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Validation of a 2-mm videoendoscope for the evaluation of the paranasal sinuses with a minimally invasive technique

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Abstract

Objective: To describe the technique, experience, and limitations of using a 2-mm flexible endoscope to perform standing minimally invasive sinoscopy.

Study design: In phases 1 and 2, we used cadaveric heads (ex vivo). In phase 3, we used unaffected horses (in vivo).

Animals: Five cadaveric equine skulls in phase 1 and 10 cadaveric equine skulls in phase 2. Six horses older than 5 years in phase 3.

Methods: In phase 1, the specimens were used to determine the suitability of the endoscope for sinoscopy and the ideal landmarks to approach the paranasal sinuses through minisinusotomies performed with a 14 gauge needle. In phase 2, a non-blinded evaluation of the visualization of the different sinus compartments was performed, and a score was attributed to each structure. Procedures were video recorded and compared with direct visualization of the sinuses after performing frontal and maxillary flaps. In phase 3, the technique was validated in healthy horses under sedation.

Results: The landmarks determined in phase 1 allowed a thorough exploration of the sinuses in phases 2 and 3. Sinoscopy findings were confirmed after direct visualization of the sinuses via frontal and maxillary bone flaps in phase 2. The procedure was well tolerated by all horses.

Conclusion: Minimally invasive sinoscopy was readily performed without relevant complications in standing horses. A thorough evaluation of most sinus structures was obtained only using the frontal and the rostral maxillary portals.

Clinical significance: Minimally invasive sinoscopy offers an alternative diagnostic tool to veterinarians. A specialized endoscope and appropriate training are required to perform this minimally invasive procedure.

1 | INTRODUCTION

Paranasal sinus disease is the most common cause of unilateral nasal discharge in horses; however, the diagnosis of sinus pathology remains a challenge mainly because of horses' complex anatomy and the diagnostic limitations of traditional imaging techniques.[1] Upper airway endoscopy correctly identifies the sinuses as the source of nasal discharge in 50% to 100% of horses, and radiography yields a definitive diagnosis in less than 40% of affected horses.[1,2] The lack of precision and the limited diagnostic information provided with these techniques contributes to the chronic presentation and high recurrence rate frequently observed with sinus affections.[1,2] Hence, advanced imaging techniques or sinoscopy are often required to reach a definitive diagnosis. Computed tomography (CT) identifies apical infections in 97% of cases and is the current gold standard to diagnose sinus diseases.[3,4] Limitations of CT include cost, availability, and

the requirement for general anesthesia for select units, especially in North America.

Sinoscopy allows direct visualization of the paranasal sinuses and reaches a diagnostic rate of approximately 70%.[1] However, the technique is invasive because it requires surgical trephination (10–15 mm) of the skull and, in some instances, may even require multiple trephine holes for a thorough evaluation of all sinuses.[5-7] The development of a minimally invasive sinoscopic technique (MIST) may simplify the surgical approach and the invasiveness of the procedure (especially in cases in which traditional sinoscopy may require multiple trephine holes), and popularize the use of sinoscopy as a basic diagnostic tool. Thus, this technique could serve as a diagnostic alternative to traditional sinoscopy or when CT is not available.

The objective of our study was to describe the technique, experience, and limitations of using a 2-mm flexible endoscope to perform standing minimally invasive sinoscopy in horses. We hypothesized that a 2-mm flexible endoscope could be used to achieve a complete evaluation of the paranasal sinuses in standing horses. We also hypothesized that MIST could be easily and successfully performed in multiple sinus compartments during the same procedure without any complications.

2 | MATERIALS AND METHODS

The study was designed in three phases. In phase 1, cadaveric heads were used to determine ideal landmarks to perform MIST. In phase 2, cadaveric heads were used to assess sinus evaluation while using MIST. In phase 3, MIST was performed in healthy horses.

2.1 | Equipment

A flexible 2-mm-diameter and 18-cm-long endoscope was designed in cooperation with BioVision Technologies (Golden, Colorado) based on a 0.9-mm-diameter endoscope that is already commercially available from the company (Figure 1). This flexible endoscope is compatible with the Next Generation Needle view arthroscope suite (BioVision Technologies) used in horses for standing arthroscopy.[8,9] This flexible endoscope is reusable, requires manual manipulation to be guided (absence of control knob), and lacks a flush system or instrument channel. The endoscope can be sterilized with ethylene oxide or cold sterilization.

2.2 | Phase 1

Five equine heads that had been collected from medium-sized horses older than 5 years that had been euthanized for reasons unrelated to the study (four client-owned horses donated to research after euthanasia and one horse enrolled in another research study [IACUC: 18-RECH-1578]) were included in this phase. These specimens were used to determine the suitability of the flexible endoscope for sinoscopy and to determine the ideal landmarks to approach the frontal sinus (FS), caudal maxillary sinus (CMS), and rostral maxillary sinus (RMS).

