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Citation for published version:
Easley, J, Dixon, PM & Reardon, RJM 2015, 'Orthodontic correction of overjet/overbite ("parrot mouth") in 73 foals (1999 - 2013)', *Equine Veterinary Journal*, pp. n/a-n/a. https://doi.org/10.1111/evj.12540

Digital Object Identifier (DOI):
10.1111/evj.12540

Published In:
Equine Veterinary Journal

Received Date : 24-Feb-2015

Revised Date : 07-Aug-2015

Accepted Date : 09-Oct-2015

Article type : Article

Orthodontic correction of overjet/overbite ("parrot mouth") in 73 foals (1999 - 2013)

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Keywords: horse; overjet; overbite; parrot mouth; dentistry; malocclusion; equine orthodontics

Summary

Reasons for performing study: There are limited reports on the efficacy of functional orthodontic correction of overjet or overbite in foals.

Objectives: To report the outcome of using orthodontic tension bands in combination with an inclined plane biteplate in the treatment of overjet, with or without concurrent overbite and rates of correction of these two malocclusions and associated complications and to examine factors associated with outcomes.

Study design: Retrospective case series.

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record. Please cite this article as doi: 10.1111/evj.12540

Methods: Clinical records for 73 foals treated at a single clinic, by the same surgeon were analysed. Overall change and rates of change in overjet and overbite were calculated. Associations between potential explanatory variables including age, severity of initial malocclusion and surgeon experience were examined using linear regression.

Results: Records for 73 foals (43 colts, 30 fillies) were evaluated. The median number of implant placements per animal was 2 (range 1-4). Of 61 cases with complete records, reduction in overjet and overbite dimensions were achieved in 95% and 90% of foals, respectively, with mean reductions in malocclusions of 9.9 mm and 8.4 mm, respectively. Complete reduction in overjet was achieved in 25% (15/61) and reduction of malocclusion dimensions to ≤5 mm (i.e. functionally corrected) was achieved in 51% (31/61). Increasing animal age was significantly associated with decreased total reduction in overjet and decreased rate of reduction in overbite. Increased original severity of overbite was significantly associated with increased rate of its correction. Short-term complications included intra-operative haemorrhage, transient facial nerve neuropraxia and irritation of the mare's udder by the brace. Longer term complications included cheek teeth diastema formation and incisor discoloration and maleruption.

Conclusions: Using this technique, correction or improvement of these malocclusions is rapid, with minimal complications. Often more than one implant is required. Animal age at the start of treatment is associated with rate and amount of correction achievable, so initiating treatment at an early age is recommended.

Introduction

The colloquial terms "parrot mouth" or "overshot jaw" are used to describe horses with rostral malocclusion of the upper incisors in relation to the lower incisors. This disorder is more correctly termed Class II dental malocclusion, that can be subdivided into *overjet*, where the upper incisors protrude labially (rostrally) in the horizontal plane in relation to the lower incisors and *overbite*, where additionally, the occlusal surfaces of the upper incisors lie ventral to the occlusal surfaces of the lower incisors (Fig 1). Severe Class II malocclusions can impair the ability of affected animals to prehend forage and along with neglected, concurrent cheek teeth disorders (overgrowths of the upper 06s and of the lower 11s in adult horses) these disorders may predispose to chronic dental problems, malnutrition and growth retardation [1]. However, the incisor malocclusions alone usually cause minimal clinical problems in horses, which adapt well to prehending food with their lips [2].

Humans, and many other species, normally have a slight degree of overjet, however the presence of any overjet in horses is considered abnormal [3]. The degree of incisor overjet present in affected foals can be quite variable, ranging from slight labial misalignment of the upper incisors, to complete absence of incisor occlusion. Overbite develops later, as the foal grows, with the rostral aspect of the incisive bones (premaxillae) drifting ventrally due to absence of any incisor occlusion. Overbite can be exacerbated by incisor overgrowth due to lack of wear and can result in the lower incisors becoming trapped behind the upper incisors, which in turn leads to caudal pressure on the mandible, further retarding rostral mandibular growth and development.

Overjet/overbite is considered to be an inherited disorder and has shown some familial tendencies in Thoroughbred horses [4]. With this in mind, ethical considerations may arise when treating this disorder, although in humans most non-traumatic orthodontic problems are considered to be due to a combination of polygenic hereditary and environmental factors [5].

Several techniques have been described to correct these malocclusions in foals. In foals with minor overjet but without any overbite, orthodontic treatments include the sole use of tension band wires, or the sole use of a fixed orthodontic appliance (biteplate) attached to the upper incisors [6,7]. Alternatively, a combination of these two orthodontic techniques can be used, such as described in this study [3,8,9]. In particular, the use of a biteplate with an inclined plane (angled dorso-rostrally) has been shown to lengthen the mandible in humans [10]. In older animals where minimal manipulation of natural jaw growth is possible, other surgical corrective options such as mandibular osteodistraction have been used [11,12].

