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Treatment of class 2 malocclusion by corrective osteotomy using two short locking compression plates

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Summary

Objective: To describe a symphyseal osteotomy stabilised with two short locking compression plates (LCPs) for treatment of class 2 malocclusions.
Study design: Case series.
Methods: Five horses (age range 8 months to 5¾ years) with overjets and/or overbites ranging from 6 to 32 mm and from 0 to 60 mm, respectively, were treated by osteotomy through the caudal third of the mandibular symphysis, cranial to the interdental space. After cranial distraction and ventral rotation of the rostral part of the mandible, two short (5/6 hole), bent 3.5 mm LCPs were applied ventro-laterally and secured with two or three locking screws on each side of the osteotomy. In one case, the osteotomy gap was filled with bone marrow.
Results: Final outcome was good to excellent. Two cases needed a second corrective surgery, one because of non-occlusion of the cheek teeth and another because of abaxial deviation of the rostral portion of the mandible. In three cases with a persistent fistula, LCPs were removed after bridging; drainage resolved and wounds healed. The time to bridging of the osteotomy gap ranged from 2 to 6.5 months. The procedure is technically challenging. It is important that the incisors are well aligned, which proved to be difficult when there was an abnormal maxillary incisor arcade. Incisors should not make contact when LCPs are fixed. The cheek teeth, however, should have good occlusion after positioning and fixation of the LCPs. Endodontic treatment of open incisor pulp cavities may be helpful.
Main limitations: The study population was small and relatively heterogeneous in severity. A larger population with more severe cases might have allowed for a more definitive assessment of the value of the technique for clinical practice.
Conclusions: This technique can be used to achieve a good correction for class 2 malocclusions. The approach provides adequate stability with smaller implants than other published techniques that require transection of both rami. The technique is less invasive and preserves the roots of the incisors and cheek teeth, as well as the mandibular canal.

Keywords: horse; equine orthodontics; overjet; overbite; surgery; LCP

Introduction

Class 2 malocclusion is, though still uncommon, the most frequently encountered developmental defect of the mandible in horses [1]. This malocclusion can be present at birth but typically develops later, during growth, as a variable discrepancy in jaw length with the mandible being shorter than the maxilla. An overjet is defined as a rostral advancement of the central maxillary incisors with respect to the central mandibular incisors when projected in the horizontal plane [2]. An overbite is a ventral displacement of the central maxillary incisors relative to the central mandibular incisors when projected in the vertical (sagittal) plane [2]. Overjet and particularly overbite are highly undesirable conformational features because they are unsightly and can cause long-term problems with mastication. In sheep and cattle, this malocclusion is inherited in a recessive manner [3,4]. In the horse, the exact mode of inheritance is unknown, but a novel locus associated with class 2 malocclusion has recently been identified [5]. Most studbooks do not accept animals with evident abnormalities and owners are discouraged to breed with horses showing class 2 malocclusion. The condition does not correct spontaneously and, in severe overbite cases, surgical correction is necessary.

Few surgical techniques have been reported. In foals, overjet can be corrected by retarding the growth of the incisive part of the maxilla through cerclage wiring linking the maxillary incisors to the upper premolars [2]. In overbite cases, cerclage wiring has to be combined with a biteplate to facilitate elongation of the mandible without continuous obstruction by incisors of the maxilla [2,6]. Cerclage wiring is effective but should only be used in foals with sufficient growth potential [2,6–8]. Easley *et al.* showed a positive relationship between severity of overbite and final correction using cerclage wiring with a biteplate [2]. Verwilghen *et al.* reported successful gradual mandibular osteo-distraction in a severe overbite case using an IMEX™ semi-circular external fixator system [9]. In another study, a type 1 external fixator was used effectively but with serious morbidity in seven horses [10]. In these patients, the fixation was unstable, which caused prolonged pain. Infections of the osteotomy site and pin tract were frequent complications. Another technique, using a specific locking compression plate (LCP) has been reported for successful stabilisation of a corrective osteotomy in an 8-month-old filly with a severe overbite [11].

The current report describes a surgical technique in five horses in which an osteotomy was performed transversely through the symphysis, cranial to the interdental space. For fixation, in all cases, two short (5/6 hole), 3.5 mm LCPs were used.

