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Maxillary sinus-floor elevation: an animal model

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Abstract

Objectives: To find an animal model for modified Caldwell–Luc procedure training. The animal model should have (1) a proper cortical thickness in the lateral wall; (2) a similar morphology and resistance of the Schneiderian membrane in humans; and, finally, (3) an oral approach.

Materials and methods: Twelve fresh heads (four Merino sheep, four Murciano–Granadina goats and four Large–White pigs). Two skulls from each of these species were also used. Several three-dimensional imagings from the skulls of each species were acquired using a C-arm. Two fresh heads of each species were used to perform the modified Caldwell–Luc procedure. Two fresh heads of each species were firstly frozen at −30°C for 48 h and then sawed in blocks containing only the target region of the maxillary sinus.

Results: The average thickness was 2.03 mm in goat and sheep and 2.80 in pig. Releasing and elevation of the Schneiderian membrane from the sinus floor were easy in the three species. The approach of the maxillary sinus in sheep, goat and pig from the buccal vestibule required a previous surgical enlargement of the buccal vestibule.

Conclusions: In conclusion, the cortical bone thickness and Schneider membrane characteristics in Merina sheep and Murciano–Granadina goat allow a perfect training for the modified Caldwell–Luc procedure. However, the approach from the oral cavity needs, in these species, a previous enlargement of the buccal vestibule. The excessive thickness of the cortical bone restricts the use of pigs for this technique.

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The advanced atrophy of the maxilla and the subsequent pneumatisation of the maxillary sinus imply a challenge for the implant rehabilitation (Roldan et al. 2004). The sinus-floor elevation procedure was developed to solve this problem and to allow making dental implants in areas where the bone is thinner than 4 mm (Misch 1987). This technique, known as the modified Caldwell–Luc procedure (Tatum 1986), tries to enter into the maxillary sinus through the lateral wall, release the Schneiderian membrane and elevate it from the sinus floor in order to obtain a larger place between them and to place the dental implant (Martín Villa 2005). This procedure requires a previous training, but up to now, no articles have been found to compare the different anatomical morphologies in the domestic species to conclude which one is the best model. Some authors have made reference to animal models like sheep (Brumund et al. 2004), rabbit (Benninger et al. 1993; Forsgren et al. 1993; Watanabe et al. 1999; Asai et al. 2002), goat (Nevins et al. 1996) and monkeys

(Hanisch et al. 1997; Kirker-Head et al. 1997).

The maxillary sinuses are paranasal cavities lined with a pseudostratified, ciliated columnar epithelium, known as the Schneiderian membrane. Their development does not end at birth; they continue to grow for some time, until the complete eruption of permanent teeth. In the pig, the maxillary sinus is situated within the maxilla and zygomatic bones, and it consists of one cranial and another caudal part. It is connected to the middle meatus of the nasal cavity by means of the nasomaxillary aperture. In the ruminants, the sinus lies between the maxilla and zygomatic bone and the bulla lacrimalis. The maxillary sinus and the palatine sinus are diverticula of the middle nasal meatus and they communicate directly with the nasal cavity through the nasomaxillary aperture (Schummer et al. 1978).

The purpose of this study was to find an animal model for a modified Caldwell–Luc procedure training. The animal model should have (1) a proper cortical thickness in the lateral wall; (2) a similar morphology and resistance of the Schneiderian membrane in humans; and, finally, (3) an oral approach. Different dissections and anatomical sections were made to achieve this in the pig, sheep and goat.

Material and methods

Twelve fresh heads (four Merino sheep, four Murciano–Granadina goats and four Large–White pigs) obtained from the slaughterhouse were used for this study. Two skulls from each of those species were also used. Both the heads and the skulls were from adult animals (older than 24 months) with a complete growth of the permanent teeth and free of nasosinusal pathologies.

