Comparing nasal physiology after superior ethmoidal and traditional endoscopic anterior cranial base approaches*

Varun Patel[1], Rohan Viswanathan[2], Randall Ruffner[1], Maria Peris-Celda[3,4], Tyler Kenning[3], Carlos D. Pinheiro-Neto[1,3]

[1] Division of Otolaryngology / Head and Neck Surgery, Department of Surgery, Albany Medical Center, Albany, NY, USA
[2] Albany Medical College, Albany, NY, USA
[3] Department of Neurosurgery, Albany Medical Center, Albany, NY, USA
[4] Adjunct Assistant Professor, Department of Neurosurgery, Mayo Clinic, Rochester, MN, USA

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To the Editor:

Endoscopic endonasal approaches can be effective for treating a wide variety of skull base pathologies with reduced complications compared with open approaches[1]. The traditional endoscopic endonasal anterior cranial base approach (TA) involves total ethmoidectomies, middle and superior turbinectomies, near-total septectomy, sphenoidotomies and wide maxillary antrostomies. However, these patients may develop chronic nasal crusting postoperatively requiring debridement [2].

In contrast to the TA, the endoscopic endonasal superior ethmoidal approach (SEA) is a more conservative technique to access the anterior cranial base with preservation of middle turbinates, ostiomeatal complexes and most of the septum. It has been designed as an alternative method to approach intracranial anterior cranial base lesions that have minimal or no extension intranasally [3] (Figure 1).

Computational fluid dynamics (CFD) is a useful tool to examine nasal physiology and has advantages over conventional methods [4,5]. A recent study has used CFD to demonstrate different airflow, wall shear stress (WSS), heat flux and humidifying efficiencies in patients following the TA compared to controls [6]. However, no CFD studies have examined the effects of the SEA on nasal physiology. The objective of our study is to compare the impact on simulated airflow and heat transport between the TA and SEA using CFD.

Three control patients with normal nasal anatomy were included. Six patients with anterior cranial base meningiomas without intranasal extension were also included: three who underwent the TA and three who underwent the SEA. Because all of the tumour burden in our study was exclusively intracranial, surgeon experience, rather than the type of pathology, dictated which approach was used. Both approaches granted the same degree of tumour resection. Figure 1 shows the intranasal structures removed for both approaches. CT scans with sinus protocol at least six months postoperatively were obtained and uploaded to Nasal FlowTM (Nasal Advanced Systems of Airflow Lab, Madrid, Spain) to develop three-dimensional models. Six months was used as a minimum criterion as this is sufficient time for nasal packing to dissolve and for acute postsurgical radiographic changes to subside. Outcome measures from the simulations include nasal cavity volume, airflow rate, temperature, WSS, resistance and airflow velocity. Further details are described in the supplementary material (Supplemental Figure 1).

Our results showed that in the SEA group, nasal preservation did not prevent tumour resection as complete resection was achieved in all three cases despite large tumour sizes (mean tumour size 3.4 x 3.0 x 1.8 centimeters). Compared to the control group, the TA group had significantly increased average nasal cavity volumes (6.92 ml to 17.38 ml, $p=0.007$) and airflow (5.57 l/min to 12.77 l/min, $p=0.029$), whereas the SEA group did not have significant increases in either (6.92 ml to 10.13 ml, $p=0.074$ and 5.57 l/min to 6.94 l/min, $p=0.251$). Supplemental Table 1 highlights additional results.

Differences in nasal airflow distribution were also notable. In the control group, airflow was predominantly in the floor of the nose and around the septum, inferior turbinate and middle meatus. The TA group showed a much wider airflow distribution with flow directed more toward the maxillary sinus, sphenoid sinus, and the nasal roof. In contrast, airflow in the SEA group was similar to that seen in the control group, but with a small stream of airflow directed to the superior ethmoid space before passing into the choana (Figure 2).