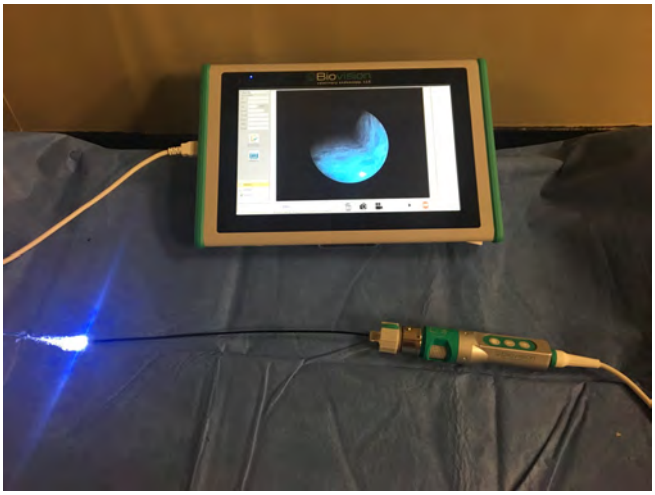

FIGURE 1 Image of the novel 2-mm flexible endoscope attached to the camera and the monitor

On the basis of previously reported landmarks, a minisinusotomy was performed to access the FS, CMS, and RMS.[6,7] Briefly, the skin overlying the paranasal sinuses was clipped, and a 3-mm incision was performed through the skin and subcutaneous tissue at the reported landmarks with a No. 11 scalpel blade. Then, a minisinusotomy was performed by advancing, with the aid of a mallet, a 3.8–cm-long, 14 gauge needle (2.1-mm outer diameter) through the frontal (FS), zygomatic or lacrimal (CMS) or maxillary bones (RMS; Figure 2). The needle used to perform the minisinusotomy was then removed with the aid of circular movements, the 2-mm endoscope was inserted freely through the hole, and sinoscopy was performed.

2.3 | Phase 2

Heads of adult horses older than 5 years were included in this phase because the teeth reserve crown in younger animals precludes a thorough evaluation of the maxillary sinuses.[6] Six heads from horses older than 10 years with no history of sinus disease were collected from client-owned horses donated to research after euthanasia (5/6) or from horses euthanized at the end of another research study (1/6; IACUC: 18-RECH-1578) and frozen at −20°C until the study was performed. Four heads from horses between 5 and 10 years were collected with permission from a nearby abattoir because of the lack of specimens of those ages available

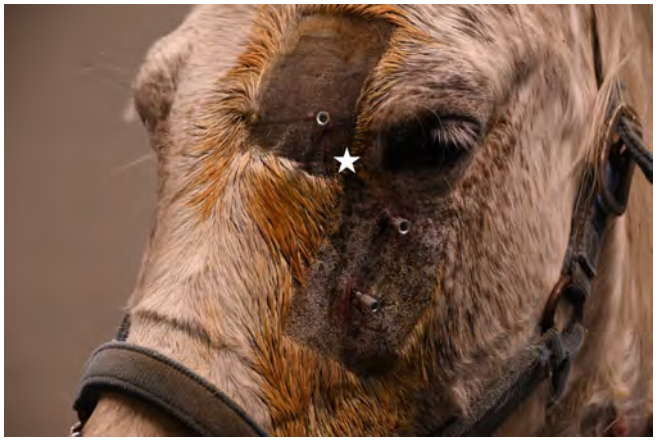

FIGURE 2 Image of needle placement for performing minisinusotomy in the frontal, caudal maxillary, and rostral maxillary sinuses. The needle introduced in the rostral maxillary sinus is oriented slightly upward to allow the endoscope to pass over the infraorbital canal and visualize the ventral conchal sinus. The white star marks the position of the rostral lacrimal tubercle

at our institution during the study period. These specimens were used either fresh (2) or frozen (2) at −20°C until the study was performed.

The procedure was evenly and randomly performed as previously described in the left or right paranasal sinuses in both age groups. For each procedure, video recordings were obtained and graded after agreement by two unblinded observers. Sinus evaluation was later compared with direct visualization of the paranasal sinuses after performing frontal and maxillary flaps.

A grading score determined by the authors was assigned for each structure that should be visualized during sinoscopy: 3 for complete visualization, 2 for subcomplete visualization (approximately 51%–99% of the structure visualized), 1 for partial or limited visualization (approximately 1%–50% of the structure visualized), and 0 for no visualization. The information was then recorded and tabulated in Excel (Microsoft, Redmond, Washington). For each horse, the scores of each structure that should be visible from an individual approach (see below) were summed and expressed in a global score for each approach. If a structure was not present within the sinus due to anatomic variability (ie, tooth 08), the individual score was not considered, to prevent negatively affecting the global score of visualization.[10] The structures graded from each approach were

- From the FS: ethmoid, caudal recess of the frontal sinus (FS "cul-de-sac"), caudomedial aspect of the dorsal conchal sinus, frontomaxillary opening, maxillary septal bulla (MSB), caudal aspect of the caudal maxillary sinus, infraorbital canal, entrance to the sphenopalatine sinus, and roots of maxillary teeth 110/210 and 111/211.
- From the CMS: ethmoid, frontomaxillary opening, MSB, infraorbital canal, entrance to the sphenopalatine sinus, caudal aspect of the caudal maxillary sinus, and roots of maxillary teeth 110/210 and 111/211.
- From the RMS: roots of maxillary teeth 108/208, 109/209, and 110/210; infraorbital canal; MSB; and ventral conchal sinus (VCS).

Whenever these structures had a score of 1 or less during MIST, the minisinusotomy was enlarged by using a 5-mm Steinmann pin with the aid of a Jacobs chuck. Sinoscopy and grading were then repeated through the enlarged hole to determine whether it would improve visualization of the different sinus structures.

Only during this phase and after enlarging the frontal minisinusotomy with a 5-mm Steinmann pin, the MSB was fenestrated. For this purpose, the endoscope and a bent 14 gauge catheter trocar were simultaneously introduced through the slightly enlarged sinusotomy (5 mm), and the MSB was fenestrated under endoscopic guidance by piercing the MSB with the catheter trocar. After fenestration, the opening on the MSB was slightly enlarged by performing rotational movements with the catheter trocar. The fenestration was made at the level of the infraorbital canal (medial to lateral direction) and as dorsal and rostral as possible in the segment of the MSB protruding through the frontomaxillary opening. The flexible endoscope was then inserted through the newly created opening, and the RMS and the VCS were evaluated.

