Goat Model for Direct Visualizing the Effectiveness of Detaching Sinus Mucosa in Real Time During Crestal Maxillary Sinus Floor Elevation

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The procedure of crestal maxillary sinus floor elevation presents a great challenge to the field of implant dentistry. Due to the limited visualization in this procedure, the effectiveness of detaching sinus mucosa could not be assessed in real time. We recently developed an ex vivo goat sinus model by cutting the goat residual skulls along four lines determined from computerized tomography (CT) scans, extracting the maxillary premolar or molar teeth, and preparing implant socket in the maxilla. The generated ex vivo goat sinus models exposed the maxilla and the whole maxillary sinus mucosa, thus enabling real-time observation of detaching maxillary sinus mucosa via directly visualizing the working situation of sinus lift tool in the models and directly measuring the length of detached mucosa and space volume generated under the elevated sinus mucosa. One commercially available umbrella-shaped sinus lift curette was used to detach the maxillary sinus mucosa to evaluate the effectiveness of the ex vivo goat sinus models. The results showed that this curette could detach the sinus mucosa 3.75 mm in length in the mesiodistal direction and 2.81 mm in the buccal-palatal direction. Moreover, a space volume of 52.7 \( \mu l \) could be created under the elevated sinus mucosa in the goat ex vivo models. All the experimental results suggested that this ex vivo goat sinus model might be useful in the evaluation of improved or newly designed sinus lift tools for elevating the maxillary sinus mucosa via the crestal approach.

Key words: maxillary sinus mucosa, ex vivo model, crestal, detaching

INTRODUCTION

Edentulism is a persistent public health problem due to poor oral care and an aging population. The prevalence of edentulism among seniors is estimated to be 26% in the United States, 15%–78% in Europe, 24% in Indonesia, 11% in China, and 23% in Brazil. Edentulism seriously affects the quality of life and nutrition intake of the patients. Dental implants are among the main dental prosthetic restorations for edentulous patients. However, when the maxillary posterior teeth are lost, the height and width of related alveolar bone gradually decrease due to normal bone resorptive processes. This insufficient maxillary bone could limit successful dental implantation and reliable implant fixation in the jawbone. In these cases, bone regeneration or augmentation is required for successful dental implantation. Among the techniques used in clinical practice, a crestal maxillary sinus floor elevation offers a less invasive solution to dental implantation at edentulous posterior maxilla via bone augmentation. Sinus lift procedures provides a sufficient amount of bone under the elevated maxillary sinus mucosa. During the procedure, maxillary sinus mucosa is detached from the inner bone walls after the transcrestal access to the maxillary sinus mucosa is completed at the edentulous posterior maxilla. The resulting space created under the lifted maxillary sinus mucosa may be filled with autograft, allograft, or xenograft. It has been recognized that the implant survival rates depend on the successful maxillary sinus floor elevation with sufficient height and lack of a perforation of the maxillary sinus mucosa. However, although significant efforts have been made to improve the techniques and design novel tools for crestal maxillary sinus elevation, maxillary sinus membrane perforation is the most common complication for maxillary sinus
floor elevation.\textsuperscript{8,13,14} Recently, we have been designing novel tools for better detaching the maxillary sinus mucosa.\textsuperscript{15,16}

Ex vivo animal models with the capability of real-time direct visualization have great advantages in the evaluation of the effectiveness of improved or newly designed tools.\textsuperscript{17,18} Selection of the proper animal model is crucial to evaluating novel technologies and new materials designed for clinical applications.\textsuperscript{19}

