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Research Paper

Evaluation of sheep sinonasal endoscopic anatomy as a model for rhinologic research☆

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Abstract *Objectives:* Despite many publications describing sheep models for functional endoscopic sinus surgery (FESS) procedures, accurate endoscopic anatomical studies are lacking. There are no publications correlating computed tomography (CT) and 3D models with endoscopic anatomical descriptions. This study evaluates and describes the endoscopic anatomy of a sheep model.
Methods: Ten live sheep (20-sides) were included. Two cadaveric specimens, imaged using thin slice CT for 3D reconstruction correlation were also included. Using endoscopy, anatomical structures were measured and described. Measurement of the same structures was carried out using the 3D imaging model.
Results: Three sets of turbinates were identified at 2.3, 5.1 and 8.5 cm from the anterior nasal sill. Frontal recess and uncinate process were identified at 12.7 cm. The septum has a bony and cartilaginous component and measures 10.5 cm. The sphenopalatine foramen was measured at 12.1 cm. All anatomical measurements were correlated with the measurements on the CT scan 3D volume-rendering model, thereby allowing for an accurate description of the sheep sinonasal anatomy.

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Conclusion: This study describes the endoscopic sinonasal anatomical measurements of the adult sheep. It is the first study to evaluate the sheep CT and endoscopic anatomy in order to determine its feasibility as an animal model for research in FESS.

Introduction

Animal models are living organisms with an inherited, naturally acquired, or induced pathological process that, in one way or another, resembles the same phenomenon in man.[1] There is an ongoing need to find an animal model to study new treatment modalities in humans. These include pharmaceutical and toxicology research (where animal models can be used to determine effect, efficacy, effective dose, toxicity profile, and patho-medications)[1] and functional endoscopic sinus surgery (FESS) research and training.[2,3] Many different animal models have been used in FESS-related research, including rabbits,[4] sheep,[5] and swine.[6]

Among these animal models, the sheep model has been demonstrated to be favorable for FESS-related research. Even though rabbits are readily available and easy to breed, their nasal cavities are too small to accommodate even the smallest diameter sinonasal endoscopes (2.7 mm pediatric endoscope) for endoscopic maneuvers.[7] Although the configuration of the sheep's head is different to that of a human, the nasal cavity appears to be quite similar and, as noted from computed tomography (CT) scans, the major sinuses (maxillary, ethmoidal and frontal) lie in approximately the same orientation as in humans. Furthermore, the model itself is spacious enough to accommodate standard instruments, affordable, easily obtainable and of good tissue quality.[3]

Despite many publications describing sheep models for FESS procedures, accurate endoscopic anatomical studies are lacking. Furthermore, there are no publications correlating computed tomography (CT) and 3D models with endoscopic anatomical descriptions. In this study, we aim to evaluate and accurately describe the endoscopic anatomy of a live sheep model using CT and 3D models.

Material and methods

Our group chose Dorset cross strain sheep (*Ovies aries*) as a candidate for an animal model. We obtained 10 live sheep for endoscopic evaluation and 2 sheep cadaver heads for imaging and 3D reconstruction, for a total of 24 sides. All 10 live specimens were female, with a mean age of 12 months and mean weight of 70 kg (SD = 9 kg). Sheep were procured by the Centre for Comparative Medicine at the University of British Columbia. Animal ethics approval was obtained from the University of British Columbia Research Ethics Board (#A14-0172).

Anatomic evaluation through CT images

Routine image guided CT protocol for sinonasal procedures was ordered and performed on two sheep cadaver specimens. Axial, coronal and sagittal planes were obtained using a GE low-dose volume CT (VCT, General Electric, Fairfield, CT, USA). Images of both specimens were evaluated independently by 3 rhinologists (ARJ, LMV, and AFK) to identify similarities and differences from human sinonasal anatomy. The evaluation was carried out using OsiriX 2 software (version 8, 32-bits for Mac OS). The orientation of sinonasal outflow tracts, identification of superior, middle and inferior turbinates, and the potential area encompassing the sphenopalatine foramen were also evaluated. Measurements and volume evaluations were obtained using an electronic ruler and protocols from the software mentioned previously (Fig. 1).