2.4 | Phase 3

Six horses without history of sinus diseases from a research herd at Université de Montréal were enrolled to validate the technique in live animals and to report safety and complications associated to the procedure. Animal use was approved by the Institutional Animal Care and Use Committee of the College of Veterinary Medicine of the University of Montreal.

After complete physical examination, horses were lightly sedated with detomidine (0.01 mg/kg intravenously [IV]) or xylazine (0.4 mg/kg IV) and radiographically screened (laterolateral and dorsoventral radiographic projections of the skull) to rule out any obvious/severe sinus pathology. Horses were then premedicated with procaine penicillin (22 000 UI/kg intramuscularly [IM]) and phenylbutazone (2.2 mg/kg IV), sedated with detomidine (0.01 mg/kg IV) and butorphanol (0.01 mg/kg IV), and restrained in standing stocks. The surgical sites were clipped and aseptically prepared. Skin and subcutis were anesthetized with 1 mL of lidocaine 2% at the selected landmarks. Access to the right (three horses) or left (three horses) FS, CMS and RMS was performed as previously described and randomly distributed with research randomizer software (https://www.dcode.fr/).

For the RMS approach, special attention was given to prevent damage to the levator nasolabialis and the levator labii superioris muscles as well as the angularis oculi vein. The structures were dorsally displaced with a finger at the time of performing the minisinusotomy. The minisinusotomy was first performed in the three selected locations, and then the different sinuses were evaluated with the flexible endoscope as described in phase 2 (Figure 2). A 5-mm Steinman pin was not used to enlarge the minisinusotomy in this phase. Video recordings were obtained for each procedure. The endoscope was cleaned and disinfected solely with alcohol between horses.

At the end of the procedure, the sinuses were flushed with 300 to 500 mL of a sterile isotonic solution by introducing a 14 gauge needle through the FS and RMS minisinusotomies. Skin closure was not performed, and a light head bandage with adhesive material was applied around the head before horses were returned to their stalls. Horses received one more dose of phenylbutazone (2.2 mg/kg IV) 12 hours postoperatively and were kept on stall rest for 2 days before returning to small pasture turn out. Horses were monitored twice per day for 7 days and then once per day for 7 more days. Wound healing and the presence of any complications during the postoperative period were recorded.

2.5 | Statistical analysis

A Wilcoxon signed-rank test was performed in Prism (GraphPad Software, San Diego, California) to determine the best approach to examine the CMS (FS vs CMS) and to compare sinus evaluation with minisinusotomy vs pin hole. $P < .05$ was considered statistically significant.

3 | RESULTS

3.1 | Phase 1

Heads from one Hanoverian horse, one paint horse, two quarter horses and one appendix horse were included. Mean age was 17.4 years (range, 14–21).

Minisinusotomies were performed in the first two specimens with a commercially available 0.9-mm flexible endoscope. However, we concluded that the light output was insufficient for adequate sinus visualization. The endoscope was then modified, and the diameter was increased to 2 mm for the remaining specimens, which allowed increased light output and appropriate sinus visualization. The endoscope was easily guided within the sinuses by means of manual manipulation.

Standard landmarks for minisinusotomy/sinoscopy were slightly modified to allow a complete examination of the sinuses with the 2-mm endoscope:

1. To access the frontal sinus, the minisinusotomy was performed at 40% of the distance from the medial canthus of the eye to midline and 2 cm caudal to the rostral aspect of the rostral lacrimal tubercle, with the needle inserted perpendicular to the bone (Figure 2). The rostral lacrimal tubercle is a boney prominence palpable just rostral and slightly dorsomedial to the medial canthus and serves as the insertion point for the orbicular muscle.
2. To access the caudal maxillary sinus, the minisinusotomy was performed 1 cm rostral and 3 cm ventral to the rostral aspect of the rostral lacrimal tubercle, with the needle inserted perpendicular to the bone (Figure 2).
3. To access the rostral maxillary sinus, the minisinusotomy was performed 40% of the distance from the rostral end of the facial crest to the level of the medial canthus and 1 cm ventral to a line joining the infraorbital foramen and the medial canthus, with the needle directed slightly upward (approximately 30°; Figure 2). This needle orientation facilitates advancement of the scope over the infraorbital canal.

Dissection after sinoscopy revealed mild fragmentation of the maxillary bone around the needle insertion in one specimen. It was also noted that circular movements of the 14 gauge needle would slightly enlarge the minisinusotomy when additional space to maneuver the endoscope was required.

3.2 | Phase 2

Specimens included in this phase were obtained from four males and six females of different breeds (four standardbreds, three quarter horses, one Percheron, one Hanoverian, one Welsh pony). The mean age was 12 years (range, 6–20). Heads from horses other than medium-sized breeds were included to ensure the suitability of the procedure in horses of most sizes.

The scores obtained for the different approaches in phase 2 are presented in Table 1. No differences were found when sex or breed were considered. As previously reported, we found that the maxillary septum was mostly oblique and changes in position with age.[10] The maxillary septum was completely absent in specimen seven.

