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Morphological variations of the infraorbital canal during CT has limited association with headshaking in horses

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Abstract

Headshaking is a common problem in horses. The etiology is unknown but thought to involve sensory input from branches of the trigeminal nerve, some of which are within the infraorbital canal. The objective of this retrospective cross-sectional study was to describe the CT anatomy and variations of the infraorbital canal in horses with local disease processes and normal horses, and to examine associations between those findings and headshaking. Computed tomography scans were reviewed and morphological changes of the infraorbital canal were described. Presence of changes was then tested for association with headshaking prevalence, presence of disease processes in the region of the infraorbital canal, age, and sex. Nonparametric tests were used and a *P*-value of .05 was considered significant. A total of 218 horses were included, 9% of which had headshaking and 45% had CT lesions in the region of the infraorbital canal. Morphological changes to the bone of the infraorbital canal were found in 121 horses (56%) and included the following: increased mineralization 39 (18%), decreased mineralization 89 (41%), deformed shape 51 (23%), displaced position 43 (20%), and disruption 11 (5%). All changes of the infraorbital canal significantly increased in frequency with the presence of adjacent disease. Increased mineralization and disruption of the infraorbital canal were significantly associated with headshaking in horses with adjacent disease; the latter only reached significance after exclusion of dentally immature horses. No other changes were significantly associated with the presence of headshaking. No association was found between headshaking and the age or sex of the horse.

KEYWORDS
equine head, maxillary, neurological, sinusitis, trigeminal nerve

1 | INTRODUCTION

Headshaking in horses is a commonly encountered syndrome, recognized by spontaneous and often repetitive uncontrolled movements of the head and neck, which can occur intermittently or persistently.[1,2] Headshaking can be caused by local disease such as dental problems, periapical dental osteitis, rhinitis, intranasal masses, and sinusitis.[3–5] However, a large proportion of cases exhibit the syndrome with no evidence of underlying disease, this is termed idiopathic headshaking.[1,3,6] It has been observed that anesthesia of the infraorbital, maxillary, or posterior ethmoidal nerves can alleviate symptoms in some idiopathic headshaking horses[4,7] and sensitization of the trigeminal nerve has been demonstrated in headshaking cases.[8] Hence, headshaking has been suggested to be due to neuropathic pain. There is a long-standing comparison between idiopathic headshaking and trigeminal neuralgia, a neuropathic pain syndrome in humans[9]; compression of the trigeminal nerve as seen on MRI in human patients is a commonly stated cause of trigeminal neuritis.[4,9–11]

The infraorbital nerve originates from the maxillary branch of the trigeminal nerve; it is contained within the infraorbital canal, which is a hollow bony structure within the maxillary sinus.[7,12,13] Computed tomography is a valuable method of investigating the structures and pathology of the equine head. Computed tomography is used commonly in horses due to swift acquisition, good spatial resolution, and the introduction of CT in the sedated standing patient[14–16]; conversely MRI data of horses heads is limited by the limited number of MRI units that can image heads, requirement of general anesthesia, long acquisition times, and high expense.[17] The structure and CT appearance of the infraorbital canal and surrounding sinuses has been infrequently described in equine literature.[18–20] Based on our review of the literature, the morphological variations of the infraorbital canal have not been reported in horses, either with respect to changes found in association with disease or possible structural associations with headshaking.

The first objective of the study was to characterize the normal appearance and morphological variations of the infraorbital canal (variations in shape, mineralization, and position) and their associations with pathological processes in the region of the infraorbital canal (adjacent disease). The second objective of the study was to explore possible associations of those variations with a history of headshaking both in horses with and without adjacent disease. Hence, the null hypotheses were that adjacent pathology has no association with morphological variation of the infraorbital canal, and variation of the infraorbital canal has no association with headshaking.

2 | MATERIALS AND METHODS

2.1 | Case selection

The study design was cross sectional and retrospective. All CT examinations of the equine head obtained from the period of February 2015 until December 2016 in the picture archiving and communication system (Impax, version 6.6.1.3004, N.V., Mortsel, Belgium) of the Division of Diagnostic Imaging were considered for inclusion. Additionally, CT examinations of the head of headshaking horses from January 2017 until February 2019 were considered for inclusion. Client-owned horses were used with consent given and anonymity conserved. Examinations were excluded if inadequate patient history was available or the examination did not include the entire region of the infraorbital canal and sinuses. The inclusion criteria were assessed by a European College of Veterinary Diagnostic Imaging resident (R.A.E.), under supervision of a European College of Veterinary Diagnostic Imaging diplomate (S.V.) and European College of Veterinary Surgeons diplomate (H.H.). The hospital information system (Vetware, version 1.6.131-rc01. Agfa healthcare, Rijswijk, the Netherlands) was also analyzed for additional information regarding patient history. In cases of repeat examinations of the same patient, only the original examination was considered.