This study describes the use of functional orthodontic tension bands in combination with an inclined plane biteplate in the management of overjet/overbite in 73 foals, including recording the effectiveness of the technique and rates of correction of these two malocclusions, surgical complications and examination of factors associated with the outcome of treatment.

Materials and methods

Case recruitment

Clinical records for foals treated surgically for incisor overjet and/or overbite from a population of first opinion and referral cases at "Easley Equine Dentistry, Equine Veterinary Practice" between 1 January 1999 and 31 December 2014 were available for analysis.

The signalment, overjet lengths, overbite heights (if present) and treatment details (including numbers and dates of treatments) were collected. Overjet (measured as the distance from the rostral aspect of the upper Triadan 01s to the rostral aspect of the lower 01s, with the foal's head in a resting position) and overbite (measured as the distance the occlusal surface of the upper incisors lay ventral to the occlusal surfaces of the lower incisors, when the mouth was closed with the cheek teeth in full occlusal contact) measurements were made using manual metric calipers. To allow a more complete evaluation of the success of treatment, cases with a follow-up period of less than 18 months (last case first treated on 21 May 2013) were excluded from comparative analysis.

Details of treatment

Pre-operative considerations:

All foals were examined for the presence of other congenital or developmental abnormalities. Owners/trainers were advised about breed registry requirements (some breed societies do not allow registration of offspring of horses that have had orthodontic treatment) and the possible genetic nature of overjet/overbite, the likely number of surgical orthodontic procedures required and likely success of surgery and the risks and costs of the treatment. To prevent interference with the eruption of the 02s (intermediate deciduous incisors), treatment was postponed until these teeth were in wear (normally at 6-12 weeks of age). All foals had latero-lateral skull radiographs and incisor occlusive measurements taken prior to orthodontic treatment. The 3 deciduous cheek teeth (premolars) were gently floated to slightly reduce any tall transverse ridges present and also any rostral maxillary 06 or caudal mandibular 08 overgrowths that were sometimes present in older foals. However, aggressive odontoplasty (floating) of the cheek teeth occlusal surfaces was avoided, as this would prevent any cheek tooth occlusal contact during mastication when the biteplate was fitted. Foals over 6 months of age were weaned prior to surgery and younger unweaned foals were offered pelleted food prior to surgery in case they had difficulty in nursing when the orthodontic appliance was initially fitted.

Surgical Procedure

All foals received pre-operative gentamicin sulphate (Legacy[a]) (6.6 mg/kg bwt intravenously [i.v.]), procaine penicillin (Norocillin[b]) (20,000 i.u./kg bwt intramuscularly [i.m.]) and flunixin meglumine (Banamine[c]) (1.1 mg/kg bwt i.v.) and their mouths were thoroughly rinsed with 0.1% chlorhexidine solution (Diluted 2% Chlorhexidine Gluconate, Dermachlor[d]). Sedation with xylazine hydrochloride (Xylazine HCl[e]), 1.1 mg/kg bwt i.v. was administered prior to induction of general anaesthesia with ketamine hydrochloride (Vetalar[f]) 2.2 mg/kg bwt i.v. Anaesthesia was maintained with an intravenous infusion of xylazine HCl (500 mgs), ketamine HCl (1000 mgs) and guaifenesin (Guaifenesin[g]) (1 l, 5% solution) (i.e. triple drip) to effect, with oxygen administered at 10 l/min through a nasal catheter.

The basic surgical technique used has been described [2,3], and precise details are provided in Supplementary Item 1. In summary: under general anaesthesia loops of 18 gauge stainless steel orthopaedic wires were placed bilaterally between the maxillary Triadan 07 and 08 teeth then the other ends of the wires were tensed and twisted together on the labial surface of the upper incisors. Using paraffin rope strips as a "dam" (Fig 2), dental acrylic (Jet denture repair acrylic[h]) was then moulded by hand onto the petroleum jelly (Vaseline[i]) covered hard palate caudally, the orthodontic wires laterally and the labial surface of the upper incisors rostrally. A 3.2 mm thick perforated aluminium plate was then placed on the acrylic, covering the occlusal surface of the upper incisors and the acrylic overlying the hard palate (Fig 2) and became bonded to it as the acrylic cured.