The pyramid-shaped maxillary sinus in humans is the largest paranasal sinus cavity with a volume of 12–15 cm\textsuperscript{3}. Its base is the lateral nasal wall with its apex pointing toward the zygomatic process of the maxilla; its roof is the maxillary orbit; its anterior wall is the facial surface of the maxilla, forming the maxillary tuberosity and pterygopalatine fossa; its posterior wall is the infratemporal surface of the maxilla, separating temporal fossa and maxillary sinus, and its floor is the alveolar process of the maxilla. Pigs,\textsuperscript{18} sheep,\textsuperscript{20} rabbits,\textsuperscript{21–24} beagle dogs,\textsuperscript{25–27} and goats\textsuperscript{28,30} are frequently used as the experimental animals both ex vivo and in vivo in the preclinical studies of maxillary sinus elevation to evaluate the tools, techniques, and bone-grafting materials. Among these experimental animals, primates have maxillary sinus morphology and maxillary sinus floor mucosa properties that are most similar to those in humans. Therefore, primate animals should be the first choice as the experimental animals for sinus lift studies. That said, it is relatively difficult to obtain such primate animals. However, it has been found that the maxillary sinuses in goats are located similarly as in humans.\textsuperscript{31–33} The cortical bone of the goat sinus floor has been found to be similar in thickness and structures to that in posterior edentulous patients. Studies using light microscope have shown that goat maxillary sinus mucosa is composed of mucoperiosteum that includes three layers, namely, epithelium, lamina propria, and periosteum. The epithelium is pseudostratified ciliated columnar epithelium, lamina propria is a loose connective tissue, and visible glands and blood vessels and periosteum are dense connective tissues. The exception is that a goat’s maxillary sinus mucous membrane has a thickness of 0.9 mm, while the thickness of human maxillary sinus mucosa is 0.8 mm. As compared with human beings, goats generally have a slightly smaller mesial-distal slope and a relatively larger buccal-palatal slope in the maxillary sinus floor. Therefore, goats are suitable for use as large experimental animal models in maxillary sinus mucosa floor elevation in both macroscopical and microscopical aspects.

In this study, we aimed to develop ex vivo the goat sinus model for the purpose of directly visualizing the effectiveness of detaching maxillary sinus mucosa in real time during sinus lift via the crestal approach. Herein, we report the establishment and preliminary evaluation of the ex vivo goat sinus model.

**Materials and Methods**

The tools and instruments used included bone saw (Tianjin Yutong Medical Instruments, Tianjin, China), osteotome instruments (Kelor, Germany), Philips 256-slice Brilliance CT, CV MM-II portable dental micromotor (Fushan, China), emery grinding needle (Rufeng Diamond Grinding Materials and Grinding Tool Co, Linyi, Shandong, China), and umbrella-shaped sinus lift curette (Model #YSL-04, MTC, Seoul, Korea). This curette had two end tips, end tip a\textsubscript{1} (4.0 mm in diameter) and end tip a\textsubscript{2} (4.0 mm long bent tip), and a stem right beneath the curette tips (1.5 mm in diameter; Figure 1).

Twenty-four 1.5–2-year-old goats (male or female, 20–30 kg) were purchased from the Animal Experimental Center at the First Affiliated hospital of PLA General Hospital. They were ensured to be healthy with fully developed maxilla and without maxillary sinus diseases. They were housed at 20°C and under close daily observation for 1 week before killing to ensure the effectiveness of generated goat ex vivo models. Only goats in generally good condition were used to generate the goat ex vivo models. The animal protocol was approved by Institutional Animal Care and Use Committee of First Affiliated Hospital of PLA General Hospital.

The goats were killed in the animal laboratory to obtain the entire heads. After cleaning, the goat heads (Figure 2a) were scanned using a CT to determine the locations for cutting to avoid destruction of the maxillary sinus mucosa and to limit maxilla size in the generated models. The maxillofacial soft tissues were separated from the hard tissues after the CT scans, and the mandibles were removed using a bone saw (Figure 2b). Four lines were marked on the residual skulls: 1) 1 straight up-and-down line that was 5–6 cm away from the nose tip; 2) 1 straight line that was above the occlusal plane, 2 cm away from the maxillary alveolar ridge and parallel to the alveolar ridge; 3) a horizontal straight line that was below the orbital rim; and 4) a straight up-and-down line formed by connecting the rear edge of the maxilla and the rear orbital margin (Figures 2c through f). Cuts were made along the four mark lines using a bone saw to obtain the primary model (Figures 2g and h). The maxillary premolar or molar was extracted from the primary model, and the implant socket was prepared in the maxilla by simulating the clinical procedure of crestal maxillary sinus floor elevation until reaching the position of 1–2 mm beneath the maxillary sinus floor. The last 1–2 mm bone was infractured using the osteotome technique to create a transcrestal access to the maxillary sinus mucosa. The resulting models for real-time direct visualization of detaching sinus mucosa during