Materials and methods

Cases

From 2012 to 2015 five Warmblood horses aged 8 months to 5¾ years were presented with various degrees of overjet/overbite. The individual characteristics of the cases can be found in Table 1. All cases underwent a complete physical examination and were pre-operatively subjected to oral and radiographic examinations (Fig 1a, 2a, Supplementary Item 3) under

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TABLE 1: Case details class 2 malocclusion: age, sex, overjet, overbite, anamnesis, earlier treatment, dental/oral remarks initial examination, surgery, type fixation, complications, second surgery, bridging, plates removed and outcome

Case	Age (years)	Sex	Breed	Overjet (mm)	Overbite (mm)	Anamnesis	Earlier treatment	Dental/oral remarks initial examination	Surgery	Type of fixation	Complications	Second surgery	Bridging (months)	Plates removed (months)	Out come[b]
1	8 months	M	DW	27	10	Normal at birth, C2M noted at pre-purchase exam	–	–	Osteotomy + castration	Two 6 hole 3.5 LCPs, four locking screws each	Non-occlusion cheek teeth, persistent fistula	After 7 days second surgery to correct non-occlusion cheek teeth	2	7½	Very good
2	1½	F	DW	31	23	Mild C2M at birth	–	Wolf teeth 105 –205, hooks 106 and 206	Osteotomy	Two 5 hole 3.5 LCPs, four locking screws each	–	–	2	–	Very good
3	5	G	DW	26	27	Severe C2M at birth. Masticatory problems	As yearling cerclage wiring and bite plate, yearly dental correction	Deciduous 502, 703 present: no permanent replacements. Large interdental spaces 103–101, 201–202. Hooks 106, 206, 311, 411	Osteotomy + bone marrow	Two 6 hole 3.5 LCPs, five locking screws each	Deviation rostral mandible, persistent, fistula	After 30 days second surgery to reposition rostral mandible	3	7	Good
4	2 months	F	DW	22	2	Mild C2M at birth	At 2 months cerclage wiring and bite plate	–	–	–	–	–			Very good
	2[a]			5	–				Osteotomy	Two 5 hole 3.5 LCPs, four locking screws each	Persistent fistula	–	1½	3½	
5	5¾	F	O	32	60	Severe C2M at birth. Masticatory and riding problems	Yearly dental correction maxillary and mandibular incisors	Ulceration oral mucosa caudal to maxillary incisors, cheek teeth no abnormalities	Osteotomy + ostectomy	Two 5 hole 3.5 LCPs, four locking screws each	–	–	6½	–	Excellent

M, male; F, female; G, gelding; DW, Dutch Warmblood horse; O, Oldenburg horse; C2M, class 2 malocclusion.
[a]Age when surgery with LCPs was performed.
[b]Excellent: no overjet; very good: 0 to <2 mm overjet; good: overjet 2 to <5 mm.

sedation with detomidine (Domosedan[a]; 0.01 mg/kg bwt [i.v.]). Because of the likely heritability of the disorder, the owner was advised in each case to castrate the animal if it was a colt and not to breed it if it was a filly or a mare.

Surgical procedure

In all cases, medical treatment was started just prior to surgery and consisted of gentamicin (Gentamycin[b]; 6.6 mg/kg bwt [i.v.]) and benzylpenicillin-sodium (Benzylpenicillin Natrium[c] ; 30,000 IU/kg bwt [i.v.]) as antimicrobial treatment and flunixin meglumine (Meflosyl 5%[d]; 1.1 mg/kg bwt [i.v.]) as an anti-inflammatory and analgesic drug. Horses were pre-medicated with detomidine (0.01 mg/kg bwt [i.v.]). General anaesthesia was induced with midazolam (Midazolam Actavis[e]; 0.05 mg/kg bwt [i.v.]) and ketamine (Anaestamine[f]; 2 mg/kg bwt [i.v.]) and maintained with isoflurane (Iso Flo)[g] in oxygen. All patients were positioned in dorsal recumbency, with a slightly extended head and neck. First, the overgrown incisors of the maxilla and mandible were shortened with motorised equipment (diamond coated cut-off wheel, Equine Specialities)[h]. When present, the hooks of the cheek teeth were also removed. The mouth was then closed and, with the cheek teeth in occlusion, the mandible was taped to the maxilla halfway along the rami of the mandible.