At the initial treatment of foals with severe overbite, the bite plate was laid horizontal to the hard palate (Fig 3), to cause less separation of the cheek teeth occlusal surfaces and so allow some occlusion of the tips of the cheek teeth transverse ridges (lophs and styles) during mastication. At subsequent treatments, once the overbite was reduced, the caudal aspect of the biteplate was elevated off the hard palate by placing additional acrylic beneath it at this site, to create a steep inclined plane. After the acrylic had set, the foal was allowed to recover from anaesthesia and was placed back with the dam, unless previously weaned. Most foals quickly learned to nurse with the appliance in place. Young nursing foals were given a complete foal ration for 12-24 h post-surgery until they could nurse with their orthodontic appliance in place.

Post-operative Care

The skin incisions were kept clean until they healed. Most foals received oral omeprazole for 4-5 days post-operatively. If foals initially appeared uncomfortable when nursing/eating it was advised that oral phenylbutazone (Butapaste[d]) (4.4 mg/kg bwt per *os*) be administered for a few days. It was requested that the bite plate and wires be examined daily by owners/grooms to allow removal of food trapped under the wires and to detect loose or broken wires or loose or worn biteplates.

Additionally, monthly veterinary examinations were performed to ensure that the appliance was intact, secure and not causing any soft tissue trauma.

Orthodontic appliances were removed (using standing sedation) or replaced (under general anaesthesia) when they showed signs of wear including, broken or loose wires, worn aluminium plates and loose or broken acrylic. If orthodontic correction was incomplete at that stage, the procedure was repeated until the desired or improved results were achieved. Completion of treatment was defined as the point at which further treatment was not recommended, or when owners opted for no further treatment. Images of a foal before and towards the end of treatment with a single appliance are shown in Figure 4.

Data Analysis

Descriptive statistics, including means, ranges and confidence intervals were produced. Outcome variables were defined for each animal as follows for both overjet and overbite:

1. Total change in malocclusion measurement (mm) calculated as:

   Measurement prior to treatment – Measurement after last treatment

2. Aimed at overjet correction defined as:

   a. Complete: Final overjet measurement of 0 mm

   b. Treatment Goal: Final overjet measurement of ≤5 mm

3. Total percentage change in measurement calculated as:

   100 – ([Measurement after the last treatment/Measurement prior to first treatment] x 100)

   i.e. total change in malocclusion measurement/baseline x 100.

4. Rate of change in measurement per day of treatment, defined in two ways:

a. *Total, calculated as:*

Total change in measurement (mm)/Sum of lengths of time implants were in place (days)

b. *Individual, calculated as:*

Change in measurement between start and end of individual implant period/days of implant application for each individual implant

5. Number of implant placements per animal

The following potential explanatory variables were examined:

1. Animal age
    a. At first implant placement (in days and 30 day periods)
    b. At each individual implant placement (in days and 30 day periods)
2. Surgeon experience with the procedure, produced by ordering all implant placements by date, then ascribing a number on a continuous scale (starting at 1), to each (lowest to the earliest procedure and highest to the most recent)
3. Severity of original overjet/overbite (mm) = measurement prior to first surgical implant
4. Number of implant placements per animal

Scatter plots of outcomes versus predictors were used as an initial screen for the appropriateness of linear models.

Single level univariable linear regression was used to examine the associations between:

1. Total change in measurements for overjet and overbite with: animal age at first implant placement; surgeon experience; and number of implants per animal.
2. Total percentage measurement change of overjet and overbite with: animal age at first implant placement; surgeon experience; severity of original overjet/overbite; and number of implants per animal.
3. Total rate of correction of overjet and overbite with: animal age at first implant placement; surgeon experience; severity of original overjet/overbite; and number of implants per animal.

4. Animal age at first implant placement with: severity of original overjet/overbite.

To account for repeat sampling within animals, multilevel linear regression models, in which animal was included as a random effect, were used to assess the associations between: individual rates of change in overjet and overbite measurements, with: animal ages at individual implant placement; and surgeon experience at individual implant placement. The distribution of residuals and pattern of residuals across fitted values were examined for each linear regression to check for regression assumptions of normality and homoscedasticity.

Kruskal-Wallis tests were performed to examine the associations between the number of implants per animal and: animal age at first surgery; and severity of original overjet/overbite.

All statistical analyses were performed in Stata 12(S.E.) statistical software. Significance was defined as $P<0.05$

Results

Animals:

Seventy-eight foals with incisor overjet greater than 4 mm had at least one orthodontic procedure performed between 1 January 1999 and 21 July 2014. Five of these had undergone their first procedure less than 18 months prior to data collection and so were excluded from further analysis, leaving 73 foals including: 55 Thoroughbreds, 9 American Quarter Horses, 2 Warmbloods, 2 Warmblood/Quarter Horse crosses, one Arabian, one Hanoverian, one Morgan, one American Paint Horse and one American Paint/Quarter Horse cross. These included 43 colts and 30 fillies. The median number of implant placements for the 73 foals was 2 (range 1-4).