Several three-dimensional (3D) imagings from the skulls of each species were acquired using a C-arm (BV Pulsera 3D-RX Option, Philips S. A., Eindhoven, The Netherlands). The C-arm rotates continuously through 200° for 30 s while acquiring a large set of 450 high-definition fluoroscopic images. The complete set of images was integrated to create a high-quality 3D volume reconstruction, and to identify the main landmarks to the subsequent surgical approach. With these anatomical references, skulls from each species underwent a maxillary sinus trepanation.

Two fresh heads of each species were used to perform the modified Caldwell–Luc procedure within 24 h of euthanasia to minimise post-mortem changes. After dissection and maxillary sinus trepanation, a stereoscopic magnifying lens (Zeiss Stemi 2000-C, Frankfurt, Germany) and rhinoscopy (Fuji 4.9 mm diameter EB-410S Bronchoscope. ST-Endoscopia, Madrid, Spain) were used to assess the Schneiderian membrane.

Two fresh heads of each species were firstly frozen at −30°C for 48 h and then sawed in blocks containing only the target region of the maxillary sinus. These blocks were frozen at −70°C for 1 week. Ten cross-sections from each head were obtained using a high-speed band saw. Transverse cryosections were studied and photographed using the stereoscopic magnifying lens.

Results

3D reconstruction of the maxillary sinus and, subsequently, of the skulls allow one to identify the main radiographic landmarks and to relate them to the anatomical landmarks in order to make the subsequent surgical approach for the sinus trepanation easy (Fig. 1). In sheep and goat, the maxillary sinus showed a small mediodorsal part and a large ventrolateral part, incompletely separated by the infraorbital canal. The dorsal part was small and extended to the rostral end of the sinus (Fig. 1b and video 1). Caudally, the sinus became larger and connected to the palatinus sinus, placed on the medial side of the infraorbital canal. The ventral edge of the maxillary sinus extended from the orbit to the facial tuber. It then continued rostrally to a point midway between the facial tuber and the infraorbital foramen (Fig. 1b and video 1).