Our simulations also illustrated differences in temperature regulation. Compared to controls, the TA group demonstrated significantly lower average nasal air temperatures (33.77˚C to 30.3˚C, $p=0.015$), whereas the SEA group had no significant changes (33.7˚C to 32.72˚C, $p=0.468$). For all patients in the con-

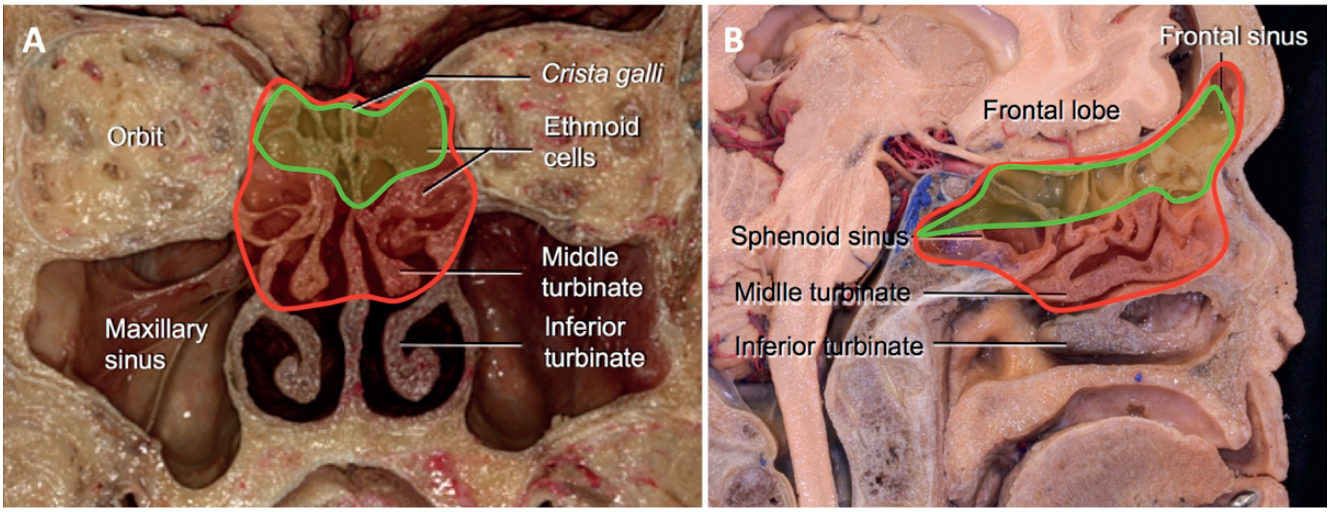

Figure 1. Anatomical dissections to illustrate the anatomy of the two types of endoscopic endonasal anterior cranial base resection. The red area represents the nasal structures resected in a traditional endoscopic endonasal anterior cranial base resection (TA); the green area represents the resection performed in the superior ethmoidal approach (SEA). The middle turbinates, uncinate processes, maxillary sinus ostia and the bulla are left intact in the SEA. (A) Coronal view. (B) Sagittal view. Reprinted with permission from Peris Celda M, Kenning T, Pinheiro-Neto CD. Endoscopic Superior Ethmoidal Approach for Anterior Cranial Base Resection: Tailoring the Approach for Maximum Exposure with Preservation of Nasal Structures. World Neurosurg 2017; 104: 311-317.