Image 3D rendering for measurements

OsiriX 2 (ver 8 32-bits for Mac OS) was used to render 3D images from an axial CT scan of each sheep cadaver model. Using a logarithmic table for opacity and a different setting of linear table values for bone density and soft tissue density, a 3D model was created (Fig. 2).[8] Using the same algorithm for density values, a virtual endoscopic reconstruction was formulated for cross checking distances of anatomical references between the cadaver model, live model and the 3-D reconstruction model (Fig. 3).

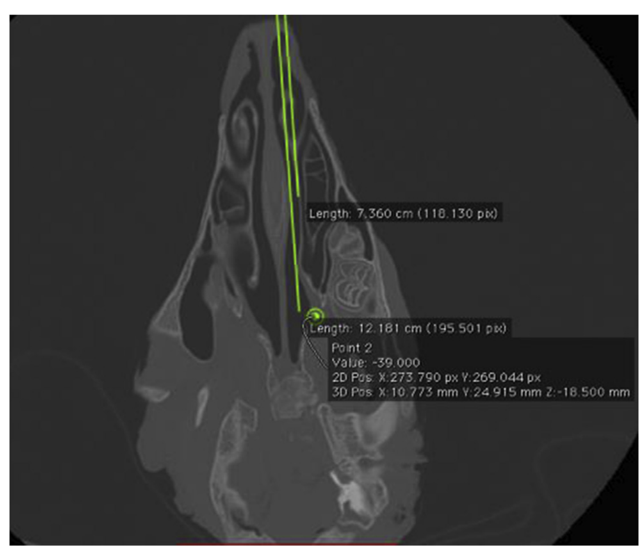

Fig. 1 An axial cut of the cadaveric specimen showing the electronic ruler function, ROI (region of interest) shows the predicted area of the sphenopalatine foramen at 12.18 cm from nasal sill (green circle).

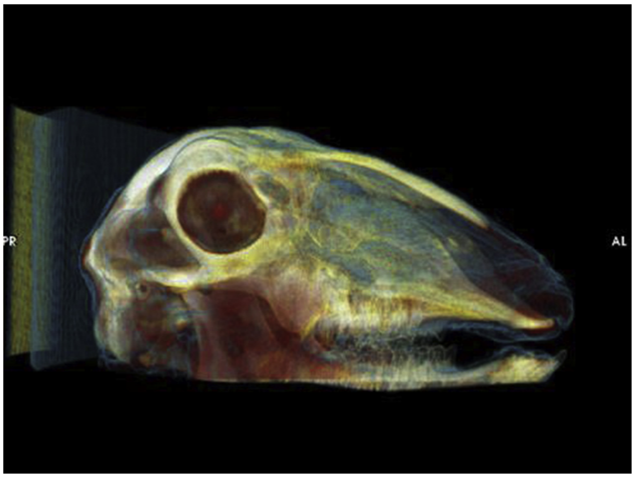

Fig. 2 Volume rendering of the CT scan images was done, obtaining a model with a reconstruction of sinonasal landmarks for measurement and comparison with the endoscopic model.

Live endoscopic sinonasal model

Sheep were induced with propofol at 46 mg/kg IV through a catheter placed in the cephalic vein. Orotracheal intubation was then performed under direct vision and anesthesia was maintained using isoflurane (45% to start and 23% for maintenance).

After intubation, an orogastric tube was placed in position to prevent bloat. Monitoring took place with standard monitoring equipment including heart rate, electrocardiogram, non-invasive blood pressure, expired carbon dioxide, inspired and expired isoflurane, oxygen saturation and temperature. A steady state of anesthesia was reached prior to beginning surgery.

With the specimen in prone position, the head was elevated to approximately 30°. Rigid sinonasal endoscopy was performed utilizing standard endoscopes used in FESS (4.0-mm 0-degree and 30-degree 18 cm Hopkins telescope Karl Storz, Endoscopy, Tuttlingen, Germany) on the anaesthetized sheep. Systematic evaluation and measurement of pertinent intranasal structures was obtained for all 10 sheep and analyzed as 20 discrete nasal cavities. All sheep were extubated satisfactorily after the procedure and returned to their individual pens for postoperative observation.

Results

Imaging and virtual endoscopy model

Numerous intranasal structures were consistently observed and measured during the CT evaluation. The nasal septum has both a cartilaginous and bony component with a mean anterior to posterior distance of 10.5 cm. Three different sets of turbinates were easily identified and found to be consistently at a mean distance of 2.3, 5.1 and 8.5 cm from the anterior nasal sill. Turbinates appear to have larger mucosal surface in the form of concentric semicircular architecture.