2.2 | Data collection

The patient data of all eligible horses were retrieved from the picture archiving and communication system and hospital information system. Aforementioned data were examined as to the presence or absence of any reported headshaking, and horses were classified as headshaking positive or headshaking negative, respectively. Headshaking positive horses were classified as those with a history of shaking or jerking their head uncontrollably without any apparent physical stimulus.[3] The remaining horses that did not fit the criteria for headshaking positive were classified as headshaking negative. The patient age, breed, and gender were also recorded.

The eligible CT examinations were assessed by a European College of Veterinary Diagnostic Imaging resident (R.A.E.) under the supervision of a diplomate in the same field (S.V.). Neither was aware of the history of the patient at the time of evaluation. The examinations were analyzed using the aforementioned picture archiving and communication system system (Impax, version 6.6.1.3004, N.V., Mortsel, Belgium); multiplanar reconstructions were created as required for accurate assessment. The clinical history was recorded by the same resident (RAE), with supervision by a European College of Veterinary Surgeons diplomate (H.H.). The assessment of the clinical history was undertaken using the hospital information system at another time period to the assessment of CT images, without reference to the imaging findings.

All eligible horses were first assessed for the presence or absence of CT evidence of disease adjacent to or involving the infraorbital canal (later referred to as adjacent disease), such as those affecting the maxillary sinuses, maxillary bone, or upper arcades of molars, for example sinusitis, space occupying lesions, alveolitis, and fractures. Second, morphological changes in the structure or shape of the infraorbital canal were recorded for all eligible horses. Morphological changes of the wall of the infraorbital canal were assigned to the following categories (Figure 1):

(1) Increased mineralization: Any evidence of focal or diffuse thickening, or increased attenuation of the mineral attenuation of the infraorbital canal wall.
(2) Decreased mineralization: Any evidence of focal or diffuse thinning, decreased attenuation, or absence of the mineral attenuation of the infraorbital canal wall.
(3) Deformed shape: Any evidence of deviation from the normal circular to oval contour of the infraorbital canal wall, including asymmetrical changes in size, shape, and margination.
(4) Displaced position: Displacement of the infraorbital canal from normal position, made evident by asymmetrical position to the contralateral infraorbital canal.
(5) Disruption: Circumferential loss of the infraorbital canal wall, either over part or the entire length of the canal.

The position of the primary focus of the change was recorded by the affected quartile of the canal length. The morphologic changes were recorded for horses with and without evidence of adjacent disease, so it was expected and anticipated that some changes would be due to said disease process and some incidental variation. Bilaterally symmetrical deviations related to unerupted molars in dentally immature horses were not classified as variations and all analyses were repeated with only dentally mature horses of 6 years or older.

2.3 | Data analysis

The data were analyzed with commercially available statistics software (IBM SPSS Statistics for Windows, Version 24. IBM Corp, Armonk, NY, USA) by a European College of Veterinary Diagnostic Imaging resident (R.A.E.) under supervision of a diplomate in the same field (SV). Nonparametric testing was used for categorical data. All data was clustered in respect to individual horses, rather than separate