Most structures were assigned a score of 3 (complete visualization) for the FS and the CMS. Partial to no visualization of the FS cul-de-sac and the caudomedial aspect of the dorsal conchal sinus was noted when the 14 gauge needle was used to perform the FS minisinusotomy in two specimens. Nevertheless, complete or subcomplete visualization was achieved in nine of 10 specimens for FS cul-de-sac and in all specimens for the caudomedial aspect of the dorsal conchal sinus after the minisinusotomy was enlarged with a 5-mm Steinmann pin. The lowest score through the CMS approach was related to one specimen in which the MSB was

TABLE 1 Visualization scores obtained for each structure during phase 2 with the needle and the Steinmann pin[a]

		Needle		Pin	
Portal	**Structures**	**Total score**	**Mean ± SD**	**Total score**	**Mean ± SD**
Frontal sinus	Ethmoid	30	3 ± 0	30	3 ± 0
	Frontomaxillary opening	29	2.9 ± 0.3	30	3 ± 0
	Caudal cul-de-sac	20	2 ± 0.9	24	2.4 ± 0.9
	Caudomedial aspect of dorsal conchal sinus	19	1.9 ± 0.9	29	2.7 ± 0.7
	Maxillary septal bulla	28	2.8 ± 0.6	30	3 ± 0
	Caudal maxillary sinus, base of ethmoid	30	3 ± 0	30	3 ± 0
	Infraorbital canal	30	3 ± 0	30	3 ± 0
	Tooth roots 11	30	3 ± 0	30	3 ± 0
	Tooth roots 10	29	2.9 ± 0.3	30	3 ± 0
	Caudal cul-de-sac of the caudal maxillary sinus	30	3 ± 0	30	3 ± 0
	Sphenopalatine sinus	28	2.8 ± 0.6	28	2.8 ± 0.6
	Total	303*/330	2.8 ± 0.6	321*/330	2.9 ± 0.4
Caudal maxillary sinus	Ethmoid	30	3 ± 0	30	3 ± 0
	Maxillary septal bulla	26	2.6 ± 0.9	30	3 ± 0
	Frontomaxillary opening	27	2.7 ± 0.6	30	3 ± 0
	Caudal cul-de-sac of the caudal maxillary sinus	30	3 ± 0	30	3 ± 0
	Sphenopalatine sinus	30	3 ± 0	30	3 ± 0
	Tooth roots 11	30	3 ± 0	30	3 ± 0
	Tooth roots 10	28	2.8, ± 0.4	29	2.9 ± 0.3
	Infraorbital canal	30	3 ± 0	30	3 ± 0
	Total	231/240	2.9 ± 0.4	239/240	2.9 ± 0.1
Rostral maxillary sinus	Ventral conchal sinus	23	2.3 ± 0.8	27	2.7 ± 0.5
	Infraorbital canal	27	2.7 ± 0.5	30	3 ± 0
	Maxillary septal bulla	22	2.2 ± 1.1	27	2.7 ± 0.7
	Tooth roots 10	18/18	3 ± 0	18/18	3 ± 0
	Tooth roots 09	29	2.9 ± 0.3	30	3 ± 0
	Tooth roots 08	7/24	0.8 ± 1.4	18/24	2.25 ± 0.9
	Total	108**/162	2.3 ± 1.0	132**/162	2.8 ± 0.5

[a]The maximum score for each structure is 30 (3 × 10 specimens), except for the roots of the 110/210 and of the 108/208 tooth that were not in the rostral maxillary sinus for four cases (maximum score of 18) and for two cases (maximum score of 24), respectively, while performing the rostral maxillary sinus portal.

*$P = .0156$.

**$P = .0234$.

completely vertical and not initially visualized (score = 0) but was completely visualized when the pin was used to enlarge the minisinusotomy. We did not find a difference in scores between the FS and CMS approaches for evaluation of the CMS ($P > .99$ for the minisinusotomy and for the pin).

As with traditional sinoscopy, maneuverability of the endoscope within the RMS was limited due to the smaller size of this sinus and the amount of structures present within it.[5-7] We obtained partial to no visualization of the tooth roots of 108/208 in six cases, of the VCS in two cases, and of the MSB in three cases. Visualization of these structures was improved in all horses after enlarging the portal with a 5-mm Steinmann pin (Table 1). The scores obtained after enlarging the frontal and the rostral maxillary portals with the pin were higher ($P = .0156$ and $P = .0234$, respectively), but this was not the case for the caudal maxillary portal ($P = .250$).

Perforation of the MSB was deemed difficult (specimens 1, 4, 7, 8) or impossible (specimen 6) when the MSB was not protruding through the frontomaxillary opening. Complete visualization of the RMS and/or the VCS after fenestration of the MSB was achieved in only three of nine specimens. After the endoscope was introduced through the perforated MSB,

TABLE 2 Visualization scores obtained for each structure during phase 3 with the needle and the Steinmann pin[a]

Portal	Structures	Total score	Mean ± SD
Frontal sinus	Ethmoid	18	3 ± 0
	Frontomaxillary opening	18	3 ± 0
	Caudal cul-de-sac	9	1.5 ± 0.8
	Caudomedial aspect of dorsal conchal sinus	14	2.3 ± 0.5
	Maxillary septal bulla	18	3 ± 0
	Caudal maxillary sinus, base of ethmoid	18	3 ± 0
	Infraorbital canal	18	3 ± 0
	Tooth roots 11	18	3 ± 0
	Tooth roots 10	17	2.8 ± 0.4
	Caudal cul-de-sac of the caudal maxillary sinus	18	3 ± 0
	Sphenopalatine sinus	18	3 ± 0
	Total	166/198	2.8 ± 0.5
Caudal maxillary sinus	Ethmoid	18	3 ± 0
	Maxillary septal bulla	18	3 ± 0
	Frontomaxillary opening	8	1.3 ± 0.5
	Caudal cul-de-sac of the caudal maxillary sinus	18	3 ± 0
	Sphenopalatine sinus	18	3 ± 0
	Tooth roots 11	18	3 ± 0
	Tooth roots 10	18	3 ± 0
	Infraorbital canal	18	3 ± 0
	Total	134/144	2.8 ± 0.6
Rostral maxillary sinus	Ventral conchal sinus	18	3 ± 0
	Infraorbital canal	18	3 ± 0
	Maxillary septal bulla	18	3 ± 0
	Tooth roots 10	12/12	3 ± 0
	Tooth roots 09	18	3 ± 0
	Tooth roots 08	6/6	3 ± 0
	Total	90/90	3 ± 0