A natural bony dehiscence is encountered on the lateral nasal wall at 12.1 cm from the nasal sill and 1.5 cm from the floor of the nose. Within this foramen, both vascular and muscular contents were identified; this area was identified most closely to resemble the human sphenopalatine artery (SPA) foramen. The frontal recess area and uncinate

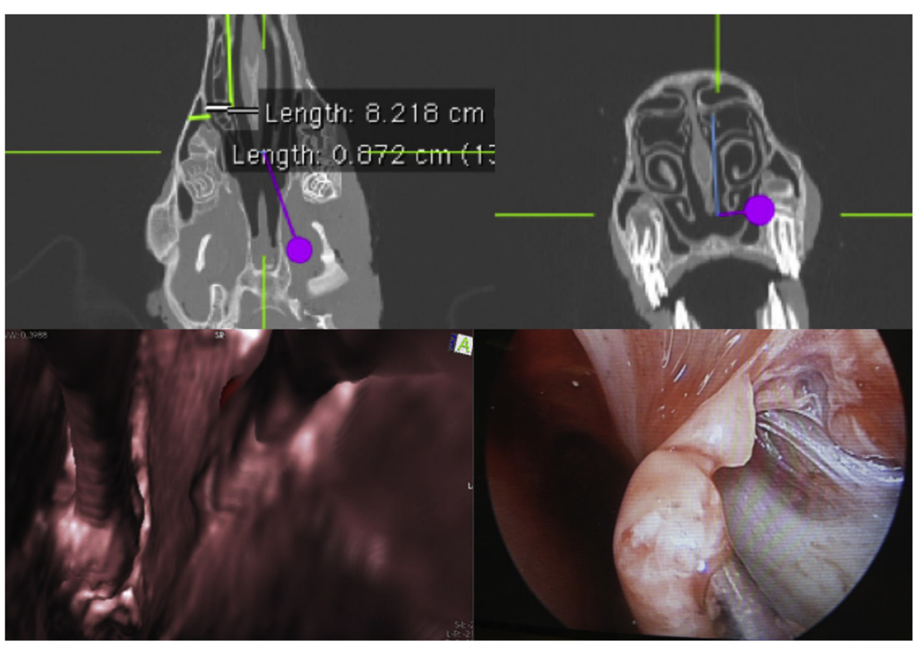

Fig. 3 Superior images: Axial and coronal cuts used for the reconstruction of the virtual endoscopy model (lower left image), comparison of the same area in the cadaveric model dissection (lower right image) showing the area of the sphenopalatine foramen, accurately predicted with the 3D model previously.

process were identified at 12.7 cm from the nasal sill and 1.8 cm from the floor of the nose, respectively.

The nasal septum did not extend to the full length of the nasal cavity and ended significantly short of the nasopharynx. The distance between the posterior boundary of the nasal septum and the posterior wall of the nasopharynx was found to be 13.8 cm with a mean area of 3.8 cm^2. This posterior gap allowed visualization of the contralateral lateral nasal wall using angled scopes. All measurements were corroborated using virtual endoscopy, which was developed from the axial cuts of the CT scan as noted previously (Fig. 4). All anatomical measurements were compared in triplicate between the endoscopic, tomographic and 3D models to improve accuracy (Table 1).

Discussion

Although publications already exist describing the sheep model for evaluation of surgical competency in FESS[9] and basic research,[10] there is scarce literature regarding anatomical description of the identifiable anatomical structures in a sheep model. Furthermore, the use of cadaveric models for surgical competency has the limitation of not having real life conditions (i.e. no bleeding) to contribute to the acquisition of surgical skill.[11]

Many animal models have been tested for research in rhinology, including rabbits,[4] swine[7] and sheep.[5] As described by the authors, swine is not suitable for surgical manipulation due to insufficient intranasal space.[7] Similar restrictions apply to the rabbit model, although both have been used successfully for in vivo research in chronic rhinosinusitis (CRS).[12] Based on our measurements and experience with live endoscopy of the sheep nasal cavity, the sheep model seems very appropriate for endoscopic surgical manipulation. Interestingly, the anatomical characteristics of the septum allow visualization of the contralateral nasal wall, opening the possibility of bi-nostril instrumentation and a two surgeon, four-handed training model.This model has also been proven viable for CRS research.[13]