Available information:

A summary of the available data, including foal ages, implant durations, overjet and overbite measurements and correction rates (mean and range), sub-divided by procedure number, are shown in Supplementary Item 2. Descriptions of the missing case details are provided as Supplementary Item 3. Change in overjet/overbite measurements between prior to first implant procedure and following last implant removal were calculable for 61/73 cases. Total combined implant durations were calculable for 59/73 cases. Total correction rates were calculable for 53/73 cases.

Changes in malocclusion measurements:

Overjet and overbite measurements were recorded for 69/73 cases prior to their first treatment and these malocclusions were present in 100% and 91% (63/69) of all cases, respectively.

Overjet:

Total change in overjet was calculable for 61 cases, in which reduction in overjet occurred in 95% (58/61). Complete reduction in overjet was achieved in 25% (15/61) of cases and reduction to less than 5 mm (treatment goal – where incisor occlusion was still present) was achieved in 51% (31/61) of cases. One foal developed an increase in overjet during treatment; it began treatment very late (at 342 days old), when it had an overjet of 10 mm and an overbite of 2 mm. Following 2 procedures over a total implant treatment period of 197 days (119 and 78 days), it finished with an overjet of 13 mm and an overbite of 0 mm. The second implant was removed prematurely as the foal was sent away for training. No change in overjet was observed for 2 cases, which had overjet values of 5 mm and 16 mm and overbite values of 0 mm and 12 mm pre-treatment, respectively. One of these cases also had a very late initial treatment (at 426 days).

Overbite:

Total change in overbite was calculable for 61 cases, in which reduction in overbite occurred in 90% (55/61). No change in overbite was observed in 6 cases, all of which had no overbite pre-treatment; one of these cases had no change in its overjet either (see above). It was observed that additional to usual ventral incisive bone curvature in overbite, a distinct ventral deviation was also present in some cases, where the lower incisors contacted the hard palate.

Complications:

Short term

Intra-operative complications were minimal, with no anaesthetic-associated problems encountered. Two foals experienced transient oral haemorrhage following trauma of the major palatine artery that were managed by applying pressure over the vessel for circa 10 min, before successfully completing the procedure. Persistent bilateral major palatine artery haemorrhage occurred in a third foal that required the wires to be replaced more rostrally (between the 06 and 07 teeth). Transient postoperative facial swelling developed around the skin incisions in 12 foals, which resolved by 6 days in all cases. Transient, unilateral facial nerve paralysis (neuropraxia) was observed in one foal and spontaneously resolved in 2-3 weeks.

The orthodontic device appeared to hurt the udder on several mares (especially primiparous mares with small teats) that were noted to resent the foal nursing. These mares were milked for several days and the foals bottle-fed with their milk, before being gradually reintroduced to suckling the mare. Forage became caught around the wires and buccal pouches of most foals, but this was easily managed by daily manual removal of food and oral lavage by their grooms.

Longer term

Most foals developed gingivitis beneath the acrylic appliance, most notably on the labial aspect of the (deciduous) incisors, with residual distortion of the gingival margin present in some cases. Dark staining of incisor cementum was common and the orthodontic wires commonly created grooves in the clinical crowns of the underlying maxillary deciduous incisors. Seven horses had problems when the permanent incisors erupted, including 2 horses that had crowding of permanent incisors; 4 horses with retained deciduous incisors, including 2 cases where retained 01 upper incisors caused the permanent 01s to erupt labial to the retained deciduous teeth. One yearling lost a 503 when the attached biteplate loosened and no (permanent) 103 subsequently erupted.

Cheek tooth malocclusions were not accurately measured and documented, but during the course of treatment, small valve diastemata developed between the upper 07s and 08s in all foals, due to rostral distraction of the 07s and 06s. Abnormal wear patterns (rostral overgrowths of the upper 06s and caudal overgrowths of the lower 08s and exaggerated transverse ridges) developed in some older foals and were repeatedly corrected when the orthodontic appliances were in place and also during the period between removal of the acrylic appliance and the long term follow-up examination.

Associations

No violations of the assumptions of linear regression were identified. Results of single level univariable linear regression analyses are shown in Table 1 and results of multilevel univariable linear regression analyses are shown in Table 2.

Animal age at implant application

First implant:

Six cases with no overbite at the start of treatment were excluded from analysis of overbite change. From univariable analysis, increasing animal age at first implant placement was significantly associated with: a decreased "total" reduction in overjet (P = 0.003); and a decreased total percentage reduction in overjet (P = 0.004, Table 1). These findings could be interpreted as: for each day increased age at time of first implant placement, the reduction in overjet was 0.03 mm less or 0.15% lower, respectively; and for every 30 days increase in age at time of first implant, the reduction in overjet was 0.8 mm less or 4.6% lower, respectively.