[a]The maximum score for each structure is 18 except for the roots of the 110/210 and of the 108/208 tooth that were not in the rostral maxillary sinus for two cases (maximum score of 12) and for four cases (maximum score of 6), respectively, while performing the rostral maxillary sinus portal.

we were unable to easily direct the endoscope because of the small size of the perforation performed and the lack of a control knob in this device. Because of these limitations, perforation of the MSB was not pursued during phase 3.

Minimally invasive sinoscopy findings were confirmed in all instances after direct visualization of the sinuses via frontal and maxillary bone flaps. No complications were detected during the procedure other than iatrogenic damage of the infraorbital canal in one specimen in which pin entry was performed inappropriately fast.

3.3 | Phase 3

Horses included were four females and two males from various breeds (three paint, two quarter horse, and one Arabian) weighing approximately 500 kg. The mean age was 15 years (range, 13–18).

Scores obtained for the different approaches in phase 3 are presented in Table 2.

A score of 3 (complete visualization) was given for most structures in all horses and validated MIST (Figures 3–4, and 5). Visualization of the FS cul-de-sac was partial in four of six horses, subcomplete in one horse, and complete in one horse. Visualization of the caudomedial aspect of the dorsal conchal sinus was subcomplete in four of six horses and complete in two of six horses.

In agreement with phase 2, there was no difference for the visualization of the structures within the CMS when the FS approach and the CMS approach were compared ($P = .32$). In this regard, the most relevant difference was

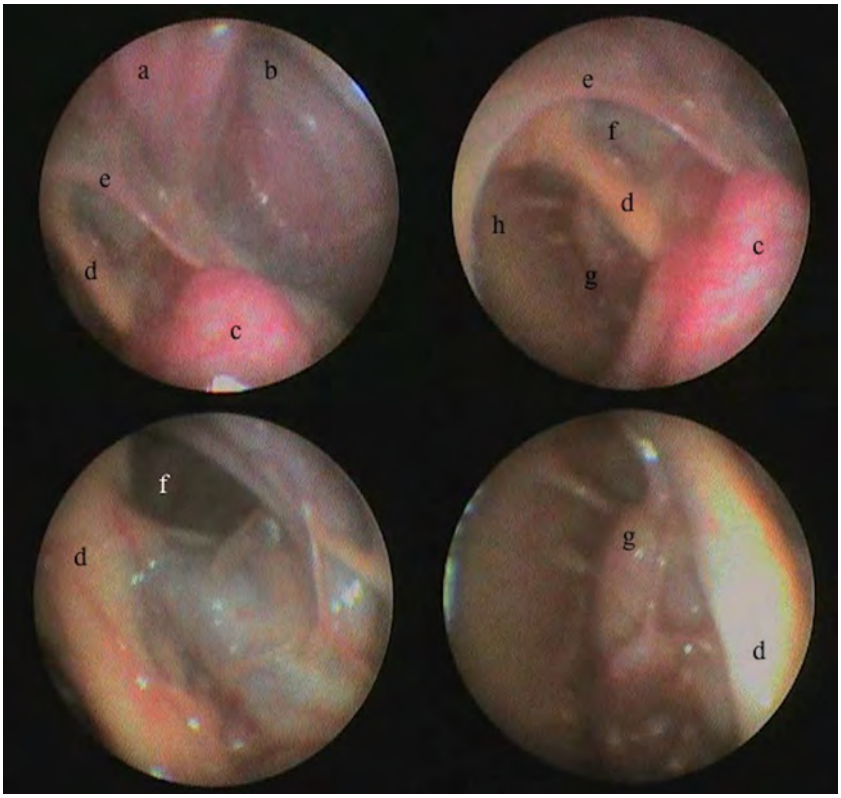

FIGURE 3 Endoscopic images of the structures visualized during minimally invasive sinoscopy in the right frontal sinus of a horse: ethmoid (a), caudal aspect of the dorsal conchal sinus (b), maxillary septal bulla (c), infraorbital canal (d), frontomaxillary opening (e), entrance to the sphenopaltin sinus (f), roots of the 111 tooth (g)