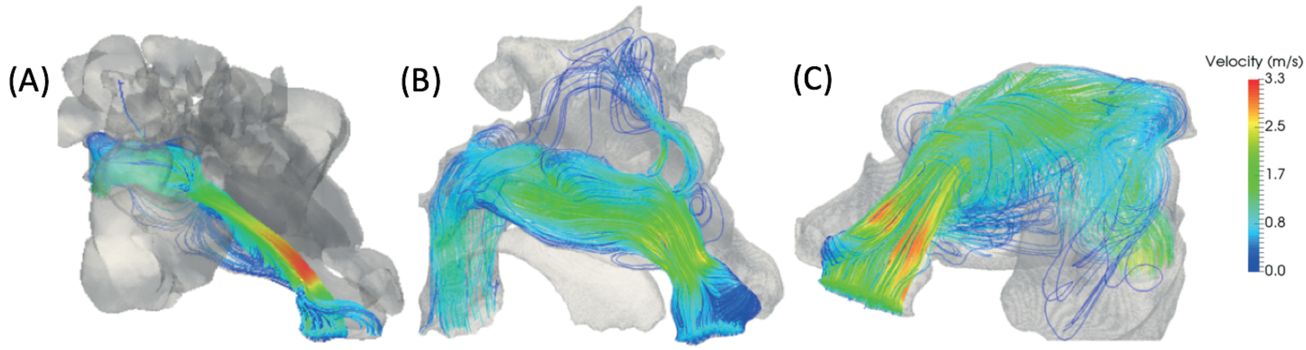

Figure 2. Three-dimensional nasal cavity airflow distribution and velocity profile in control patients (A) and following the superior ethmoidal approach (B) and traditional endoscopic endonasal anterior cranial base approach (C). In patients that received the superior ethmoidal approach, airflow was similar to that seen in the control patients, but with a small stream of airflow directed to the superior ethmoid space before passing into the naso-pharynx. Compared to the superior ethmoidal approach, the traditional approach demonstrated much wider airflow distribution with flow directed more toward the maxillary sinus, sphenoid sinus, and the nasal roof.

trol group and the SEA group, nasal air temperatures reached a maximum of 36.5˚C in the choana. However, only one out of three patients in the TA group reached this maximum. Supplemental Figure 2 illustrates regional temperature distributions in the nasal cavities.

WSS was higher in the anterior nasal cavity and nostrils compared to other nasal regions for all groups (Supplemental Figure 3). However, in the TA group, increased WSS was also noted at the nasal roof.

To our knowledge, this is the first study to utilize CFD models postoperatively to compare two different endoscopic approaches to the anterior cranial base. In 2019, Tracy et al. conducted a similar study using CFD to analyze three patients that underwent the TA [6]. Our study yielded similar results to their study. They found dramatically increased nasal cavity volume postoperatively, with increased airflow distribution toward the sphenoid sinus, maxillary sinus and nasal roof. Additionally, their study also showed decreased humidifying and heating efficiency in the nasal cavity.

Removal of nasal tissue in endoscopic skull base surgery has been associated with nasal crusting in the postoperative period [7,8]. Our internal chart review demonstrated that the three patients in the TA group had more severe nasal crusting requiring extensive debridement compared to those in the SEA group, in agreement with prior literature. This may be due to loss of heating and humidification efficiency in the TA group.

Our study is not without limitations. First, it is restricted by small sample size and therefore does not enable us to fully capture potential variations. Additionally, one patient in the SEA group received neo-adjuvant radiation, and its effects were not directly accounted for. Radiation may cause further adverse effects to nasal physiology and symptomatology [9]. Furthermore, due to technical limitations, we were unable to calculate filtering capability and humidification. We postulate that the TA would lead to poorer filtration and humidification compared to the SEA due to the degree of mucosal resection and anatomical alterations. This may ultimately result in inadequate pulmonary airflow and function. Although following the TA patients may not have long-term symptoms, not much is known about how changes in nasal physiology affect pulmonary physiology or other systemic parameters. This raises our concern and a need for further research. In conclusion, the SEA preserves not only most of the anatomical structures of the nasal cavity in the anterior cranial base resection, but also more closely maintains normal physiologic airflow and heat transport mechanisms postoperatively.

Key words: ethmoid sinus, nasal mucosa, nasal surgical procedures, skull base neoplasms, turbinates

Conflict of interest

None.

Authorship contribution

VP: data collection, data analysis, manuscript writing; RV: data collection, data analysis, manuscript writing; RF: data analysis, manuscript writing; MPC: study design, oversight; TK: study design, oversight; CPN: study design, manuscript writing, oversight.