Individual implant placement:

Multilevel univariable model results showed that increasing age at time of "individual" implant placement was significantly associated with decreasing "individual" correction rate for overbite (P = 0.04, Table 2): for each day increased age at time of implant placement, the overbite reduction rate decreased by 0.0002 mm/day, or for every 30 days increase in age at time of implant placement, the overbite reduction rate decreased by 0.0058 mm/day.

No other significant associations with animal age at time of individual or first implant were observed.

Surgeon experience

No significant associations between surgeon experience and any of the outcomes examined were observed.

Severity of original overjet/overbite

The original overbite severity was significantly positively associated with total overbite correction rate (P<0.001, Table 1). This finding could be interpreted as: an increase in original overbite dimensions by 1 mm resulted in a 0.004 mm/day increase in overbite correction rate.

Severity of overjet prior to treatment was significantly (H = 9.92, 3 d.f., P = 0.02) positively associated with the number of procedures, (animals undergoing more procedures had larger overjet dimensions prior to the first procedure).

No other significant associations with severity of original overjet or overbite were observed.

Number of implant placements per animal

Foals that had had 4 procedures had significantly (P = 0.05, Table 1) lower total percentage change in overjet, than those that had had one procedure. Foals that had had 4 procedures had significantly (P = 0.01) greater total reduction in overbite, than those that had had one procedure. The overjet correction rate was significantly (P = 0.008, Table 1) lower during the third implant than during the first.

Discussion

This report provides details of treatment and outcomes for foals treated for overjet/overbite by the same surgeon, using a combined orthodontic tension wire and biteplate technique. This is the largest study on this procedure and the amounts and rates of orthodontic corrections, as well as success rates, provide useful information for veterinarians making treatment decisions for foals affected by overjet/overbite. The use of retrospective clinical case records is a limitation of the study and resulted in exclusion of a number of cases from analyses because of missing case details.

Equine overjet/overbite has also been termed brachygnathia (meaning it is caused by a shortened mandible) [13], but there are no radiographic, cephalometric or skeletal age determinant studies to support this supposition. Indeed the limited available evidence indicates that it may be due to maxillary bone elongation, i.e. maxillary retrognathism [14,15]. The condition is not life threatening and with proper dental care and feeding management, most affected horses can have productive performance careers without orthodontic treatment. However, surgical treatment can be effective, improving the appearances of incisors and reduces the requirement for subsequent dental treatments to manage the inevitable incisor overgrowths and to a variable extent, the cheek teeth overgrowths.

Whilst no long term radiographic or cephalometric studies have been performed before or following orthodontic treatment in horses, clinically the equine jaw bones appear to respond to orthopaedic and orthodontic forces similarly to those reported in human and experimental animal studies [16]. Studies in monkeys have shown that the temporomandibular joint is capable of functional adaptation when the mandible is displaced in a rostral direction [17]. Experiments in rats following functional orthodontic device application have shown rostral displacement of the mandible and bone remodelling that increases the total mandibular length [18]. The rostral sutures in the maxilla, that are believed to remain open in adult horses [19], have been shown to respond to both compression and distraction forces to retard or accelerate bone growth, respectively. This effect is seen in the midpalatal suture as well as in other facial bone sutures in histological rat studies as well as in bone biopsies in children [20] and likely explains the mechanism of effect of the treatment used in this study.

Tension band orthodontic wires on the upper jaw, without addition of an inclined plane orthodontic device, have been successfully used in foals with minor degrees of overjet but no overbite [7]. However, this technique is contraindicated in foals with >1 cm of overjet or those with existing overbite [3,4], as it will exacerbate the latter. Mild overjet in young foals can also be corrected using a removable biteplate, without wires [3]. A fixed acrylic appliance attached to the upper incisors was reported to partially correct a 2 cm overjet in a 5-month-old foal [6]. Combining the application of an inclined plane biteplate, attached to the upper incisors, with an orthodontic tension band, additionally provides upward pressure on the upper incisors, thus helping to prevent or correct any existing overbite. In man, contact of the lower incisors with the angled biteplate during mastication tends to pull the lower jaw rostrally, promoting its growth [21–23]. Additionally, the thickness of the acrylic platform and inclined plane contacting the lower incisors separates the premolars, which prevents possible rostro-caudal “lock” of the mandible by the transverse ridges (lophs and styles) on opposing cheek teeth, thus allowing the lower jaw to move forward independently of the upper jaw [3,8,9].