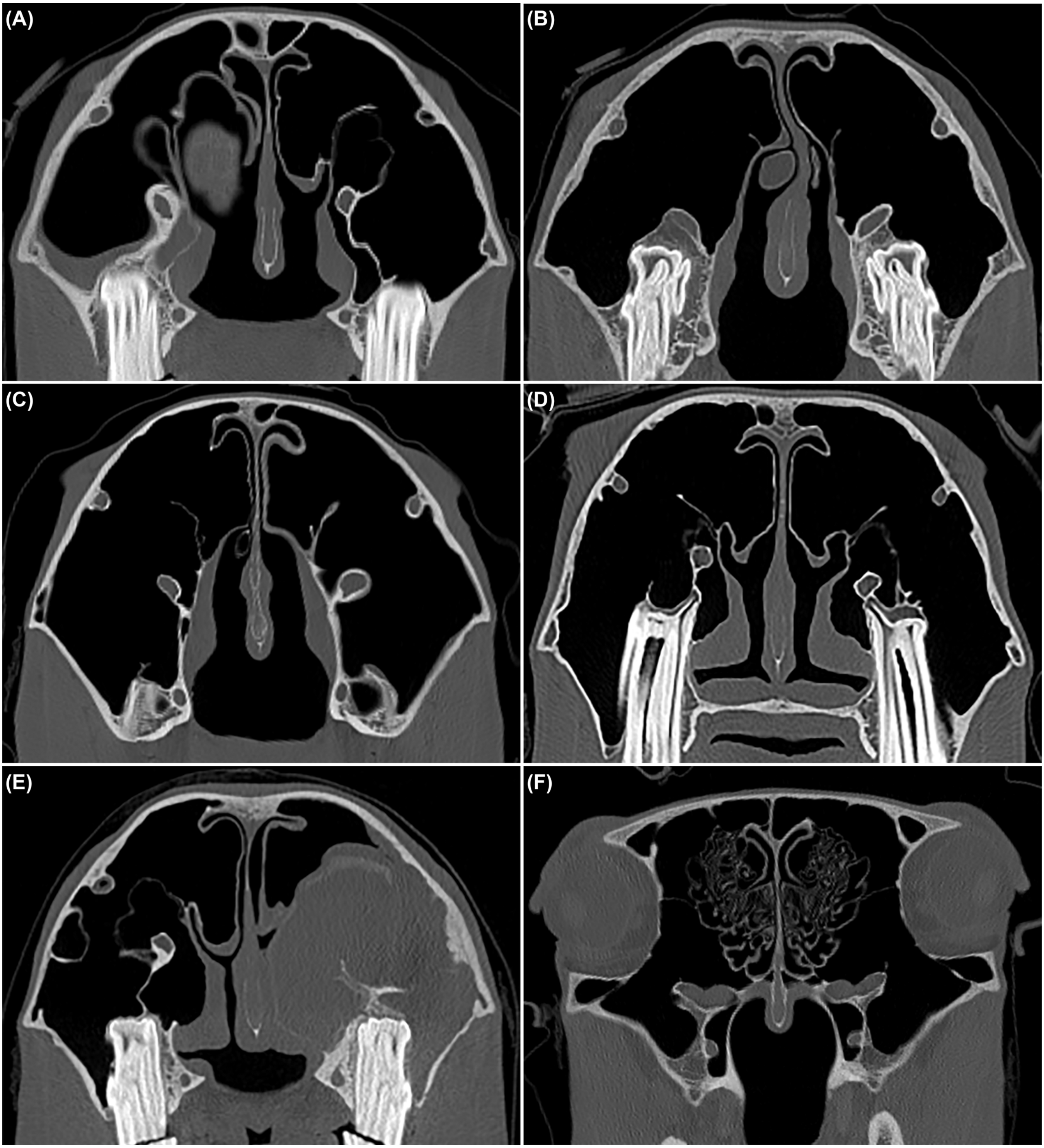

FIGURE 1 Transverse CT images illustrating categories of changes recorded for the infraorbital canal in included horses. All images are bone algorithm (H60f),1 mm slice thickness, 3000 window width, and 600 window length. A, Increased mineralization of the right infraorbital canal. B, Decreased mineralization of the right infraorbital canal. C, Deformed shape of the right infraorbital canal. D, Displaced position of the right infraorbital canal. E, Disruption of the left infraorbital canal. F, Caudo-dorsal decreased mineralization of both infraorbital canals. Evidence of unilateral sinusitis is seen in cases a, b, and e

assessment of right and left infraorbital canals. Fisher's two-sided exact tests were used to assess correlations between the above-mentioned five changes of the infraorbital canal and the presence or absence of adjacent disease and headshaking. Fisher's two-sided exact tests were then used to assess the proportion of headshaking horses with the described changes in subgroups of those with and without adjacent disease present, and finally all testing was repeated including only all dentally mature horses of 6 years or older. A *P*-value $< .05$ was considered statistically significant.