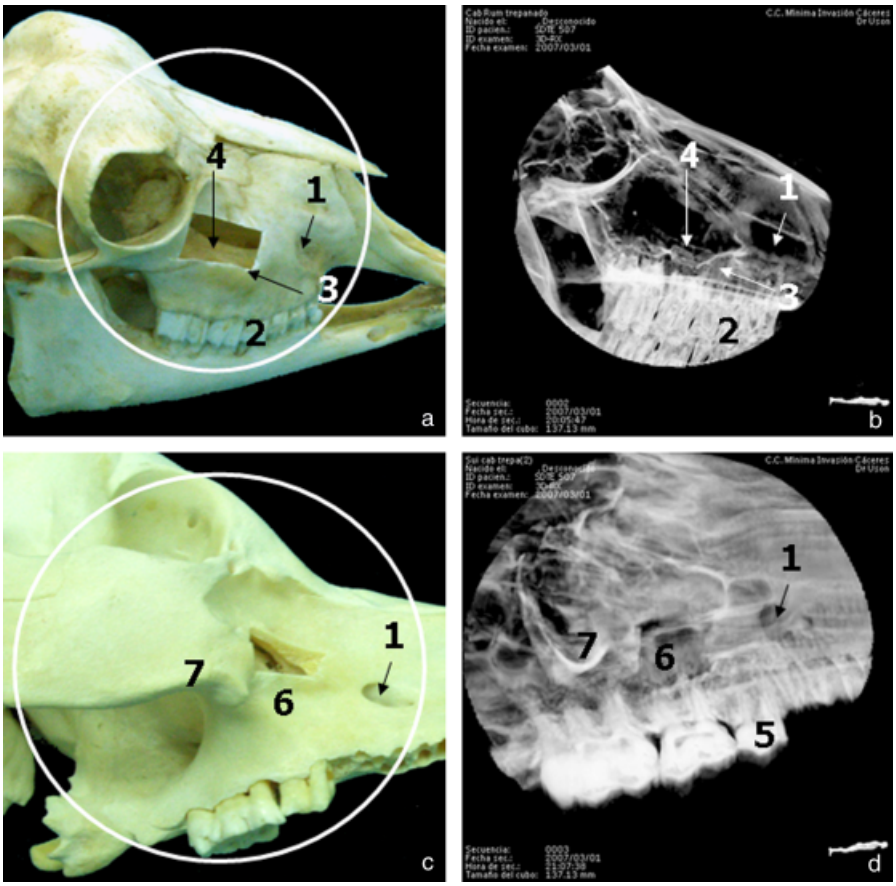

Fig. 1. Images of skulls with maxillary sinus trepanation. (a) Sheep's skull with the anatomical landmarks for sinus trepanation. (b) Fluoroscopic image of previous skull. (c) Pig's skull with anatomical landmarks. D: Fluoroscopic image of previous skull. 1. Infraorbital foramen, 2. second molar, 3. facial tuber, 4. infraorbital canal, 5. third molar, 6. Canina fosa, 7. zygomatic arch.
Video 1. Fluoroscopy 3-dimensional reconstruction from Fig. 1a. (see Supporting information).
Video 2. Fluoroscopy 3-dimensional reconstruction from Fig. 1c. (see Supporting information).

The accurate references in sheep and goat to perform the modified Caldwell–Luc procedure are 1 cm caudal and 1 cm dorsal to the facial tuber (Fig. 1a and b, Video 1). However, in pig, the sinus lies ventral to the orbit in the base of the zygomatic arch, but the absence of maxillary sinus rostral to the orbit had been noted. The third upper molar (M3) and facial crest were the references in pig to perform an oral approach to the sinus. (Fig. 1c and d, Video 2).

3D images showed the main radiographic landmarks. In sheep and goat, the outline of the sinus was represented by a radio-paque line. The infraorbital foramen was a radiolucent area close to the rostral limit of the sinus. Between the ventral limit of the sinus and the infraorbital foramen, a radiopaque area corresponded with the facial tuber. Ventrally, molar roots showed a high radiographic density, using the second upper molar as a landmark. Caudally, the sinus was delimited by a radiopaque bend line that represented the ventral orbit limit. In pigs, the same landmarks were found but the rostral limit of the sinus was marked by a point between the infraorbital foramen and the canina fosa that corresponded with the third upper molar. In general, radiodensity was higher in pigs than in sheep.

The approach of the maxillary sinus in sheep and goat from the buccal vestibule required a previous surgical preparation because of the small size of the mouth, which just allowed reaching the first molar. After shaving the external maxillary sinus area, the buccal vestibule was exposed over a 2-cm skin incision led caudally from the angle of the mouth to the second molar (Fig. 2a). Another perpendicular, dorsal, 2-cm incision was connected at the end of the other one. A mucocutaneous flap was raised after incision and the outer surface (facies facialis) of the maxilla and the origin of the masseter muscle were fully exposed (Fig. 2b). Using as a reference the facial tuber and the second molar (2 M), the trepanation was carried out. The masseter muscle was detached at the site of origin. A bur was used to create a bone window sized 1 × 1 cm and to expose the intact Schneiderian membrane (Fig. 2c). Care was taken during this procedure to avoid damage to the sinus membrane. Cortical bone resistance was suitable for trepanising the maxilla.