The rostro-ventral area of the mandible (from lower lip to tape) was clipped, aseptically prepared and draped. At the level of the symphysis, an 8-cm-long, Y-shaped skin incision was made, starting over the symphysis and with the arms of the Y running over the ventral aspects of the mandibular rami. The periosteum was incised in a similar pattern and reflected. The mandible was then cut using an oscillating saw perpendicular to the long axis of the mandible through the caudal third of the symphysis, i.e. cranial to the interdental space and mental foramen. The oral soft tissues were left intact whenever this was possible. When cut, the rostral part of the mandible was distracted cranially, using a combination of various elevators/stifle distractors (lamina spreader) and manual force. The mandible was moved towards an imaginary curved line that started at the rostral maxilla and used the maxillary incisors as a landmark. This line followed what should be the normal contour of the maxillary and mandibular incisor arcade (Fig 3a). Because of the length of the shortened maxillary incisors and the limited degree to which the oral soft tissues can be stretched, a ventral rotation of the severed section of the mandible was necessary to achieve a correct position of the upper and lower incisors (Fig 3b–c). In the first case, incisor occlusion was pursued, but this resulted in non-occlusion of the cheek teeth after securing of the plates. In later cases, a 5 mm gap between the incisors was left open, which was achieved by placing a 5 mm thick aluminium strip between the incisors before applying the plates. In all cases, two short 3.5 mm LCPs (locking compression plates)[i] were used, which were contoured, and applied ventro-laterally (Figs 1b, 3d). Substantial bending of the LCPs was necessary in all cases. The LCPs were secured with two or three 3.5 mm self-tapping locking screws on each side of the osteotomy. In the third case, which had an abnormal maxillary incisor arcade (Supplementary Items 2 and 3), class 2 malocclusion could be corrected, but it was difficult to align the maxillary and mandible arcades accurately because of the lack of normal dental landmarks. In this case, the osteotomy gap was filled with bone marrow, harvested from the sternum. The osteotomy gap was left empty in all other cases. In the fifth case, which had very substantial (32 mm) overjet and overbite (60 mm) (Fig 2a), an additional wedge ostectomy was performed to facilitate ventral rotation and achieve adequate positioning of the rostral mandible (Fig 2b).

The incisions were closed in three layers. Continuous sutures of USP 2–0 polyglactin 910 (Vicryl)[j] were used for periost and subcutis. An intradermal suture of poliglecaprone (Monocryl)[j] closed the skin. All patients received procaine penicillin (Depocilline[k]; 20,000 IU/kg bwt [i.m.]) at the end of the surgery. A circumferential, elastic, bandage (Tensoplast)[l] was applied around mandible and maxilla for protection of the incisions. The adhesive and elastic characteristics of the bandage ensured that the bandage did not move and the patients continued eating. In case 1, castration was carried out simultaneously by another surgeon. All patients had an uneventful assisted recovery.

In all cases except for the fourth, which had an overjet of 5 mm, the pulp cavities of the incisors were opened when they were shortened. The open pulp cavities were not further treated and left open.

Post-operative care

The circumferential bandage was removed after 2–3 days. Antimicrobial treatment was continued for 10 days, consisting of the first 3 days of gentamicin (6.6 mg/kg bwt [i.v.] q24h.) and procaine penicillin (20,000 IU/kg bwt [i.m.] q24h.), followed by trimethoprim sulphonamide (Trimethosulfmix 50%[b], 30 mg/kg bwt [p.o] q12h.) for the remainder of the period. Flunixin meglumine (1.1 mg/kg bwt [i.v.] q24h.) was continued for 5 to 10 days after surgery.

Postoperatively, wet food (soft pellets, mash) was offered to all patients, together with the ration (pellets and hay) they used to eat pre-operatively. Skin sutures were removed 12 days after surgery.

Follow-up

Clinical and radiographic examinations were performed immediately after surgery and approximately every 8 weeks until 32 weeks post-surgery. Success in reducing class 2 malocclusion was classified using the following grades: “good” was defined as an overjet of 2–5 mm, “very good” as 0–2 mm and “excellent” meant complete correction (overjet = 0). After 2 to 4 years, depending on the case, follow-up information was obtained by telephonic enquiry. No formal questionnaire was used, but questions were asked in all cases about cosmetic appearance, position of the incisors, the end stage of the wound healing, way of eating and performance of the horse.

Results

Case characteristics and outcome are summarised in Table 1. All patients were allowed access to feed immediately after surgery. The only restriction was that they were not given food that would make them use their incisors actively. For example, no grazing, no carrots and sugar beets, which are standard aftercare in patients with fractures of the incisor part of the maxilla or mandible. Although patients could post-operatively opt for wet food, all preferred their ration they used to eat pre-operatively to the mash that was offered. All patients, except for case 1 after the first surgery, had a good appetite, ate well, and did not show discomfort during their hospitalisation period. All incisors erupted and not yet erupted permanent incisors, remained vital and continued to erupt in all cases.