3 | RESULTS

In total, 218 CT studies were eligible for inclusion to the study, including 106 mares, 109 geldings, and five stallions. The median age of the sample was 9 years (range 1-33); 51 horses were aged 0-5 years, 79 aged 6-10, 51 aged 11–15, 29 aged 16–20, and seven over 20 years. Breeds included: 121 Dutch Warmbloods, 29 mixed breeds, 12 Friesians, nine Ponies, six Haflingers, five Westfalens, four Arabs, three Hanoverians, three Welsh Cobs, three Quarter horses, three Belgian Warmbloods, three Irish Hunters, three Oldenburgers, three Holsteins, and a diverse range of other breeds were represented by two or less individuals.

The CT scans were acquired in standing sedated (IV detomidine hydrochloride (0.01-0.025 mg/kg) (Domosedan, Orion Corporation, Espoo, Finland)) horses with a 64 slice sliding gantry CT scanner (SOMATOM Definition AS, Escel Edition. Siemens AG, Wittelbacherplatz 2, DE-80333, Muenchen, Germany). The scanning protocol used was 140 KVp, care dose setting controlled mAs from a reference of 328 mAs, pitch 0.8, rotation time 0.5 s, and 0.6 mm slice thickness. Bone (H60f) and soft tissue (H31f) algorithms were applied with reconstruction to 1 and 2 mm slice thickness, respectively. A standard matrix of 512×512 pixels used. Field-of-View was variable according to patient size.

3.1 | Morphological changes

At least one type of change of the infraorbital canal occurred in 121 of the 218 horses (55.5%, 95% confidence interval [48.9%, 62%]). More specifically 25 horses exhibited increased mineralization (17.8%, 95% confidence interval [13.2%, 23.4%]), 61 decreased mineralization (40.8%, 95% confidence interval [34.5%, 47.4%]), 37 deformed shape (23.4%, 95% confidence interval [18.1%, 29.3%]), 33 displaced position (19.7%, 95% CI [14.9%, 25.4%]), and seven disruptions (5.0%, 95% confidence interval [2.7%, 8.6%]) (Table 1).

A total of 97 examinations (44.5%, 95% confidence interval [38.0%, 51.1%]) had adjacent disease present and the remaining 121 horses had no evidence of adjacent disease that was considered relevant to the infraorbital canal. Of the 121 horses without adjacent disease present 45 had changes of the infraorbital canal (37.2%, 95% confidence interval [29.0%, 46.0%]), whereas 76 of the 97 examinations with adjacent disease present had morphological changes of the infraorbital canal (78.4%, 95% confidence interval [69.4%, 85.6%]). The diseases observed included 65 horses with sinusitis and 20 with lesions producing mass effect such as neoplasia, ethmoid haematomas, or sinus cysts, and 43 with other pathologies such as apical tooth root infections, congenital dental abnormalities, or trauma. Many horses had combinations of the aforementioned conditions. There were universally significant associations between the presence of adjacent disease and all five morphological changes of the infraorbital canal (*P*-values of less than or equal to 0.001) (Table 2). Disruption of the canal was only observed in horses with adjacent disease present, conversely, decreased mineralization was found in 35 (28.9%, 95% confidence interval [21.4%, 37.4%]) of horses without any adjacent disease present. Displaced position occurred in 14 (11.6%, 95% confidence interval [6.8%, 18.2%]) horses without adjacent disease present, deformed shape in 11 (9.1%, 95% confidence interval [4.9%, 15.2%]), and increased mineralization in five (4.1%, 95% confidence interval [1.6%, 8.8%]) (Table 3).

3.2 | Headshaking

Overall, 42 of the 218 included horses (19.3%, 95% confidence interval [14.5%, 24.9%]) were headshaking positive, including 16 mares (15.1%, 95% confidence interval [9.3%, 22.8%]), 26 geldings (24.3%, 95% confidence interval [16.9%, 33.0%]), and no stallions (0%, 95% confidence interval [0%, 80.6%]). The median age of the 42 headshaking positive horses was 8 years (range 3-23 years), which was not significantly different to the 176 headshaking negative horses (median 10 years, range 1-33 years).Of the headshaking positive horses eight were aged 0–5 years, 23 horses 6–10 years, nine horses 11–15 years, and one horse in each of the 16–20 and >20 years categories.

