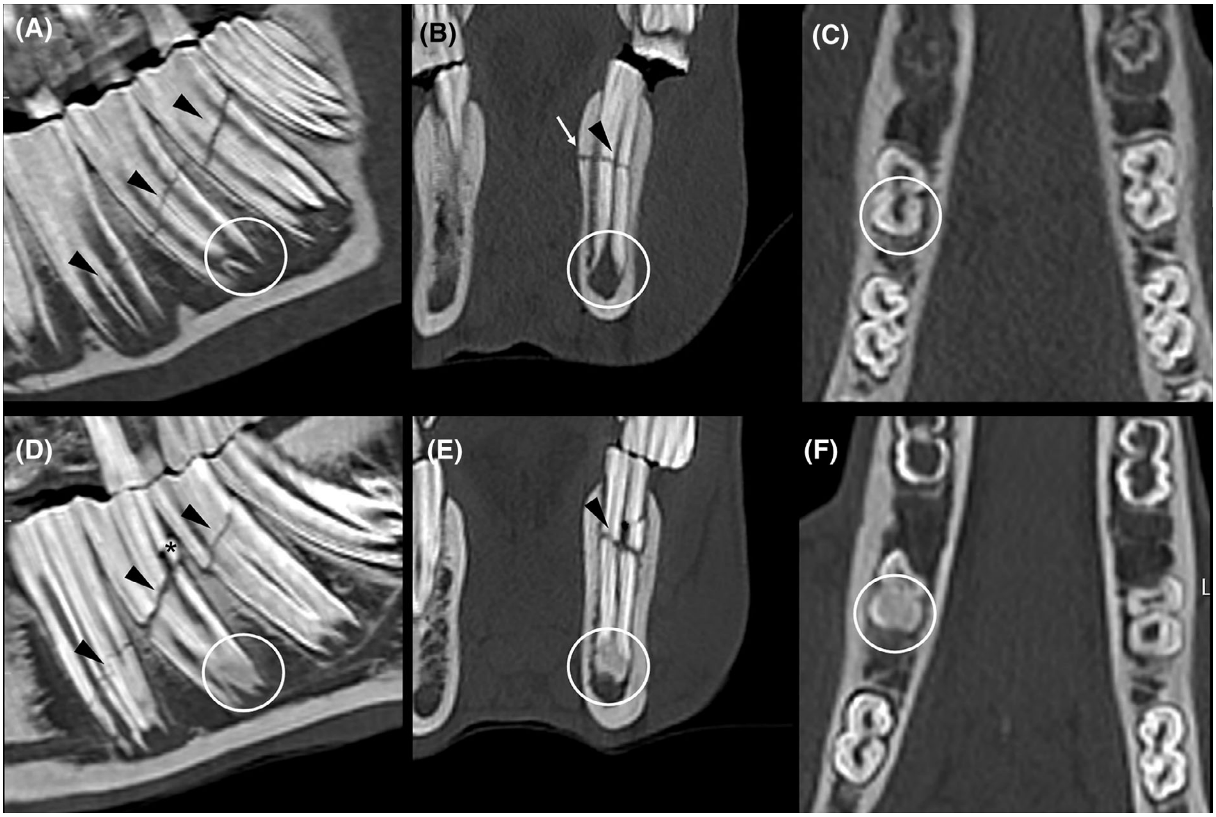

FIGURE 8 (A-C) Preoperative and (D-F) 13 months follow up multiplanar CT reconstructions of case 5 focused on the right mandible and tooth 409. Fracture lines are visible through teeth 408-410 (A, B, D, E, black arrowheads) and at the medial aspect of the mandibula (B, white arrow). Preoperatively the tissue within the distal pulp of the 409 is low attenuating (A-C, circles). One year postoperatively the apical aspect of the pulp is filled with material exhibiting an attenuation consistent with mineralization (D-F, circles). The tooth root was contacted by a screw during external application of the locking compression plate. The fracture at the medial aspect of the mandibula healed (E), but the fractures through the teeth are still visible (D, E, arrowheads). Fracture ends of the 409 and 410 are rounded. At the 409 a small fragment is dislocated at the distal aspect of the occlusal side of the fracture (star) and the occlusal fragment of the 410 is slightly displaced rostral

osteosynthesis using plates, at least 3 cortical screws or at least 2 LHS on either side of the fracture are recommended.[2] As increasing the number of pins generally increases the stability of the construct,[23] the advantage of increased stability must be weighed against the risk of pressure necrosis to the skin. Based on these principles, the risk of pressure necrosis could be reduced for caudal mandibular fractures with the use of externally applied LCPs.

In case 5 the plate was removed early because of the abscess, which was in close contact to the fracture site and the pressure necrosis of the skin and subcutaneous tissue. There was concern if, after 3 weeks only, there was enough stability at the fracture site in an adult horse. In other reports the external fixators were removed after 5-6 weeks at the earliest.[5,7,9] No further displacement of the fracture occurred in case 5, and healing proceeded. It remains uncertain if stability was provided by sufficient callus at the fracture site or by the intraoral wire.

Internal fixation of unstable, complicated mandibular fractures with conventionally applied LCPs is reported to result in excellent functional outcomes and cosmesis.[12] Implants were not used as intended by the manufacturer in this case series but the rationale behind using an ESF-LCP in selected cases is based on some specific advantages over internal fixation. With the ESF-LCP, the amount of foreign material in the infected area can be minimized.[5] Internal plate application often requires excessive soft tissue dissection whereas the ESF-LCP has the potential to reduce trauma to structures like the parotid duct, nerves and blood vessels, may help to preserve vascularization of the bone and soft-tissue support.

Adopting this method of ESF-LCP for the stabilization of mandibular fractures in large animals was further supported by biomechanical considerations.[18,24] The distance from the connecting sidebar to the bone is minimal in the ESF-LCP compared with other ESF constructs. This should be an advantage as the stiffness of the pins is inversely proportional to the third power of the distance of the sidebar to the pin-bone interface.[24]

Limitations of the study are its retrospective nature, leading to insufficient or missing information about some case details. A small number of cases were presented in this series, with diverse fracture configurations and no standardization of technique between the different surgeons involved. Long-term follow up was available for a limited time but it was potentially too short for some complications to develop. Examinations were also performed by veterinarians in the reports of long-term follow up in 3 of the 5 cases. Complications may therefore have been underreported for this technique.

In conclusion, the use of an LCP applied as a type I external fixator provides an alternative fixation technique for the stabilization of open, complicated fractures of the horizontal ramus of the mandible in large animals. Implant application and removal were achieved with minimal tissue manipulation and implants were removed without the need for general anesthesia in all equine cases. Particular attention needs to be paid to prevent soft-tissue injury, which may occur if plates are placed without sufficient space to account for postoperative swelling.

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AUTHOR CONTRIBUTIONS

Mählmann K, DVM: Acquisition and analysis of clinical data; preparation of the manuscript and illustrations. Noguera Cender A: Acquisition and analysis of clinical data and critical revision of the final version of the manuscript; contribution to illustrations. Ehrle A, DVM: Acquisition and analysis of clinical data and critical revision of the final version of the manuscript; contribution to illustrations. Lischer CJ, DVM: Acquisition and analysis of clinical data and critical revision of the final version of the manuscript.

CONFLICT OF INTEREST

The authors declare no conflicts of interest related to this report.

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