Computational Fluid Dynamics Evaluation of Sinonasal Flow During Respiration and Nasal Irrigation Following Transnasal Endoscopic Surgery

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Introduction

Transnasal endoscopic sinus surgery (TNES) removes obstructive or diseased tissue to restore normal sinus ventilation and mucociliary clearance while preserving healthy mucosa[1]. TNES variants include standard functional endoscopic sinus surgery (FESS) with ethmoidectomy and maxillary sinusotomy, FESS with extended maxillary sinusotomy (FESS-EMS), and FESS with modified extended maxillary sinusotomy (FESS-MEMS). A FESS clears pathways and widens the maxillary opening to improve drainage, whereas FESS-EMS removes a larger portion of the medial maxillary wall to enhance sinus access and postoperative irrigation[2]. FESS-MEMS is a modified FESS-EMS that preserves the anterior portion of the inferior turbinate[3,4]. Because the extent of surgery can alter sinonasal airflow and irrigation efficiency, this study uses computational fluid dynamics (CFD) to simulate airflow and saline irrigation following different TNES procedures, evaluating how surgical extent affects aerodynamics and irrigant penetration.

Methods

11 anonymized CTs were selected for each of the following groups:

- Normal anatomy (Unoperated)
- Standard FESS (Antrostomy)
- FESS-EMS (EMM)
- FESS-MEMS (MEMM)

3-D sinonasal and nasopharyngeal airway models were created from the CTs in *Simpleware ScanIP*

CFDs were simulated using these parameters:

- Inspiratory airflow simulated as air at 37 °C
- Irrigation flow simulated as saline at 21 °C
- Nasal pyriform aperture used as Inlet
- Nasopharyngeal opening used as Outlet

Flow was analyzed with the following metrics:

- Airflow visualization & irrigant penetration
- Airway resistance (Pa·s/m³) and pressure (Pa)
- Wall shear stress (Pa)

Results

Wall Sheer & Streamline Visualizations (Fig 1, Fig 2)

- Wall shear stress remained low across all models
- Streamline visualization showed increasing airflow penetration into the maxillary sinus from Unoperated to EMM and MEMM models
- Irrigation simulations revealed greater saline penetration in EMM and MEMM compared to Unoperated and Antrostomy
- MEMM achieved similar irrigant distribution to unoperated and antrostomy while preserving more physiologic airflow.

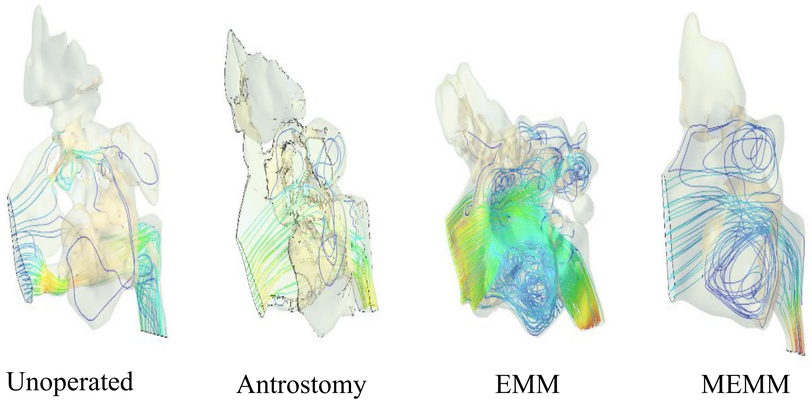

Fig 1. CFD Streamlines of post-TNES aerodynamics during Forced Inspiratory Flow

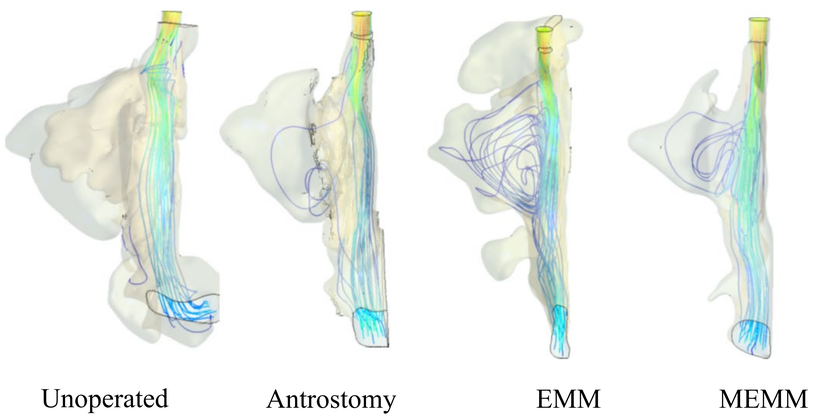

Fig 2. CFD demonstration of maxillary sinus penetration of inspiratory air after simulated antrostomy in a single model. The basal view is rotated in each case to show maxillary sinus streamlines.

Results

Airway Resistance and Airway Pressure (Fig 3)

- Average airway resistance was lowest in Antrostomy and EMM models
- MEMM demonstrated slightly higher resistance than EMM
- Highest pressures observed in MEMM

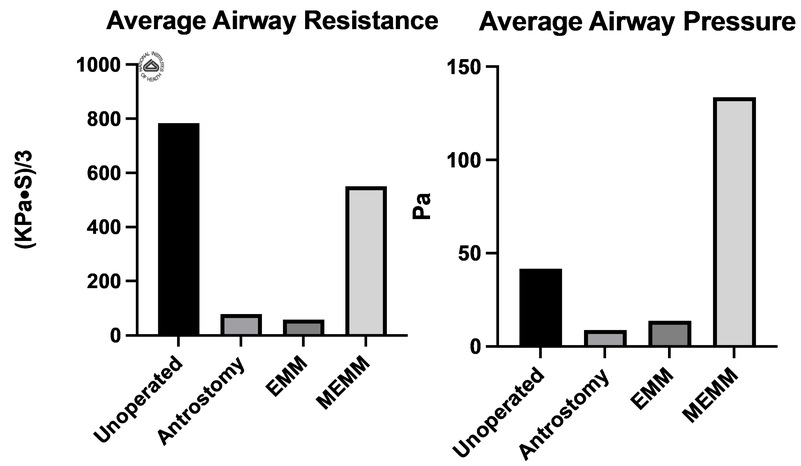

Fig 3. Average Airway Resistance (Pa·s/m³) and Average Airway Pressure (Pa) in Unoperated, Antrostomy, EMM, and MEMM models.

Conclusion

Computational fluid dynamics analysis demonstrated that surgical extent significantly influences sinonasal airflow and irrigation. Extended dissections (EMM and MEMM) enhance ventilation and irrigation but risk altered airflow dynamics. The MEMM approach, which preserves the anterior inferior turbinate, provides comparable irrigant penetration to EMM while maintaining more normal nasal airflow—supporting turbinate-sparing strategies to balance surgical access with postoperative function and comfort.

References

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