Headshaking occurred in 24 of the 121 horses (19.8%, 95% confidence interval [13.1%, 28.1%]) that had at least one morphological change of their infraorbital canals, and 18 of the 97 with none (18.6%, 95% confidence interval [11.8%, 27.2%]); this difference in occurrence was not statistically significant ($P = .9$). The proportion of headshaking positive to headshaking negative horses was not significantly different in horses with and without any of the individual types of change (Table 1), with *P*-values varying between .4 and .8. The position of change to the infraorbital canal in relation to headshaking status was tested, with no significant associations found ($P = .6$).

In horses with adjacent disease present headshaking occurred in a significantly higher proportion of horses with increased mineralization than those without ($P = .05$). No other significant changes in proportion were found in horses with adjacent disease present, although disruption was seen in an insignificantly higher proportion of horses with headshaking than those without ($P = .1$; Table 2). Deformed shape of the infraorbital canal was found in proportionally more headshaking positive horses with no adjacent disease present, however, the changes did not reach a level of significance ($P = .1$). No other changes to the infraorbital canal approached significance in horses without adjacent disease present (Table 3).

TABLE 1 Morphological changes of the infraorbital canal with respect to headshaking status

Morphological change	All		Headshaking positive		Headshaking negative	
	Number of horses	Percentage of total, 95% confidence interval (n = 218)	Number of horses	Percentage of total (n = 42)	Number of horses	Percentage of total (n = 176)
Increased mineralization	39	17.9% (13.2%, 23.4%)	8	19.0% (9.4%, 32.7%)	31	17.6% (12.5%, 23.7%)
Decreased mineralization	89	40.8% (34.5%, 47.4%)	15	35.7% (22.6%, 50.8%)	74	42% (34.9%, 49.4%)
Deformed shape	51	23.4% (18.1%, 29.3%)	9	21.4% (11.2%, 35.5%)	42	23.9% (18.0%, 30.6%)
Displaced position	43	19.7% (14.9%, 25.4%)	6	14.3% (6.2%, 27.1%)	37	21.0% (15.5%, 27.5%)
Disruption	11	5% (2.7%, 8.6%)	3	7.1% (2.1%, 17.9%)	8	4.5% (2.2%, 8.4%)

TABLE 2 Morphological changes of the infraorbital canal with respect to headshaking status in horses WITH adjacent disease present

Morphological change	All		Headshaking positive		Headshaking negative	
	Number of horses	Percentage of total, 95% confidence interval (n = 97)	Number of horses	Percentage of total (n = 11)	Number of horses	Percentage of total (n = 86)
Increased mineralisation*	34	35.1% (26.1%, 44.9%)	7	63.6% (34.8%, 86.3%)	27	31.4% (22.3%, 41.7%)
Decreased mineralisation	54	55.7% (45.7%, 65.3%)	7	63.6% (34.8%, 86.3%)	47	54.7% (44.1%, 64.9%)
Deformed shape	40	41.2% (31.8%, 51.2%)	4	36.4% (13.7%, 65.2%)	36	41.9% (31.8%, 52.4%)
Displaced position	29	29.9% (21.5%, 39.5%)	3	27.3% (8.3%, 56.5%)	26	30.2% (21.3%, 40.5%)
Disruption	11	11.3% (6.2%, 18.8%)	3	27.3% (8.3%, 56.5%)	8	9.3% (4.5%, 16.8%)

*A significantly greater proportion of headshaking positive horses had increased mineralization compared to headshaking negative $P = .05$.

TABLE 3 Morphological changes of the infraorbital canal with respect to headshaking status in horses WITHOUT adjacent disease present

Morphological change	All		Headshaking positive		Headshaking negative	
	Number of horses	Percentage of total, 95% confidence interval (n = 121)	Number of horses	Percentage of total (n = 31)	Number of horses	Percentage of total (n = 90)
Increased mineralisation	5	4.1% (1.6%, 8.8%)	1	3.2% (0.4%, 14.1%)	4	4.4% (1.5%, 10.2%)
Decreased mineralisation	35	28.9% (21.4%, 39.4%)	8	25.8% (13.0%, 42.9%)	27	30% (21.3%, 40.0%)
Deformed shape	11	9.1% (4.9%, 15.2%)	5	16.1% (6.4%, 31.8%)	6	6.7% (2.8%, 13.2%)
Displaced position	14	11.6% (6.8%, 18.2%)	3	9.7% (2.8%, 23.6%)	11	12.2% (6.7%, 20.2%)
Disruption	0	0%	0	0%	0	0%