Case 1

After the first surgery, a correct position of the incisors was achieved but the patient still had difficulties with mastication. The cheek teeth appeared to barely occlude and a second surgery was necessary to readjust the LCPs, allowing for better cheek teeth occlusion. Two months after the second surgery, the osteotomy site was bridged with bone. Functional outcome was excellent, but after 7.5 months there was still a persistent fistula, for which reason the plates were removed. Fistulation ceased after the second surgery and the final cosmetic outcome was judged as very good. The horse was sold 19 months after surgery. There were no relevant abnormalities found at the pre-purchase examination and the horse was being ridden successfully at the time of data collection.

Case 2

After 2 months, the osteotomy was bridged with bone and a very good correction was achieved (Fig 1c). The plates were left in place. Four years after surgery all incisors were in a correct position, with the plates still in place, and the horse was successfully used in show jumping.

Case 3

Thirty days after the first intervention, a second surgery was performed to correct a left-sided deviation of the mandible with respect to the maxilla. During this second surgery, the plates were removed, the rostral mandible

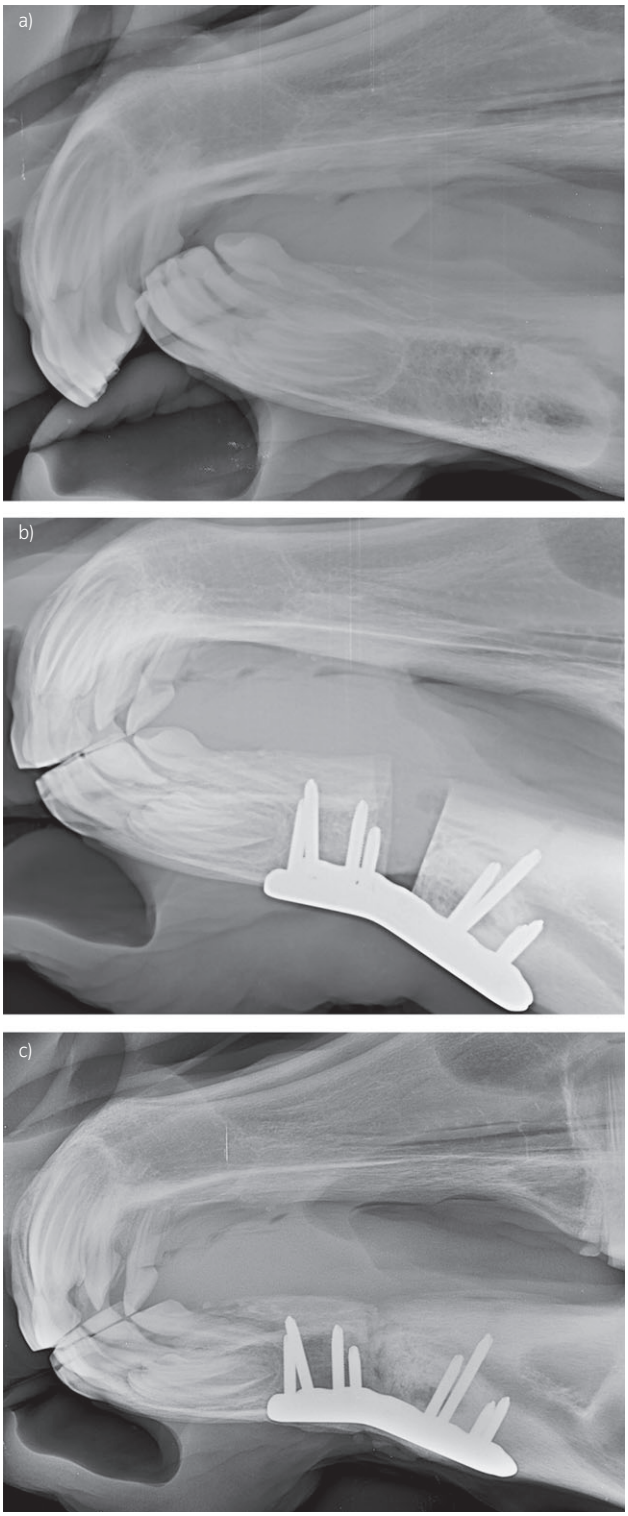

Fig 1: a) Second case pre-operatively. b) Second case 1 day after surgery. c) Second case 2 months after surgery.

was repositioned correctly, and the LCPs were re-applied. At surgery, increased mobility of the mandibular symphysis was noticed, and additional stabilisation was provided using two Steinmann pins crossing the symphysis. These were removed 2 weeks later because of loosening.