![Figure 1. The umbrella-shaped sinus lift curette. Inserted images showed the end tips.](image-url)
sinus mucosa elevation were preserved at 4°C and used for the following experiments within 24 hours.

During the process to generate such ex vivo models, the operation should be carefully performed to avoid damage to the maxillary sinus mucosa. First, the goat’s maxillofacial soft tissues should be completely removed; second, the maxillofacial bone tissues should be cut via the four mark lines, using a wire saw for the first and fourth lines and a band saw for the second and third lines. Bone tissues around the first and fourth lines were relatively hard, and it was easier to cut these places using a wire saw. While the second and third lines were nearby the maxillary sinus mucosa, the use of a band saw could avoid any tears to the maxillary sinus mucosa. The entire cutting step of the operation should be gently performed, avoiding any violent actions that might cause damage to the maxillary sinus mucosa.

To evaluate the effectiveness of the goat ex vivo models, an umbrella-shaped sinus lift curette (Figure 1) was used to detach and lift the maxillary sinus mucosa using a transcrestal access approach. For the first group of goat ex vivo models (n = 18), the mucosa was mesiodistally detached using the umbrella-shaped sinus lift curette. In particular, the round shaped tip a₁ was used to initially detach the sinus mucosa and the other tip, a₂, was used to further detach the sinus mucosa along the mesial-distal directions through the implant sockets. Detaching the sinus mucosa was stopped when the curette could not be forced farther through the implant socket. For each model, the lengths of the detached mucosa were determined by
measuring the distance the tool could travel under the detached sinus mucosa in the mesial direction and distal direction from the edge of implant sockets.

For a second group of goat ex vivo models (n = 18), the mucosa was buccally and palatally detached using the umbrella-shaped sinus lift curette. Specifically, the round-shaped tip a1 was used to initially detach the sinus mucosa, and tip a2 was used to further detach the sinus mucosa along the buccal-palatal direction through the implant sockets. The operation of detaching sinus mucosa was stopped when the curette could not be forced farther through the implant socket. For each model, the lengths of the detached mucosa were determined by measuring the distance the tool could travel under the detached sinus mucosa in the buccal direction and the palatal direction from the edge of the implant sockets.

For the third group of goat ex vivo models (n = 11), the mucosa was mesiodistally, buccally, and palatally detached using the umbrella-shaped sinus lift curette to visualize the space volumes created after sinus lift. The operation of detaching the sinus mucosa was stopped when the curette could not be forced farther through the implant socket. Before and after detaching sinus mucosa for the third group, saline was added into the space under the sinus mucosa to obtain the space volume under the initial sinus mucosa (V1) and the space volume under the elevated sinus mucosa (V2; Figure 3). The space volume created by crestal sinus lift was calculated by subtracting V1 from V2. In particular, after the sinus mucosa detachment, the ex vivo goat models were placed on a leveled bench top with the exposed sinus mucosa facing down and the exposed maxilla facing up. Saline was then added to the implant socket using microliter syringes to fill the cavities via gravity until the saline level reached the top surface of the bone surrounding the implant sockets. The amounts of saline were recorded. This operation avoided the possibility of further detaching the sinus mucosa due to pressure since the pressure exerted onto the mucosa was minimal.

All the detaching operations were conducted firmly, evenly, and gently by the same laboratory personnel. The numerical data were reported as mean ± standard deviation and analyzed using SPSS 17.0 statistics software.