3.3 | Analysis of excluding dentally immature horses

No significant associations between age or sex and the frequency of the changes to the infraorbital canal were found. However, the appearance of the infraorbital canal was found to subjectively alter with age, predominantly due to the presence of unerupted cheek teeth within the maxillary sinus in younger horses. The infraorbital canal was observed to flatten and move subtly dorsally around these unerupted cheek teeth. As such the analysis of infraorbital canal changes with respect to headshaking was repeated excluding dentally immature horses (those 0-5 years old) revealing similar results. This analysis excluded 51 horses (eight headshaking positive and 43 headshaking negative) to leave a group of 34 headshaking positive and 132 headshaking negative horses. The excluded horses included 12 with increased mineralization of the infraorbital canal, 27 decreased mineralization, 14 deformed shape, eight displaced position, and three destroyed contours. In the group of horses with adjacent disease present significance was reached in respect to disruption ($P = .04$, previously .1), but not increased mineralization ($P = .1$, previously .05). In those without adjacent disease present deformed shape moved further from significance ($P = .3$, previously .1). All other proportions were similar and far from significance.

3.4 | Additional findings

During data collection, observations of the most common changes to the infraorbital canal in horses without disease were made. The most commonly observed zone of decreased mineralization was a small region of thinning of the caudodorsal margin of the infraorbital canal just rostral to the maxillary foramen (Figure 1). This variance in appearance was termed caudal demineralization and accounted for 23 of the 36 horses with demineralization without adjacent disease.

Caudal demineralization was tested for association with headshaking status without significant results ($P = .8$). Following this, decreased mineralization excluding horses with caudal demineralization was also tested for association with headshaking in horses without adjacent disease, without significant results ($P = 1.0$). Excluding horses with caudal demineralization from testing those with adjacent disease (removing nine of 54 horses with decreased mineralization) increased the proportion of headshaking positive horses with decreased mineralization, although significance was not reached ($P = .3$ compared to .8 pre-exclusion).

No other consistent variations in horses without adjacent disease were observed. Displaced or asymmetrical position of the infraorbital canal, deformed shape, and decreased mineralization (excluding cases of caudal demineralization) were most often observed at the second quartile of the infraorbital canal or at the level of the first molar, and rarely observed in the first quartile. Increased mineralization was most commonly observed in the third quartile (level of the second molar). No significant associations of age and morphological changes of the infraorbital canal were found.

4 | DISCUSSION

Based on our review of the literature, this is the first study to investigate the anatomy and changes of the infraorbital canal in a large group of horses, both in response to adjacent disease and in relation to headshaking. The study expands on previous descriptions of the normal anatomy of the infraorbital canal in the literature,[13,14,20,21] by adding a more detailed understanding of variations. The study provides novel information regarding morphological changes of the infraorbital canal in horses with and without adjacent disease. Universally significant variance in the frequency of all morphological changes of the infraorbital canal was found between horses with and without adjacent disease present. Disruption of the infraorbital canal only occurred in horses with adjacent disease. Inversely 29% of horses without adjacent disease had some degree of decreased mineralization making it a relatively common and possibly incidental finding, which is particularly interesting as it has only been previously described as a finding in horses of neoplasia or maxillary sinus cysts.[18,19,22,23] Although in horses with no adjacent disease present, but exhibiting morphological changes of the infraorbital canal, we cannot exclude the possibility of a previous disease causing the current findings. The most common presentation of decreased mineralization was a small dorsal region at the caudal extremity of the canal, which appeared insignificant and most likely represents an anatomic region of extremely thin bone.

No significant associations were initially found between any of the changes of the infraorbital canal and the prevalence of headshaking. However, limited associations were found after division of horses into those with adjacent disease present or absent, which was considered relevant given the clinical division of headshaking horses into those apparently caused by a known disease and idiopathic cases.[1,3] Increased mineralization of the infraorbital canal and disruption, were significantly associated with headshaking in cases with adjacent disease present (the latter only after exclusion of dentally immature horses). As examined adjacent diseases included a wide range of disease processes; the individual type of adjacent disease was not assessed as many were observed to occur concurrently and it would seem speculative to attempt to subclassify which of these could be associated to the infraorbital canal changes. This could be an interesting point of further investigation. Significance was not reached in any categories in horses without adjacent disease, however, deformed shape of the infraorbital canal was found in relatively more headshaking positive horses. Common patterns and locations of morphological variations were identified, it would be a point of further study to further classify changes in a larger group of headshaking horses, to try to identify more precise parameters of deformed shape, which could be significantly associated with headshaking.