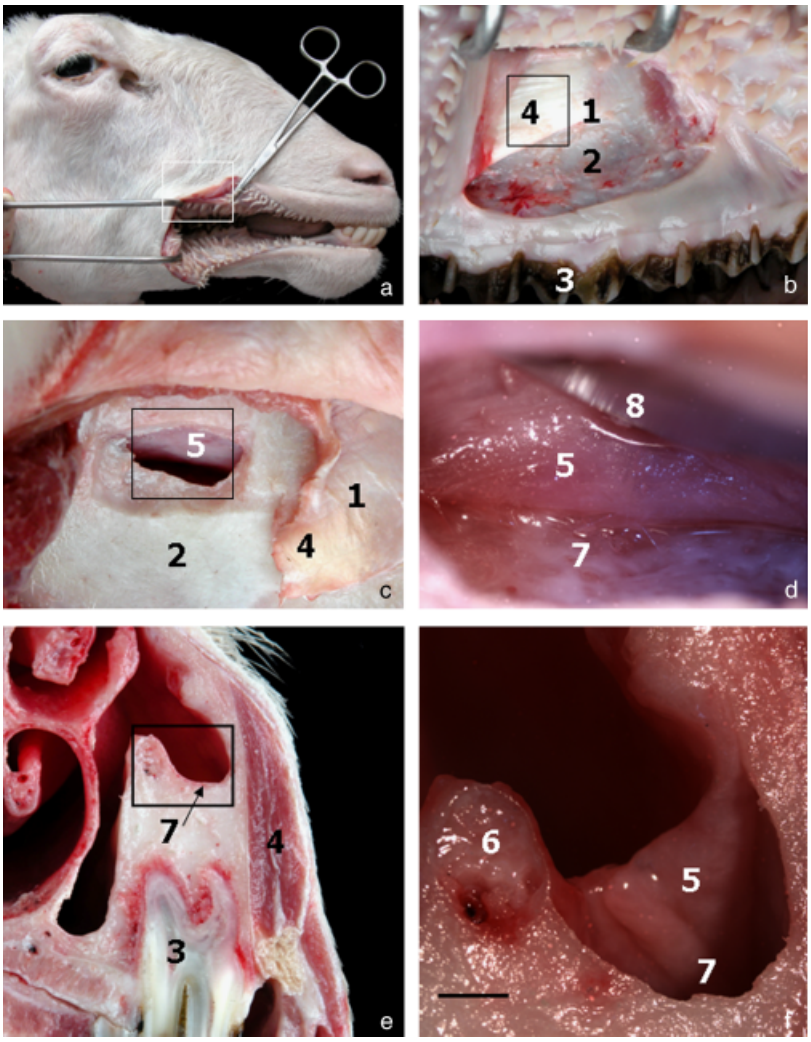

Fig. 2. (a–d): Modified Cadwell–Luc procedure in sheep. (a) Skin incision from the angle of the mouth to the second molar. (b) Magnification from the square in the previous image, dissection of origin tendon of the masseter muscle. (c) Magnification from the square in the previous image, maxillary sinus trepanation. (d) Magnification from the square in the previous image, antral membrane displaced dorsocranially with a blunt dissector. (e) Transverse cryosecctions at the level of the second molar. (f) Magnification from the square in the previous image, sinus mucosa elevated from the sinus floor. 1. Facial tuber, 2. maxilla bone, 3. second molar, 4. maseter muscle, 5. sinus mucosa, 6. infraorbital canal, 7. floor of the maxillary sinus and 8. blunt dissector. Scale magnification corresponds to 1 cm in c and e and to 2 mm in d and f.

The approach in the Large–White pig also required a previous surgical preparation. After shaving the surgical field, a skin incision from the angle of the mouth to the third upper molar was needed. The masseter muscle arises from the facial crest and the lower margin of the zygomatic arch. Using both structures as a reference, trepanation was carried out. The muscle was detached and a bone window was created with a bur. Because of the cortical resistance, the time was twice that in sheep and goat.

After sinus trepanation, the antral membrane was elevated from the bony wall and displaced dorsocranially with blunt dissectors (Fig. 2d). Release and elevation of the Schneiderian membrane from the sinus floor were easy in the three species. The stereoscopic images and rhinoscopy examination showed the intact mucosa after releasing it from the bone.

Assessment of the cortical bone thickness in the lateral wall of the maxillary sinus was carried out using the cross-sections of the frozen heads (Fig. 2e and f). The anatomic reference to carry out the sections was the second upper molar in goat and sheep, and the third upper molar in pig. The thickness values were 2.15 and 1.92 mm in goat, 2.1 and 1.95 mm in sheep and 3.1 and 2.6 mm in pig. The distance

values between the ventral limit of the sinus and the buccal vestibule were 1.4 and 1.6 cm in goat, 2.1 and 2.3 cm in sheep and 3.4 and 3 cm in pig.