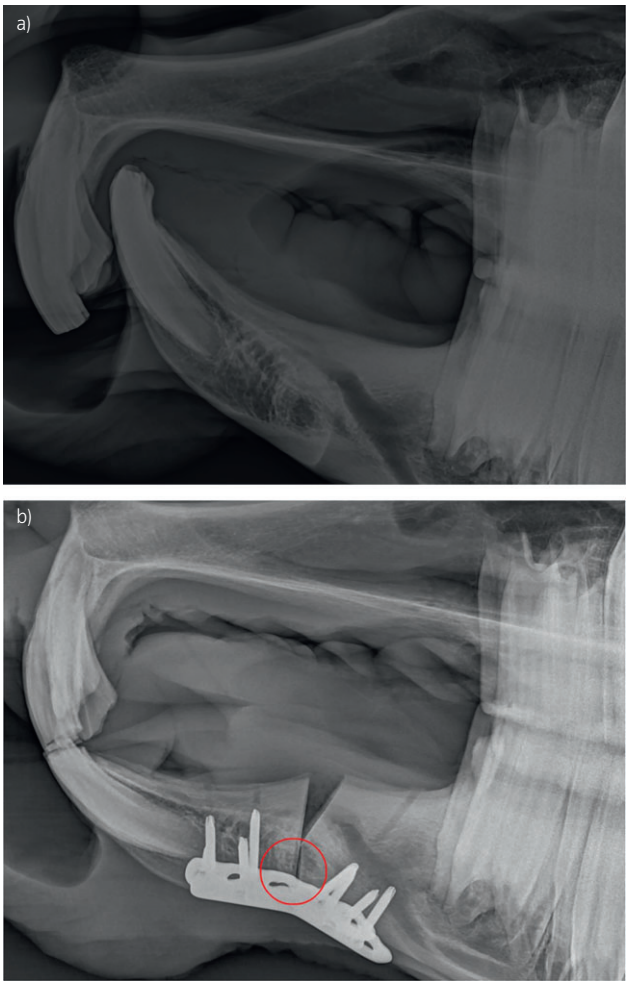

Fig 2: a) Fifth case pre-operatively. b) Fifth case 1 day after surgery; notice the additional ostectomy (ellipse) necessary to facilitate rotation and subsequent correct positioning of the severed mandible.

After 7 months the plates were removed because of a persistent fistula. Follow-up radiography confirmed good healing of the osteotomy site. Clinically the correction was good (Supplementary Item 4). Unfortunately, this horse was lost to further follow-up.

Case 4

Because of a persistent fistula the plates were removed. Functional and cosmetic outcomes were very good. Two years after surgery the horse was sold, with no relevant abnormalities reported at the pre-purchase examination.

Case 5

Functional and cosmetic outcomes were excellent (Fig 2b). Two months postoperatively the osteotomy was clearly visible. The horse was not seen at 4 months but bridging was visible at 6.5 months with a fair amount of callus formation. The plates were not removed. One and a half years after surgery, this horse was competing in dressage. All incisors had a normal appearance.

Discussion

Symphyseal osteotomy with internal fixation using short 3.5 mm LCPs can achieve good to excellent correction of significant class 2 malocclusion; in both young and older equine patients. Correct