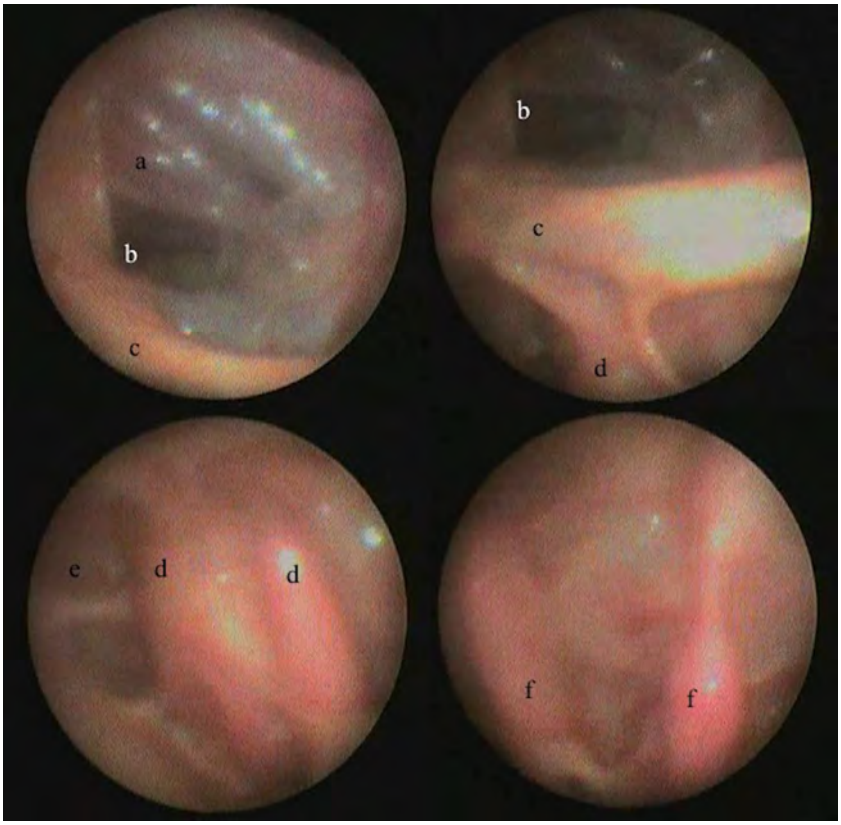

FIGURE 4 Endoscopic images of the structures visualized during minimally invasive sinoscopy in the right caudal maxillary sinus of a horse: ethmoid (a), entrance to the sphenopalatine sinus (b), infraorbital canal (c), roots of the 111 tooth (d), cul-de-sac of the caudal maxillary sinus (e), roots of the 110 tooth (f)

seen in three horses. In these animals, a voluminous MSB prevented visualization of the rostral tooth roots of 110/210 during the FS approach. Also, complete visualization of the frontomaxillary opening was difficult from the CMS approach in most horses because of the inability to remotely rotate the tip of the endoscope dorsally.

In comparison with phase 2, the results obtained for the RMS approach were excellent (score of 3 for all structures

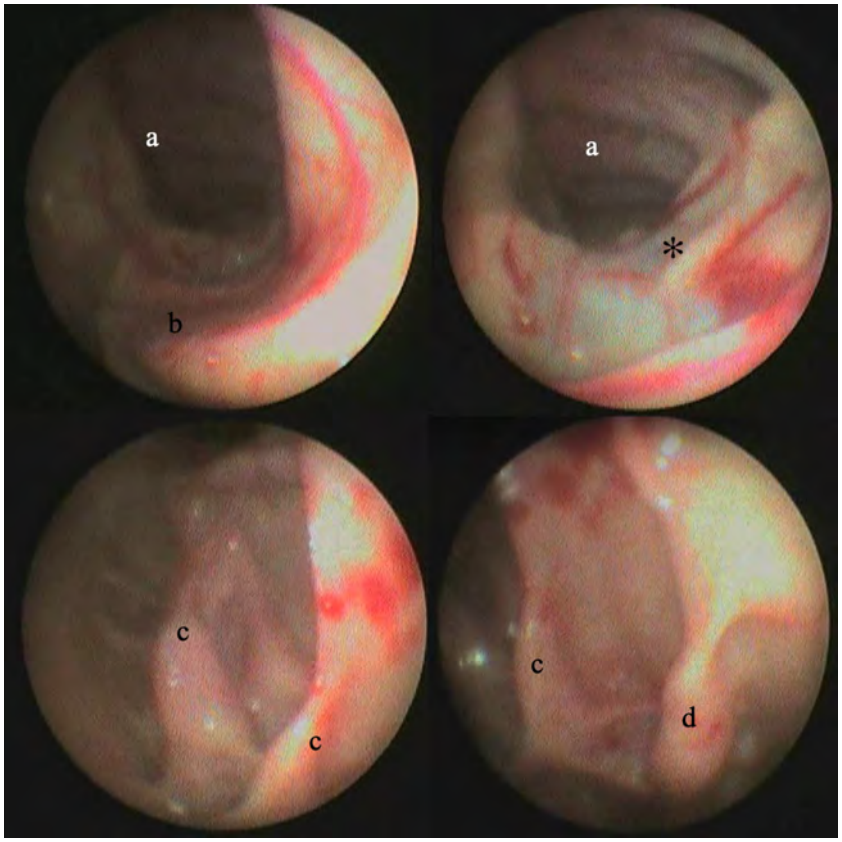

FIGURE 5 Endoscopic images of the structures visualized during minimally invasive sinoscopy in the right rostral maxillary sinus of a horse: ventral conchal sinus (a), infraorbital canal (b), roots of the 109 tooth (c), roots of the 108 tooth (d). Note the mild mucosal petechiation at the level of the rostral roots of 109. This petechiation was seen in some cases after contact of the endoscope was made with the sinus mucosa to clean the lens. Note that the ventral aspect of the ventral conchal sinus is collapsed and covered by mucosa in the upper right image (asterisk). This was commonly seen during phase 3 in healthy horses

within the sinus) for all horses. The most substantial difference was associated with the roots of 108/208. According to results of radiography and sinusoscopy, the roots of 108/208 were inside the RMS in two of six horses and visible with MIST in both of them. In contrast, the roots of 108/208 were inside the RMS according to radiography in eight of ten specimens in phase 2 and visible after needle minisinusotomy in only three of eight heads. In addition, the roots of 110/210 were only within the CMS in two of six horses; so they were not visible with the RMS approach in those two horses.