The chosen surgical technique was effective for the vast majority of cases in this study, with reduction in overjet and/or overbite occurring in 95% and 90% of the treated foals, respectively. The single case in which increase in overjet occurred had delayed onset of treatment (342 days), in addition to having its treatment prematurely stopped to start race training. Most (63%, 46/73) cases required more than one procedure, which should be taken into account when considering the costs and risks associated with the procedure, although in this population no anaesthetic-related or other serious complications were observed. Minimal, transient complications including young mares preventing nursing, facial swelling and neuropraxia were observed immediately following the procedure. Careful monitoring and management of the foals and their mares was required to ensure adequate feed intake in the early post-operative period. Longer term sequelae affecting the incisors including deciduous incisor retention, permanent incisor overcrowding or incisor loss occurred in 7/73 (9.5%) of cases, but were just of temporary or minor aesthetic concern. Most cases developed marked gingivitis around the upper incisors and also developed discoloration and abnormal wear in the labial aspects of their upper incisors due to contact with the orthodontic device. Most foals also developed rostral displacement of the upper 06s and 07s, with subsequent diastema formation between 07s and 08s. Prevention of upper 06, lower11 cheek teeth overgrowths requires life-long monitoring and dental treatment in all of these cases.

Increasing animal age at implant placement was significantly negatively associated with the total amount of change of overjet observed, and individual overbite correction rates. This is thought likely to be associated with variations in growth rates, with growth rates declining as foals age [24], resulting in faster and more complete corrections in younger animals. On the basis of this, starting treatment as early as possible (once the 02 incisors are in wear), could be recommended. Little information is available on the level of expression of overjet at birth or of the usual progression of overjet and the subsequent development of overbite as the foal grows, or about the age when they cease to develop or progress. Nevertheless it can be assumed that both of these malocclusions would likely have increased with age in all the current cases and therefore the reported improvements in dimensions of overjet/overbite following treatment underestimates the overall effect of the described treatment.

It is of interest that the findings of this study indicate a negative association between age at first implant placement and total and percentage overjet correction achieved, but that no clear associations between overjet correction rates and age or number of implants were observed. This might indicate that a factor other than foal growth rate is responsible for the observed association with age. In this population, this could be related to the requirement that implants were removed prior to sale for a number of individuals, which tended to occur at 18-22 months of age. Alternatively the lack of observed associations with correction rates might be related to sample size and would be worth re-evaluating in a larger cohort.

Increasing surgeon experience with the technique was not found to be significantly associated with amounts or rates of correction or the number of implants required. This suggests that the outcomes were more associated with other factors and indicates that the technique used was consistent between all cases. Because of the potential complications associated with wire placement, the authors would recommend full training by a competent person before attempting this technique.

The reason for the significant positive association between pre-treatment severity of overbite and total correction rate is uncertain, but could be related to the mechanical effects of the implant on more severe malocclusions or alternatively to factor(s) relating to jaw growth in the more severely affected animals. A similar (but non-significant) positive association between pre-treatment severity of overjet and increased total correction rate was also observed. No significant associations between animal age at first treatment and original overjet/overbite severity were observed, suggesting that animal age did not confound this observed association. Considering that larger overjet/overbite cases take longer to correct than those with smaller malocclusions, and that most implants have a finite lifespan before failure, the significant association between number of implants and severity of original overjet was unsurprising. The lack of significance between original overbite severity and number of implants is likely related to the fact that length of treatment/number of implants, was predominantly guided by overjet severity.

Animals that underwent 4 procedures had significantly greater total reduction in overbite (mean 14.5 mm ± 7.7) than those having only one (mean 6.7 mm ± 4.5), but they also had significantly lower total percentage reduction in overjet (mean 42% ± 26.3) than those having one (mean 75% ± 29.5). The reason for this difference between overjet and overbite correction could be related to differences in time taken for their corrections: overbite is corrected first, as once overjet has been corrected to when the incisors are in contact, overbite is no longer possible. Considering changes in growth rates, it is probable that overjet becomes more difficult to correct with time, which may explain the significant negative association with total percentage reduction. Notably the association is unlikely to be causal in this situation, where more procedures are the result of lack of improvement in overjet dimensions, rather than the cause of it, which may make these associations less clinically useful. However it is perhaps of interest that if an animal requires multiple treatments the percentage expected change in overjet is likely to be lower than that achieved in animals requiring only one procedure.

Conclusion

The combined use of orthodontic tension bands on the upper jaw combined with a fixed acrylic and aluminium inclined plane appliance may have advantages over other techniques in treating overjet/overbite and was shown to be effective in reducing overjet in 95% (58/61) and overbite in 90% (55/61) of treated foals. With proper surgical technique and attention to detail, correction or improvement of these malocclusions is relatively rapid (254 day mean total treatment length in this population), with minimal complications, although in the majority of cases more than one implant is required.