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Dr. Carlos Pinheiro-Neto, MD, Ph.D
Division of Otolaryngology
Albany Medical Center
50 New Scotland Avenue
Albany, NY
USA 12208

Tel: +1-518-262-5575
E-mail: pinheic@amc.edu

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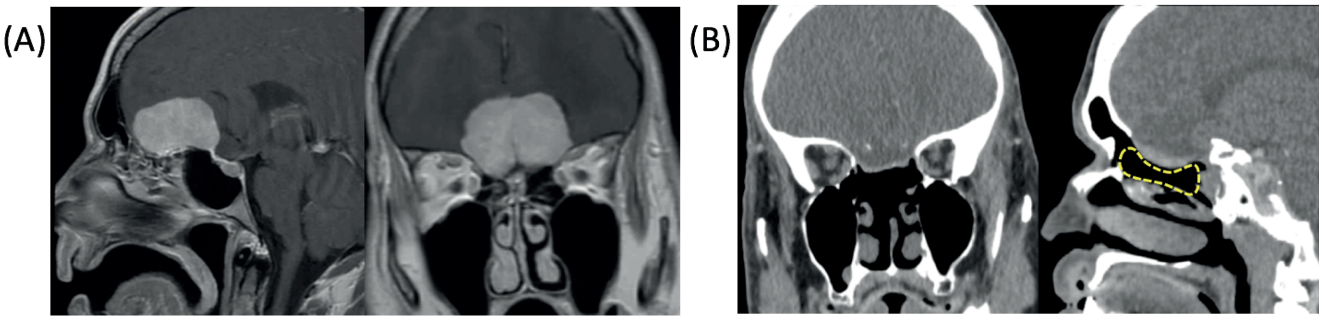
SUPPLEMENTARY DATA

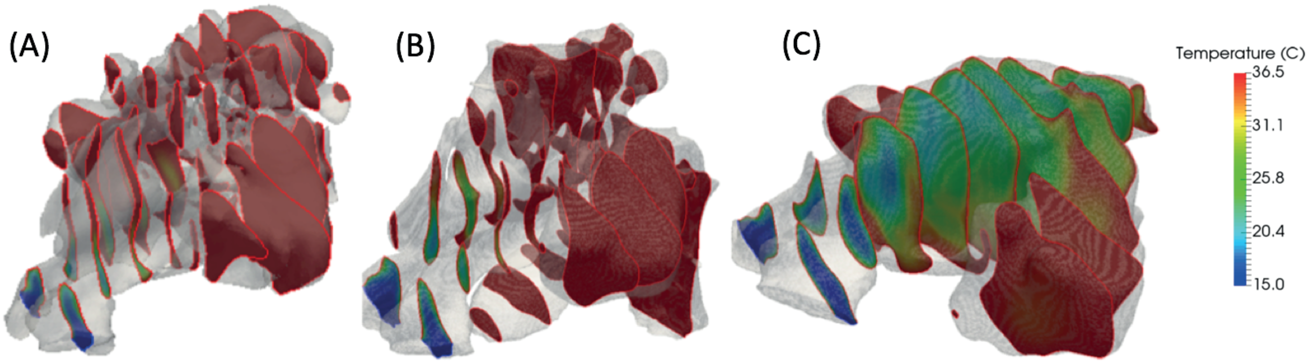
Supplemental Table 1. Main outcome measures in each group. Values of airflow velocity, temperature and WSS were calculated at nine equidistant CT coronal slices for each patient and then analyzed among the groups. Nasal cavity volume and airflow rates were calculated in each unilateral nasal cavity individually for each patient and then analyzed among the groups. Mean, range value and standard deviation are listed.