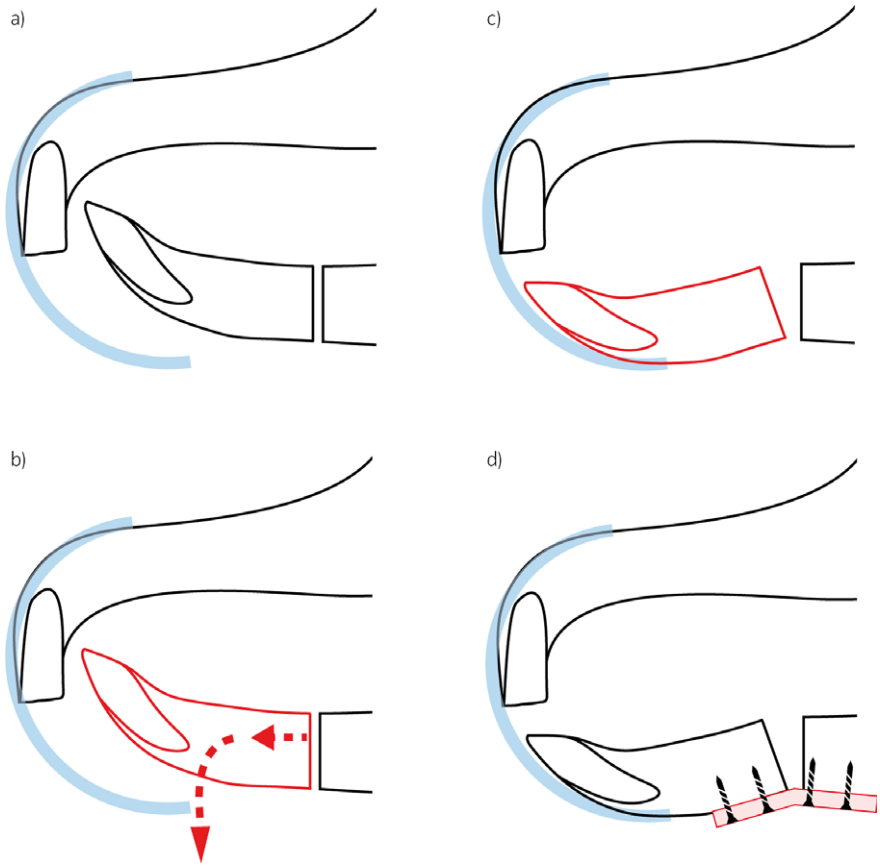

Fig 3: a) Imaginary curved line from the maxillary incisors. b) Rostral distraction and ventral rotation of the severed mandibular section. c) Correct position of the section in relation to the imaginary curved line, with the 5 mm gap between the incisor arcades. d) Fixation with bended LCP plates.

alignment of the incisors without functional occlusion and achievement of correct occlusion of the cheek teeth are critical issues in this procedure. The surgery requires special instruments and the availability of LCPs; however, these materials are usually present in more specialised equine hospitals.

The basis of the success of this technique is thought to be the site of the osteotomy and the subsequent degree of stability that can be obtained by the relatively short LCPs, which were much smaller than the implants used in earlier studies using osteotomy [9–11]. Symphyseal osteotomy as carried out in our study divides the mandible in only two segments, a rostral 'incisor' and a caudal 'cheek teeth' segment. Therefore, both mandibular rami stay connected by a bony bridge formed by the caudal part of the symphysis. In the earlier published techniques both rami are transected at the interdental space (caudal to the symphysis). This procedure results in three mandibular segments: an 'incisor' segment, with two disunited 'cheek teeth' segments (Fig 4a, b) [9–11]. With the 'three-part' technique the long implants that are used form the connection between the bony parts and have to resist the large forces generated by mastication and by the contraction of the powerful mastication muscles. With the 'two-part' technique as used in this case series, the caudal part of the symphysis connects both cheek teeth parts solidly and absorbs the masticatory forces. In this case, the much smaller implants are subjected to less and lower forces, as they must only hold the incisor part in place until the osteotomy site bridges.

The decision to use a fresh biological bone graft in the third case was based on the age of the horse, which was reaching skeletal maturity. In mice, age-related changes in osteogenic stem cells have been shown and it was hypothesised that the osteoinductive and osteoconductive properties of the graft could possibly accelerate and/or facilitate the healing process [12]. Healing time of the osteotomy was not shortened, compared to other cases. Although no conclusions can be drawn from a single case and while it cannot be excluded that this lack of effect was due to the wound infection in this case, it was decided not to use bone grafts in future cases.

Full occlusion of the cheek teeth immediately after surgery is necessary. Failure to achieve this resulted in mastication problems in the first case after the initial surgery. The cheek-teeth malocclusion may have been caused by inadequate taping of the mandible and maxilla pre-operatively or by insufficient bending of the LCPs. The subsequent tightening of the LCPs, with the incisors in an occluded position, resulted in inadequate occlusion of the cheek teeth. In later cases, we deliberately left a 5 mm space between the maxillary and mandibular incisors preventing occlusion. This procedure avoids generation of stress during mastication, which will not only result in pain and poor appetite but is also likely to lead to failure of the small screws and plates.