Authors' declaration of interests

No competing interests have been declared.

Ethical animal research

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

Acknowledgements

The owners of all the horses involved examined and treated during the study and Rob Menzies, BVSc and Sheena Bowen, DVM, for their help in collecting data.

Authorship

J. Easley treated the clinical cases and collected all data. He was involved in the study design and reviewing drafts of the manuscript. P. Dixon was involved in study design, preparation of the manuscript, editing and contributing to multiple drafts. R. Reardon was involved in study design, performed the data analysis and interpretation, and prepared the drafts of the manuscript for discussion. All authors gave their final approval of the manuscript.

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Supplementary Information

Supplementary Item 1: Details of surgical technique.

Supplementary Item 2: Details of overbite measurements at each implant placement and removal for cases first treated for overjet/overbite at "Easley Equine Dentistry, Equine Veterinary Practice" between 1 January 1999 and 21 May 2013.

Supplementary Item 3: Description of missing information for foals in study.

Table 1: Results of univariable linear regression models evaluating associations with outcomes for cases first treated for overjet and/or overbite at "Easley Equine Dentistry, Equine Veterinary practice" between 1 January 1999 and 21 May 2013. Significant associations are highlighted with bolded P-values.

Outcome Explanatory Variable	**n**	**Coef.**	**Lower 95% C.I.**	**Upper 95% C.I.**	**Standard Error**	**P-value**
Total change in Overjet (mm)						
Age at 1st surgery (days)	61	-0.03	-0.04	-0.01	0.009	**0.003**
Age at 1st surgery (30 days)	61	-0.8	-1.3	0.29	0.26	**0.003**
Surgeon experience	61	-0.004	-0.04	0.03	0.02	0.8
Number of implants: 1	18	1 Ref				
2	24	-0.06	-3.5	3.4	1.74	0.9
3	14	-0.05	-4	-3.9	1.99	0.9
4	5	1.2	-4.5	6.8	2.83	0.7
Total change in Overbite (mm)						
Age at 1st surgery (days)	55	0.009	-0.01	0.03	0.011	0.4
Age at 1st surgery (30 days)	55	0.28	-0.4	0.9	0.35	0.4
Surgeon experience	55	-0.008	-0.04	0.03	0.02	0.6
Number of implants: 1	16	1 Ref				
2	21	1.66	-1.9	5.2	1.78	0.4

3	13	1.99	-2	6	2	0.3
4	5	7	1.4	12.4	2.75	**0.01**
Total percentage change in Overjet						
Age at 1st surgery (days)	61	-0.15	-0.26	-0.05	0.051	**0.004**
Age at 1st surgery (30 days)	61	-4.6	-7.7	-1.5	1.54	**0.004**
Surgeon experience	61	-0.05	-0.26	0.15	0.1	0.6
Original Overjet severity (mm)	61	-0.6	-2.2	1	0.81	0.5
Number of implants: 1	18	1 Ref				
2	24	-9.9	-29.9	10.2	10	0.3
3	14	-17	-40	5.9	11.4	0.1
4	5	-32.9	-65.4	-0.3	16.2	**0.05**
Total percentage change in Overbite						
Age at 1st surgery (days)	55	-0.004	-0.06	0.05	0.026	0.9
Age at 1st surgery (30 days)	55	-0.13	-1.7	1.5	0.79	0.9
Surgeon experience	55	-0.0003	-0.08	0.08	0.04	0. 9
Original Overbite severity (mm)	55	-0.3	-0.9	0.28	0.29	0.3
Number of implants: 1	16	1 Ref				
2	21	-6.5	-14.9	1.8	4.15	0.1
3	13	-8.6	-17.9	0.78	4.68	0.07
4	5	-3.6	-16.4	9.3	6.41	0.6
Total Overjet correction rate (mm/day)						
Age at 1st surgery (days)	53	-0.00004	-0.0002	0.00009	0.00006	0.6
Surgeon experience	53	-0.000002	-0.0002	0.0002	0.0001	0.9
Original Overjet severity (mm)	53	-0.002	-0.00009	0.003	0.0008	0.06
Number of implants: 1	17	1 Ref				
2	17	-0.017	-0.04	0.005	0.01	0.1
3	14	-0.031	-0.05	-0.008	0.01	**0.008**
4	5	-0.017	-0.05	0.02	0.02	0.3
Total Overbite correction rate (mm/day)						
Age at 1st surgery (days)	47	0.0001	-0.00004	0.0003	0.00007	0.2
Surgeon experience	47	0.00004	-0.0002	0.0002	0.0001	0.7
Original Overbite severity (mm)	47	0.004	0.003	0.005	0.0006	**<0.001**
Number of implants: 1	15	1 Ref				
2	14	-0.001	-0.02	0.02	0.01	0.9
3	13	-0.013	-0.04	0.008	0.01	0.2
4	5	0.02	-0.008	0.05	0.01	0.1
Age at 1st surgery (days)						
Original Overjet severity (mm)	69	-2.47	-5.9	0.98	1.73	0.2
Original Overbite severity (mm)	63	1.84	-1.14	4.82	1.49	0.2

Key: n = number; Coef. = regression coefficient; C.I. = Confidence Interval; Ref = Reference value.