Outcome Measure	Control	SEA	TA
Volume (ml)	6.92 (2.31-10.71) SD (0.342)	10.13 (6.71-14.63) SD (3.68)	17.38 (9.95-22.39)** SD (4.86)
Airflow (l/min)	5.57 (1.65-11.69) SD (3.83)	6.94 (2.44-10.53) SD (2.94)	12.77 (5.11-21.42)** SD (7.38)
Resistance (Pa*s/ml)	0.05 (0.03-0.13)	0.04 (0.03-0.07)	0.05 (0.03-0.06)
Temperature (˚C)	33.77 (33.45-33.89) SD (5.03)	32.72 (32.03-33.28) SD (5.53)	30.3 (28.1-33.97)** SD (5.15)
WSS (Pa)	0.03 (0.013-0.036) SD (0.022)	0.04 (0.034-0.043) SD (0.034)	0.05 (0.023-0.060) SD (0.053)
Velocity (ml/s)	0.42 (0.229-0.587) SD (0.343)	0.61 (0.54-0.71)** SD (0.444)	0.86 (0.45-1.11)** SD (0.496)

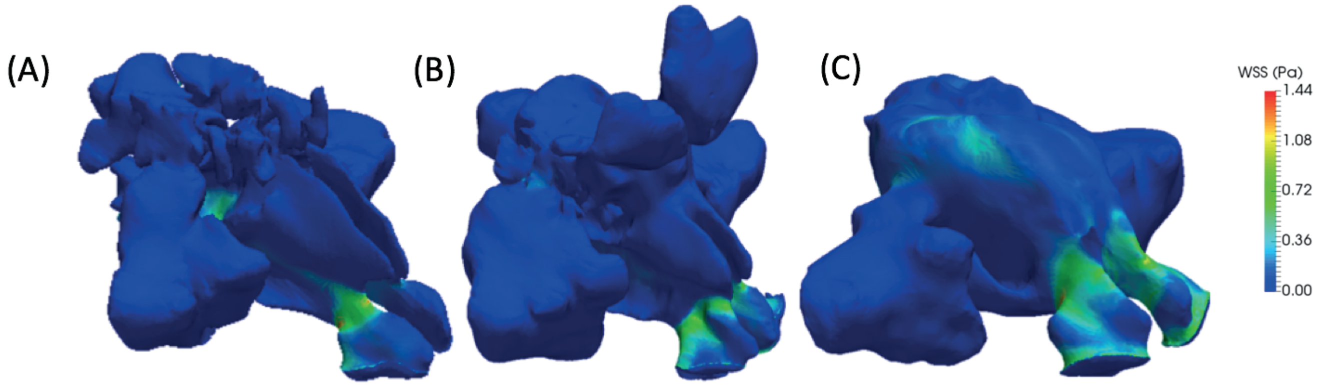
SEA=superior ethmoidal approach, TA=traditional endoscopic endonasal anterior cranial base approach, SD=standard deviation, **=statistically significant.



Supplemental Figure 1. Pre-operative magnetic resonance imaging (A) and post-operative computed tomography (B) sagittal and coronal scans of a patient that received the superior ethmoidal approach for resection of anterior cranial base meningioma. The yellow dotted line represents the area that was resected during the superior ethmoidal approach.



Supplemental Figure 2. Three-dimensional nasal cavity temperature profile in control patients (A) and following the superior ethmoidal approach (B) and traditional endoscopie endonasal anterior cranial base approach (C). Similar to control patients, patients that received the superior ethmoidal approach demonstrated higher temperatures at the area of the inferior and middle turbinates, with the addition of the nasal roof demonstrating higher temperatures as well. However, in patients that received the traditional endoscopie endonasal anterior cranial base approach, higher temperatures were only seen around the inferior turbinate, with lower temperatures noted at the nasal roof.



Supplemental Figure 3. Three-dimensional nasal cavity wall shear stress profile in control patients (A) and following the superior ethmoidal approach (B) and traditional endoscopie endonasal anterior cranial base approach (C). Overall, wall shear stress was higher in the anterior nasal cavity and nostrils compared to other nasal regions for all three groups. In patients that received the traditional endoscopie endonasal anterior cranial base approach, increased wall shear stress was noted at the nasal roof.