To achieve good correction of the malocclusion, the rostral part of the mandible needs to be distracted cranially and must also be rotated ventrally. This rotation is necessary because of the limited capacity of the oral soft tissues to stretch and because of the overgrowth of the maxillary and mandibular incisors. The overgrowth was significantly but not completely reduced. This partial reduction led to still relatively long incisors in some cases (Fig 2a) and opening of the pulp cavities in almost all cases (except for case 4). Dixon *et al.* reported a very low complication rate of pulpar exposure in complicated fractures of hypsodont incisors [13]. Nowadays, an open pulp cavity is commonly seen as a condition that needs urgent treatment [14]. In retrospect, these open pulp cavities probably should have undergone endodontic treatment; however, no negative consequences were seen clinically in any of the horses during the follow-up period.

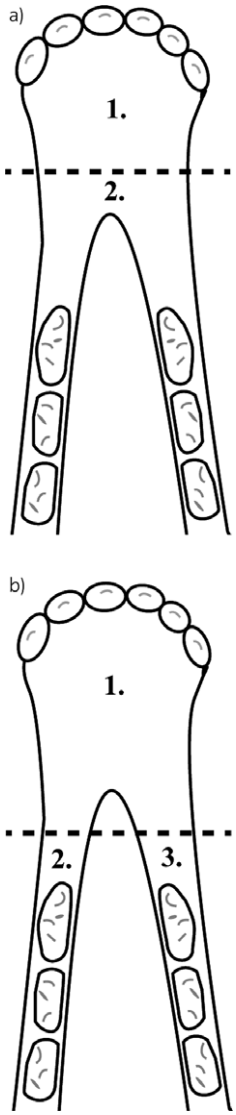

Fig 4: a) Osteotomy through the symphysis: two parts (1 'incisor' and 1 'cheek teeth' part). b) Osteotomy through the rami: three parts (1 'incisor' part with 2 'cheek teeth' parts).

The severity of class 2 malocclusion determines the degree of ventral rotation needed. If this ventral rotation results in contact between the pieces of the mandible, which happened in the fifth case, additional modelling of the osteotomy site is necessary to achieve good correction (Fig 2b).

To prevent deviation of the rostral portion of the mandible, it is important to make sure that the interdental spaces between 101 and 201 line-up exactly with those between 301 and 401. This was very difficult to achieve in the third case (Supplementary Items 2 and 3) because of the abnormally shaped maxillary incisor arcade. Although noticed pre-operatively, this peculiarity was insufficiently considered during the initial surgery, which prompted the need for a second surgery. Before the second surgery the spatial characteristics of the deviation were exactly quantified and these measurements were used for the ultimate correction.

An advantage of the technique described in this case series is that, because of the small implants, it is less invasive than other approaches. The mental nerve, which emerges from the mental foramen that is located at the transition of symphysis and interdental space, is left unharmed. Further, the technique preserves the roots of cheek teeth and incisors. Because of the proximity of the incisor roots, great care is needed when applying the cranial screws of the LCPs. Fluoroscopy can be helpful.

Although care was taken to preserve the oral mucosa during the osteotomy and the distraction/ventral rotation of the mandible, in two cases (cases 1 and 3) the oral cavity was opened. This resulted in fistula formation. No additional therapy was needed other than daily cleaning of the fistulous tract. The fourth case also developed a fistula. However, in this case the oral mucosa was left intact and only minimal manipulation was necessary to achieve good correction. In all three cases, the plates were removed after radiographic bridging of the defect. Thereafter all fistulous tracts closed without further complications.

There is always some ethical dilemma when treating patients with a possible hereditary disease. In the cases included in this series, we discussed the issue thoroughly with the owners and explicitly urged them not to the breed the animals. The first case, a colt, was castrated during the intervention. Ovariectomy was not performed on the fillies or mares because of the invasiveness of the procedure.

It is concluded that symphyseal osteotomy combined with the use of short LCPs is a good option for the treatment of class 2 malocclusion. The procedure is technically challenging, and it is important to assure that the incisors are well aligned and cheek teeth have good occlusion after positioning and fixation of the LCPs. However, the technique preserves the roots of incisors and cheek teeth, leaves the mandibular canal unharmed and results in a stable fixation with good and functional correction of the disorder.

Authors' declaration of interests

No competing interests have been declared.

Ethical animal research

Research ethics committee oversight not required by this journal: retrospective analysis of clinical data. Explicit owner informed consent for inclusion of animals in this study was not stated.