Total overjet/overbite change was calculated by subtracting post-measures from pre-measures, so more positive is equal to a larger correction towards zero (i.e. larger reduction). Total percentage change in overjet/overbite was calculated as: 100 – ([Measurement after the last treatment/Measurement prior to first treatment] x 100), so an increase in this value equates to an increase reduction. Correction rates were calculated as measurement change (as defined above) divided by days of implant placement.

Table 2: Results of multilevel univariable linear regression models evaluating associations with outcomes for cases treated on one or more occasions for overjet and/or overbite at "Easley Equine Dentistry, Equine Veterinary Practice" between 1 January 1999 and 21 May 2013. A multilevel model with horse as a random effect was used to account for repeat measures within the same horse over time. Significant associations are highlighted with bolded P-values.

Outcome / Explanatory Variable	**n (groups)**	**Coef.**	**Lower 95% C.I.**	**Upper 95% C.I.**	**Standard Error**	**P-value**
Individual implant Overjet correction rate (mm/day)						
Age at implant placement (days)	93 (59)	0.00007	-0.0001	0.0003	0.0001	0.5
Age at implant placement (30 days)	93 (59)	0.002	-0.004	0.008	0.003	0.5
Surgeon experience	96 (60)	0.00001	-0.0005	0.0005	0.0002	0.9
Individual implant Overbite correction rate (mm/day)						
Age at implant placement (days)	86 (57)	-0.0002	-0.0004	-0.000004	0.0001	**0.04**
Age at implant placement (30 days)	86 (57)	-0.0058	-0.01	-0.0001	0.003	**0.04**
Surgeon experience	89 (58)	0.00002	-0.0004	0.0005	0.0002	0.9

Key: Coef. = regression coefficient; C.I. = Confidence Interval

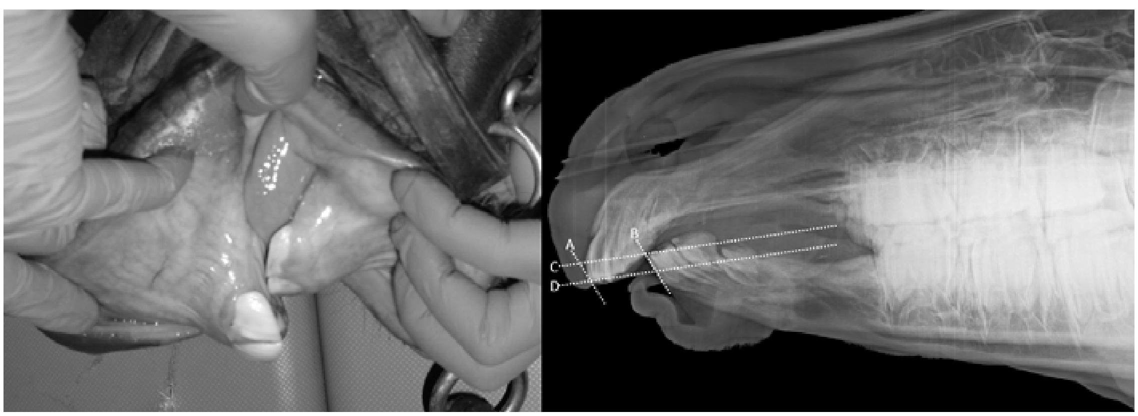
Figures

Fig 1: Photograph and lateral radiograph of 2.5 month-old Warmblood filly with a 24 mm overjet and 16 mm overbite. Dotted lines on radiograph indicate guides used for measurements. Distance from line A to B = overjet; Distance from C to D = overbite.

Fig 2: Intra-operative photos in a 3.5 month-old colt, showing placement of wax strips following tension wire placement (left) and then following placement of aluminium plate and acrylic (right).

Fig 3: Post-operative lateral skull radiograph with orthodontic tension wires and an acrylic and aluminium biteplate with minimal angulation in place.

Fig 4: A = Appearance of foal's mouth at presentation at 60 days old; B = Same foal at 8 months old after 6 months of treatment with single appliance. The bite plate and wires were removed when a wire broke one month after photo B was taken.




L


A
B