The complete MIST took 34.2 ± 5.8 minutes to perform. Manipulation of the endoscope was deemed easy in all cases, and the procedure was well tolerated in all horses. Fogging or darkening of the field of view was quickly resolved when encountered by contacting an adjacent mucosal surface or by cleaning the endoscope tip and reintroducing it. No personnel or equipment damage occurred.

No intraoperative complications were noted during the procedures other than mild petechiation in the RMS mucosa in three of six horses. This was believed to be associated with contact of the endoscope with the sinus mucosa to clean the endoscopic lens (Figure 5). All horses developed mild (2-cm diameter or less) subcutaneous emphysema at the level of the minisinusotomies within a few hours of the procedure that lasted between 12 and 24 hours. In one horse, moderate emphysema (4-cm diameter around the RMS minisinusotomy) extended rostrally and ventrally after MIST and persisted for 72 hours. Bandages were removed 48 hours after the procedure, and, at that time, all incisions were healing normally. The cosmetic appearance was considered excellent for all horses except one. This horse developed local thickening (1.5 × 1.5 cm) at the FS minisinusotomy, which resolved after 2 weeks. No signs of sinus or incisional infection were noted postoperatively.

One horse was euthanized 20 days after the procedure for reasons unrelated to the study. At necropsy, we identified partial healing of the minisinusotomies with fibrous tissue and a 2-mm circular rim of bone remodeling at the internal surface of the perforated bones.

4 | DISCUSSION

This report describes the use of a novel 2-mm endoscope to perform minimally invasive sinoscopy in standing horses through a minisinusotomy performed with a 14 gauge needle. The minisinusotomy itself is easy to perform and does not require special expertise or instrumentation. However, in-depth knowledge of sinus anatomy is required to perform and interpret the sinoscopic images obtained with MIST. The first phase of the study allowed development of accurate landmarks to perform MIST. The use of an endoscope without a control knob through a small entry point required precise landmarks

to maximize sinus visualization. Subsequent phases validated the use of MIST in cadaveric heads and healthy horses. The flexible endoscope was easy to manipulate and allowed a rapid evaluation (approximately 30 minutes) of the paranasal sinus without significant complications.

The use of MIST allowed exhaustive visualization of most structures from all approaches except the RMS in phase 2. Visualization difficulties on the RMS approach were eliminated when a 5-mm Steinmann pin was used. This technique could be used in cases in which visualization of any structure is insufficient or when minisinusotomy location is suboptimal. However, this difference was not observed during phase 3. First, the bone was softer in live horses, which facilitated further enlargement of the minisinusotomy hole by circular movement of the 14 gauge needle. This enlargement created more room to manipulate the endoscope and hence, allowed better visualization of the different structures. Second, we determined the presence of 108/208 tooth roots inside the RMS in two of six horses by radiography and sinoscopy. We are unaware of any reports describing the accuracy of radiography in detecting the presence of 108/208 within the RMS, but, intuitively, it should be high. In fact, radiographic determination for accurate placement of a trephine portal within the RMS is between 93% and 100%.[7] Visualization of 108/208 has been independently proved to be challenging even during traditional sinoscopy (their presence within the RMS is variable and age dependent) and often is of limited diagnostic value compared to CT.[4,10] A visualization success rate of 29% to 65% was reported by Perkins et al[7] when different portals to access the RMS were investigated. These authors also reported that the RMS portals provided poor visibility (0%–13%) of the VCS due to interference from the infraorbital canal and the cheek tooth roots. Accurate portal location and the small size and flexibility of our endoscope may have allowed us to navigate over the infraorbital canal more easily than previously reported. We also did not experience any interference issues with the tooth roots, but, unlike Perkins and colleagues,[7] we used horses only older than five years.

No specific attempts were made to explore the FS from the CMS approach, although we anticipate that it could be difficult due to intrinsic limitations of the endoscope (absence of control knob). No difference between the CMS and the FS approach to explore the CMS was noted. In addition, the differences found in phase 2 between the minisinusotomy and the pin hole for the FS approach were considered not clinically relevant. Because of that and the previously mentioned ease to enlarge the minisinusotomy with circular movements of the 14 gauge needle in live horses, only the minisinusotomy was performed in phase 3. Results from phase 3 (Table 2) provided evidence that the use of MIST through an FS and RMS approach should suffice for exploration of the ensemble of the paranasal sinuses, so most horses will require only two minisinusotomies. Nevertheless, use of the CMS approach should not be completely discarded and could be used on a case-by-case basis. For example, it was beneficial to visualize the rostral roots of 110/210 in the three specimens with a voluminous MSB.

In phase 2, the MSB was perforated to access the RMS because it has been associated with improving visualization of most structures within the RMS and VCS.[7] In agreement with other studies, we found that the MSB varied in shape and size among horses and that lack of protrusion through the frontomaxillary opening will render perforation of the MSB difficult to impossible.[7,11] In the few cases in which optimal perforation was achieved, visualization of the VCS and the RMS was inconsistent, so we cannot recommend this approach without additional investigation.

Nasal and paranasal mucosa is well vascularized, and damage can lead to profuse bleeding and visualization issues.[12] This bleeding could be exacerbated in horses affected by sinus pathology when the sinus mucosa is inflamed.[11] In an effort to promote clotting and minimize bleeding inside the sinuses, the needle minisinusotomies to the FS, CMS, and RMS were performed sequentially before performing MIST through each sinusotomy (FS, then CMS, and finally RMS). This technique was successful in preventing bleeding in healthy animals and has yielded positive results in three clinical cases in which the technique has been performed. In those clinical cases, bleeding was not problematic, and MIST obtained a clear diagnosis that guided targeted treatment through a trephine hole or a bone flap.