Discussion

In the study, the Merino sheep, the Murciano–Granadina goat and the Large–White pig were assessed in order to find an animal model to practice the modified Caldwell–Luc procedure orally. We have studied in depth the cortical bone thickness in the lateral wall of the maxillary sinus, the characteristics of the Schneiderian membrane and the surgical approach to the sinus.

Cortical bone thickness in the lateral wall is important to create a bone window because of the resistance. Up to now, no authors have studied this aspect. A thin cortical bone is necessary due to two main reasons: the animal model is to be used in teaching, and so it must be easy to reach the antrum; on the other hand, human cortical is very thin in edentulous patients, even transparent with a deep light. In our results, goat and sheep bone cortical was easy to trepanise with a surgical bur. The pig had a cortical bone that was very resistant and difficult to trepanise.

On the other hand, the sinus mucosa had enough consistency to carry out this technique, in sheep, goat and pigs even after freezing. Wetzel et al. (1995) and Lee et al. (2007) performed sinus-floor augmentation on several dogs and reported that the sinus membranes were found to be intact. However, Haas et al. (1998a, 1998b) have suggested that the Wetzel experiment is not comparable with sinus lift surgery in human subjects because the nasal sinus of dogs differs significantly from the human maxillary sinus in that it lacks the Schneiderian membrane and does not undergo pneumatisation. These reasons and other ethical and economic reasons confer a secondary role to the dog as a model in this technique. These economics and ethical reasons eliminate monkeys as an animal model in order to practice the procedure, in spite of being the most similar species to humans.

A similar topography and approach to the Highmore antrum or maxillary sinus in humans is also important. In sheep and goats, both of them ruminants, the ventral limit of the sinus is located distant from the buccal vestibule. The cheek teeth of the ruminants are of the hypsodont type and continue growing for some time after eruption because of the kind of feeding. This leads to a continuous growth of teeth that have a very long root, which moves the floor of the sinus dorsally. As they begin to wear, the loss of substance on the occlusal surface is compensated for, first, a true longitudinal growth at the proximal end of the tooth and, later, as growth ceases, by gradual advancement from their sockets (Schummer et al. 1978). These results are different from those obtained by Brumund et al. (2004), who reported that sheep are a useful animal model because both the general nasal anatomy and the paranasal sinus anatomy are similar to humans in appearance and orientation. In pigs, the maxillary sinus is located caudally, even located in the zygomatic bone in adult animals. It is also a smaller cavity than in sheep and goats. Therefore, the surgical approach is not possible as it is usually practiced in humans, where the access is through the mouth, because the projection field of the sinus in these animals is, at least, 2 cm dorsally and 2 cm caudally from the oral cleft. Although it is possible to perform this technique after preparing the surgical field and widening the oral cleft caudally and dorsally, up to now, a lot of authors have described an extra-oral approach of the maxillary sinus in other animal species such as minipigs (Fürst et al. 2003; Roldan et al. 2004), sheep (Haas et al. 1998a, 1998b, 2002; Jakse et al. 2003; Brumund et al. 2004), goats (Bravetti et al. 1998) and dogs (Wetzel et al. 1995; Lee et al. 2007) in order to assess different materials to sinus grafts, but nobody makes reference to an oral approach like humans.

In conclusion, the cortical bone thickness and Schneider membrane characteristics in Merina sheep and Murciano–Granadina goat allow a perfect training for the modified Caldwell–Luc procedure. However, the approach from the oral cavity requires, in these species, a previous enlargement of the buccal vestibule, as we described above. The excessive thickness of the cortical bone restricts the use of pigs for this technique.

Further studies using a wider range of animals and breeds are necessary in order to rule out intra- and interbreed variations.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Video 1. Fluoroscopy 3-dimensional reconstruction from Fig. 1a.

Video 2. Fluoroscopy 3-dimensional reconstruction from Fig. 1c.

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