The lack of any consistent associations between headshaking and changes to the infraorbital canal has several possible explanations such as: a lack of understanding of the aetiology of headshaking, changes to the infraorbital canal not affecting the infraorbital nerve in all cases (soft tissue vs bone changes), and limited sensitivity. The current literature makes strong comparisons of headshaking with trigeminal neuritis in humans and there is sustained interest in an associated etiology of headshaking as a facial pain syndrome. However, the exact location of change in horses is still unknown (trigeminal nerve, maxillary branch, infraorbital nerve, or posterior ethmoidal nerve).[8,11] The findings of diagnostic analgesia and targets of therapy are varied in practice and the literature.[1,7] Different studies have come to different conclusions on localization, the authors have considered the infraorbital canal and contained infraorbital branch of the maxillary nerve the most appropriate location for investigation; both due to the possibility of compression within the narrow bony canal and exposure to damage from any number of common pathologies of the maxillary sinus.[4,7,8] Additionally, headshaking is reported as an occasional complication of surgical trauma to the infraorbital canal,[5] which concurs to a point with our results finding that some but not all cases of disruption of the infraorbital canal were associated with headshaking. Further reducing clarity is the difference in effectiveness between diagnostic anesthesia and different therapies such as surgical coils around the infraorbital nerve, neurectomy, and neuromodulation.[1,24] To illustrate the last point; bilateral analgesia of the posterior ethmoidal nerve has a reported effectiveness of 85%, however, a long-term improvement of only 26% was achieved after specific treatment of the nerve within the same study group.[7]

A second possible explanation for a lack of significance is that the changes to the canal do not presumably always affect the nerve as such. The authors proposed the hypothesis on the assumption that physical changes of the infraorbital canal could compress and therefore cause clinical signs of headshaking (based on the facial pain syndrome in humans with headshaking). This was extrapolated from a number of successful reports of treatments based on physical pressure on the infraorbital nerve[7] and human investigation of trigeminal neuritis thought to be caused by arterial compression of the caudal infraorbital nerve.[1,9] Therefore, it is logical that bony changes to the infraorbital canal could cause similar changes; however, this is not a proven assumption in either the human or equine field. It is interesting that in our study of horses with no adjacent disease deformity came closest to significance, in which it is easy to extrapolate that either may compress the nerve. However, in horses with adjacent disease disruption and increased mineralization showed association with headshaking despite them being speculatively associated with reactive change (ie, inflammation or infection) rather than compression.

The third explanation is that a lack of sensitivity or specificity in testing the objective resulted in false negative (type II error) or positive (type 1 error) conclusions due to study limitations. The study involved a large number of horses, with 42 headshaking positive, which found some significant changes. However, a lack of power placed limitations on subdivisions analyzed due to group size. Additionally, the CT scans were only assessed by a single observer, so further repeatability studies could be considered. That being said the authors feel that the reported observations in a relatively large group of horses give a valuable initial overview of morphological variation of the infraorbital canal in normal horses and in response to adjacent disease, and how those observations may relate to headshaking. The current study did not include measurements due to variations in breed, size, and age of patient affecting objectivity, however, computer modeling over a large number of horses could perhaps provide greater insights for evaluation of normal variation.[10]

In conclusion, the appearance of the infraorbital canal is variable with morphological changes seen in both horses with and without adjacent disease present, although they occur in a significantly greater proportion of the former group. Increased mineralization and disruption of the infraorbital canal (the latter only when excluding skeletally immature horses) in horses with adjacent disease present, exhibited a significantly increased prevalence in headshaking horses. No other morphological changes were associated with the presence or absence of headshaking, either in horses without adjacent disease present or the group as a whole. A future study with a larger population of headshaking horses could enable further characterization of morphological changes and objective assessment. Additionally, utilization of MRI or neuromodulation could provide further avenues of research.

LIST OF AUTHOR CONTRIBUTIONS

Category 1

(a) Conception and Design: Edwards, Veraa

(b) Acquisition of Data: Edwards

(c) Analysis and Interpretation of Data: Edwards, Hermans, Veraa

Category 2

(a) Drafting the Article: Edwards

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