Only minor complications (emphysema and mucosal petechiation) occurred during phase 3. As previously reported, emphysema occurred in all cases after sinoscopy and resolved spontaneously within a few days.[13] Other complications commonly associated with sinoscopy, such as wound infection, bone sequestrum, or suture exostosis, did not occur and are unlikely to occur with MIST, considering the reduced invasiveness of the technique.[12] We also recommend gentle needle insertion while performing the minisinusotomy of the RMS; this will prevent iatrogenic damage to the infraorbital canal, which is located close to the maxillary bone at this level. Cosmetic outcome was excellent in all horses, and only one horse developed temporary thickening at a single minisinusotomy site. No sinus infection was seen postoperatively despite the lack of sterilization of the endoscope between horses; only alcohol cleaning was performed between patients. However, sterilization is recommended when treating clinical animals with the presence of infection.

Minimally invasive sinoscopy was proposed as a diagnostic tool for horses with sinus disease, but, as traditional sinoscopy, it could also be employed to assist during

treatment. Minisinusotomy can be used to perform sinus lavage, and we routinely use it at our institution for this purpose. In addition, MIST could be used to perform endoscopically guided trephine holes to treat a specific lesion or to perform endoscopically guided tooth repulsion. Nonetheless, and as previously mentioned for the three clinical cases in which MIST has been used, MIST will likely require a more invasive follow-up procedure such as bone flap or a larger trephination (10–20-mm diameter) to successfully treat the sinus pathology, although, less often, this can also occur with traditional sinoscopy.

Several limitations, mainly associated to the 2-mm endoscope, are present in our study. First, the flexible endoscope lacks a control knob, and, although it can be guided manually, the tip of the endoscope cannot be remotely bent after it is inside the sinus. This feature may limit the visualization of the lateral roots of 109/209 and can make visualization of the most ventral aspect of the VCS impossible. However, we found that, in healthy horses, the ventral aspect of the VCS is often collapsed and cannot be easily accessed (Figure 3). In addition, this lack of remote maneuverability also limits the possibility of reliably performing upper airway endoscopy or accessing the sinuses directly through the nasomaxillary opening without the requirement of a trephination. Second, the field of view is smaller than a 10-mm endoscope, which will require some adaptation for the new user; however, the learning curve is not steep. Third, the endoscope is not equipped with an instrument portal or a flushing system, but cleaning of the lens during the procedure was rapidly performed and was not considered problematic. However, this could be an issue in clinical cases despite the lack of visibility problems seen in the three clinical cases until now. Furthermore, the creation of a second portal for suction/irrigation could also be beneficial to improve visibility when exudate in the sinuses is present in clinical cases. Finally, sinoscopic grading was not blinded because of the difficulty in finding an observer familiar with the images obtained with this novel endoscope, so a bias effect may have played a role. In an effort to prevent bias, grading of all structures was agreed between both authors, and confirmation of sinoscopic visualization was obtained after performing a bone flap in phase 2. The same could not be performed in phase 3 because the animals were enrolled in another study.

It was not our objective to directly compare our technique with traditional sinoscopy because both techniques offer different benefits/limitations associated with the different endoscopes used for each one. Minimally invasive sinoscopy should be considered an adjunctive modality, not replacement for CT as the current gold standard to diagnose sinus pathology. At this point, MIST should be considered as another tool for the diagnosis of paranasal disease until further studies with clinical cases can determine whether it is a suitable alternative to traditional sinoscopy. Therefore, we decided to use direct anatomic visualization of the sinuses (gold standard) via bone flap as a control group in phase 2 rather than traditional sinoscopy to prevent identification errors and validate the technique in cadavers. The degree of sinus visualization obtained with sinoscopy greatly depends on the size of the endoscope used, the location of the trephination, and the experience and anatomic knowledge of the operator, which could have introduced a new bias to the study.

Small-diameter flexible veterinary endoscopes with a control knob, flush port, and instrument channel are currently available in the market, and their use could bypass the limitations present in the device used in this study. However, they are expensive, and the smallest one available has a 3-mm external diameter which would not fit through our minisinusotomy portal. Standard endoscopes for pediatrics or ureteroscopy in human medicine can reach up to 1.8-mm external diameter and could be used with MIST, but, unfortunately, these devices are both expensive and fragile, and procedure cost is a major concern. During the past 5 years, several studies comparing the repair cost of small endoscopic equipment have been published in the human literature.[14,15] These reports concluded that maintenance and repair costs associated with ureteroscopes are between $355 and $605 per case, which would not be cost effective in veterinary medicine. The 2-mm endoscope used in this study performed well for at least 10 uses, but we anticipate that it has a limited life span. Thus, it can be considered as a limited-life reusable endoscope, combining the advantages of being less expensive ($595) than a standard reusable endoscope and not requiring maintenance and/or repair costs.

In summary, MIST is a diagnostic alternative to traditional sinoscopy that offers the advantage of being portable, less invasive, rapid, and lower cost, although a special endoscope is required. Currently, MIST is described as a diagnostic tool, but additional modalities (three-dimensional imaging or traditional sinoscopy) are required when unclear results are obtained with MIST. In addition, MIST could assist treatment by providing information regarding the ideal location for treatment portals (trephine or flap). We are currently conducting a prospective clinical study to determine the benefits and limitations of MIST in clinical cases.

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CONFLICT OF INTEREST

The authors declare no financial or other conflicts of interest related to this report or to BioVision.

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