The importance of the sheep model for pharmaceutical trials and for evaluation of new biomedical devices has also been proven in recent studies. Yaniv et al recently trialed a new generation of composite removable stents using a live sheep model to test their results.[14] A recent publication from our group demonstrated the utility of the live sheep model to measure the efficacy of a novel self propelling hemostatic agent, upon creating a mucosal injury to the inferior turbinate and subsequent bleeding.[15]

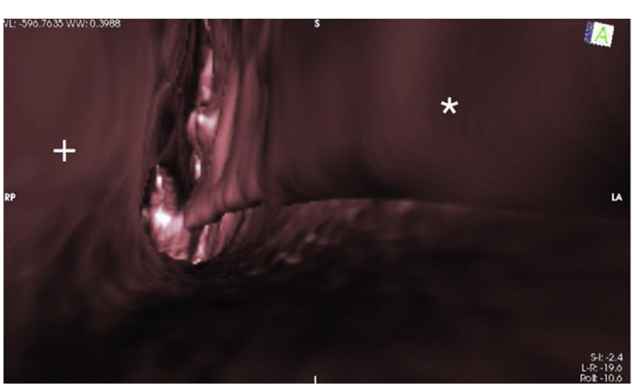

Fig. 4 Virtual endoscopy of the left nasal cavity of the sheep, based on the information obtained with the axial cuts from the CT scan. The cross (+) shows the nasal septum, the inferior turbinate (*) and the nasal floor are also depicted.

Table 1 Measurement of identifiable intranasal anatomical structures ($n=24$).

Sinonasal structure	Measurement (SD)
Head of the inferior turbinate	2.3 cm (0.3 cm)
Posterior wall of nasopharynx	24.3 cm (1.2 cm)
Posterior edge of septum	10.5 cm (0.4 cm)
Uncinate process and frontal recess area	12.7 cm (1.3 cm)
Area of the sphenopalatine Foramen	12.1 cm (1.8 cm)

We found an adequate and acceptable correlation in measurements between all three sheep models. The study revealed that the sinonasal anatomy of the sheep exhibits many similarities to human sinus anatomy. The identification of natural ostia of the sinuses and their outflow tracts, as well as areas of neurovascular contents such as the SPA foramen, opens the possibility for multiple research projects in the future.

The possibility of teaching surgical techniques under conditions resembling live operative experience could impact the way rhinology training is currently undertaken. The skillset obtained through surgical simulation using animal models has proven to be successfully transferrable to the operating theatre.[16] Sheep heads have been found useful to assess and teach surgical techniques in rhinology.[11] However, the potential application of introducing a live bleeding model may further enhance the learning experience and allow for better evaluation of surgical competency.

The sheep model meets the anatomic feasibility criteria we set out at the start of the study by making it a suitable animal model for rhinologic research. To our knowledge, this is the first study to verify, measure and correlate sinonasal landmarks accurately in the sheep model using CT3D reconstruction, virtual endoscopy and live endoscopy.

We understand that the measurement of a particular breed of sheep with specific phenotypical characteristics might not be extrapolated to other sheep models. However, we feel it is important to report measurements and descriptions of anatomical landmarks for facilitating and standardizing results for future studies using these types of animal models.

Another limitation of our study is the setting required for live surgery in the sheep model. The facilities, equipment, and staff necessary to perform this type of research may not be easily available for all research centers. Nevertheless, the benefit of having an animal model resembling the actual surgical experience of FESS may be invaluable for training programs.

Finally, considerations should be made with regards to some of the differences between sheep and human anatomy. Although the sheep model is proven to be adequate for certain endoscopic surgical procedures, limitations due to length of instruments and depth of structures should be taken into account. Certain authors have resorted to the resection of the anterior section of the sheep muzzle in cadaveric models to adjust for the working distances of standardized instruments.[17] It should also be noted that the spatial orientation and topographic characteristics of important landmarks related to complications in FESS, such as the orbit or the skull base, are different in the sheep model when compared to human anatomy.

Conclusion

This study describes endoscopic sinonasal anatomical landmarks and their measurements in an adult sheep model. This is the first study to compare both sheep CT and sinonasal endoscopic anatomy. These findings support the feasibility of using a sheep model for research in Rhinology.

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