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Authorship

Both authors contributed to the conception and design of the study. T. Spoormakers drafted the manuscript and both authors revised it critically and approved the final manuscript.

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[f]AST Farma B.V., Oudewater, The Netherlands.
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[k]Intervet, Boxmeer, the Netherlands.
[l]BSN Medical, Almere, the Netherlands.

References

1. McAuliffe, S.B. (2013) Gastrointestinal system. In: *Knottenbelt and Pascoe's Color Atlas of Diseases and Disorders of the Horse*, 2nd edn., Ed: S.B. McAuliffe, Saunders Ltd., Edinburgh. pp 1-83.
2. Easley, J., Dixon, P.M. and Reardon, R.J.M. (2016) Orthodontic correction of overjet/overbite ('parrot mouth') in 73 foals (1999-2013). *Equine Vet. J.* **48**, 565-572.
3. Heidari, M., Vogt, D.W. and Nelson, S.L. (1985) Brachygnathia in a herd of Angus cattle. *Am. J. Vet. Res.* **46**, 708-710.
4. Iannuzzi, L., Di Meo, G.P., Leifsson, P.S., Eggen, A. and Christensen, K. (2001) A case of trisomy 28 in cattle revealed by both banding and FISH-mapping techniques. *Hereditas* **134**, 147-151.
5. Signer-Hasler, H., Neuditschko, M., Koch, C., Froidevaux, S., Flury, C., Burger, D., Leeb, T. and Rieder, S. (2014) A chromosomal region on ECA13 is associated with maxillary prognathism in horses. *PLoS ONE* **9**, 1-5.
6. Gift, L.J., DeBowes, R.M., Clem, M.F., Rashmir-Raven, A. and Nyrop, K.A. (1992) Brachygnathia in horses: 20 cases (1979-1989). *J. Am. Vet. Med. Ass.* **200**, 715-719.
7. Easley, J. and Schumacher, J. (2011) Basic equine orthodontics and maxillofacial surgery. In: *Equine Dentistry*, 3rd edn., Eds: J. Easley, P.M. Dixon and J. Schumacher, Saunders/Elsevier, Edinburgh, pp 289-317.
8. Dixon, P. and Gerard, M. (2012) Oral cavity and salivary glands. In: *Equine Surgery*, 4th edn. Eds: J. Auer and J. Stick, Elsevier, St. Louis, pp 339-367.
9. Verwilghen, D., Van Galen, G., Vanderheyden, L., Busoni, V., Salciccia, A., Balligand, M., Serteyn, D. and Grulke, S. (2008) Mandibular osteodistraction for correction of deep bite class II malocclusion in a horse. *Vet. Surg.* **37**, 571-579.
10. Klaus, C.S., Hertsch, B.W., Höppner, S. and Lischer, C.J. (2013) Long term outcome after surgical correction of mandibular brachygnathia with unilateral type 1 external skeletal fixation. *Vet. Surg.* **42**, 979-983.
11. Klaus, C.S., Vogt, C. and Lischer, C.J. (2013) Mandibular corrective osteotomy using novel locking compression plate 3.5/4.5/5.0 mm metaphyseal plates. *Vet. Surg.* **42**, 984-988.
12. Bergman, R.J., Gazit, D., Kahn, A.J., Gruber, H., Mcdougall, S. and Hahn, T.J. (2009) Age-related changes in osteogenic stem cells in mice. *J. Bone Miner. Res.* **11**, 568-577.
13. Dixon, P.M., Tremaine, W.H., Pickles, K., Kuhns, L., Hawe, C., McCann, J., McGorum, B., Railton, D.I. and Brammer, S. (1999) Equine dental disease Part 1: a long-term study of 400 cases: disorders of incisor, canine and first premolar teeth. *Equine Vet. J.* **31**, 369-377.
14. Rawlinson, J.T. and Earley, E. (2013) Advances in the treatment of diseased equine incisor and canine teeth. *Vet. Clin. N. Am.: Equine Pract.* **29**, 411-440.

Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's website:

Supplementary Item 1: Lateral radiograph of third case pre-operatively.
Supplementary Item 2: Frontal view of third case pre-operatively. Note the abnormal maxillary incisor arcade with large interdental spaces.
Supplementary Item 3: Lateral view of third case pre-operatively.
Supplementary Item 4: Lateral radiograph of third case 8 months after surgery.