RESULTS
CT showed that the lowest points of maxillary sinus floor for goats were inconsistent with the area of maxillary premolar or
molar. Therefore, the maxillary premolar or molar was extracted to create the goat ex vivo model for real-time direct observation of sinus lift. Figure 4a shows the direct view of two exposed maxillary sinuses after the premolars or molars were extracted. The dental implant socket was prepared in the primary model to provide the transcrestal access to maxillary sinus floor (Figure 4a). After the maxillary sinus mucosa was detached (Figure 4b), the resulting model allowed the real-time direct visualization of the detached sinus mucosa and determination of the volume space created by the sinus floor elevation via injection of saline or other fillers (Figure 4c).

Through CT examination on the dissected goat heads and direct visualization of the ex vivo models generated, the maxillary sinus mucosa was found relatively flat (slope of 0°–30°) along the mesiodistal direction, while the slope along the buccal-palatal direction for the mucosa was very sharp with a gradient of 60°–90°.

We further tested the ex vivo models by using umbrella-shaped sinus lift curette to detach the sinus mucosa along the mesiodistal direction and/or the buccal-palatal direction, then measuring the space volume generated under the elevated sinus mucosa. The results are summarized in the Table. In the mesiodistal direction, the sinus mucosa could be successfully detached using the umbrella-shaped sinus lift curette for an average of 3.75 mm in length. However, this same tool could detach the sinus mucosa in the buccal-palatal direction only 2.81 mm in average. When this umbrella-shaped sinus lift curette was used to detach the sinus mucosa along both mesiodistal direction and buccal-palatal direction, a space volume of 52.7 μl could be created under the elevated sinus mucosa in the goat ex vivo models.

**TABLE**

The efficacy of ex vivo detaching goat maxillary sinus mucosa using umbrella-shaped sinus lift curette*

<table>
<thead>
<tr>
<th>Length of Sinus Mucosa Detached in Mesial/Distal Direction, mm</th>
<th>Length of Sinus Mucosa Detached in Buccal/Palatal Direction, mm</th>
<th>Space Volume Created Under Elevated Sinus Mucosa, μl</th>
</tr>
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<tbody>
<tr>
<td>3.75 ± 2.14</td>
<td>2.81 ± 2.11</td>
<td>52.7 ± 20.2</td>
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</table>

*Data were reported as mean ± standard deviation.

**DISCUSSION**

In this study, primary ex vivo maxillary sinus models were generated through cuts along the 4 mark lines. These cuts separated the maxillary sinus into upper and lower parts, with the lower part as the model for detaching maxillary sinus floor mucosa. Since the upside of the model was open, it was...
feasible to observe the whole procedure of detaching maxillary sinus floor mucosa via sinus lift tools. The volume generated through detaching and raising the maxillary sinus mucosa could be determined by injecting saline or other filler into the space under the sinus mucosa before and after detaching the mucosa.

Goat maxillary sinus mucosa has a slope of 0°–30° in the mesiodistal direction, while the slope is much higher for the buccal-palatal direction, reaching 60°–90°. However, the umbrella-shaped sinus lift curette used was very stiff and had umbrella-shaped tips (Figure 2). Although it had the great advantage of avoiding tear damage to the membrane, it had limited capability to reach the space under the sinus mucosa. Therefore, our results of detaching the sinus mucosa using this sinus lift tool (Table) are inconsistent with the recommendation that the umbrella-shaped sinus lift curette is suitable for detaching the sinus mucosa right around the osteotome hole.

CONCLUSIONS

The ex vivo goat sinus model was successfully generated for directly observing the effectiveness of detaching maxillary sinus mucosa via the crestal approach in real time. The real-time direct visualization on detaching sinus mucosa might be advantageous in the evaluation of different tools designed for detaching maxillary sinus mucosa during crestal maxillary sinus floor elevation. It might also be beneficial in the arena of implant dentistry, assisting surgeons and dental students the opportunity to learn and understand the technique of crestal maxillary sinus floor elevation as educational models.

ABBREVIATION

CT: computerized tomography

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NOTE

The authors declare that they have no conflict of interest.

REFERENCES


