# Development of the McGill simulator for endoscopic sinus surgery: A new high-fidelity virtual reality simulator for endoscopic sinus surgery

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## ABSTRACT

**Background:** *The technical challenges of endoscopic sinus surgery (ESS) and the high risk of complications support the development of alternative modalities to train residents in these procedures. Virtual reality simulation is becoming a useful tool for training the skills necessary for minimally invasive surgery; however, there are currently no ESS virtual reality simulators available with valid evidence supporting their use in resident education. Our aim was to develop a new rhinology simulator, as well as to define potential performance metrics for trainee assessment.*

**Methods:** *The McGill simulator for endoscopic sinus surgery (MSESS), a new sinus surgery virtual reality simulator with haptic feedback, was developed (a collaboration between the McGill University Department of Otolaryngology–Head and Neck Surgery, the Montreal Neurologic Institute Simulation Lab, and the National Research Council of Canada). A panel of experts in education, performance assessment, rhinology, and skull base surgery convened to identify core technical abilities that would need to be taught by the simulator, as well as performance metrics to be developed and captured.*

**Results:** *The MSESS allows the user to perform basic sinus surgery skills, such as an ethmoidectomy and sphenoidotomy, through the use of endoscopic tools in a virtual nasal model. The performance metrics were developed by an expert panel and include measurements of safety, quality, and efficiency of the procedure.*

**Conclusion:** *The MSESS incorporates novel technological advancements to create a realistic platform for trainees. To our knowledge, this is the first simulator to combine novel tools such as the endonasal wash and elaborate anatomic deformity with advanced performance metrics for ESS.*

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With over 400,000 cases per year, endoscopic sinus surgery (ESS) is one of the most common procedures performed by otolaryngologists in the United States.[1] Minimally invasive surgeries, such as ESS, require distinct technical abilities, in part because of the use of an endoscope in a restricted three-dimensional (3D) space.[2] Moreover, the surgeon must coordinate hand movements with the indirect visual aid of a monitor.[3] The difficulty of learning ESS is accentuated by the complex anatomy of the sinonasal tract and the proximity of numerous vital structures such as the brain, orbits, and carotid arteries.[2] In fact, a recent report indicated the rate of major and minor complications to be ~0.5 and 6.6%, respectively.[4] This may explain why ESS is the most frequent reason for otolaryngologic surgical litigation in the United States.[1] With trainees, the complication rate is even higher.[5]

The technical challenges of surgery and the high risk of complications have supported the development of alternative methods to assist the training of residents. Traditional modalities have included didactic lectures, small group sessions, and cadaveric dissections.[2] Virtual reality simulators are becoming useful for training in the skills necessary for minimally invasive surgeries such as ESS.[2]

In the field of rhinology, the ES3 was the first sinus surgery simulator developed in 1998 by Lockheed Martin.[6] Although the ES3 was shown to be beneficial for resident training, it is no longer in production and there are less than a handful of devices being used in North America.[7] After the discontinuation of the ES3, other virtual reality simulator models for ESS have been created. For example, Ruthenbeck *et al.* recently described a virtual reality simulator using advanced tissue rendering to create a more realistic nasal cavity, with improved nasal mucosa appearance and tissue characteristics.[4] However, none have published evidence supporting their routine use in resident education.[7]

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## OBJECTIVE

The objective of this article was to describe the development of the McGill simulator for ESS (MSESS), a new virtual reality simulator for ESS in a collaboration between the McGill University Department of Otolaryngology–Head and Neck Surgery, the Montreal Neurologic Institute Simulation Lab, and the National Research Council of Canada. We describe the physical components of the simulator, the tasks performed, and the metrics measured on the simulator. The potential applications of simulation in the field of rhinology will also be discussed.

## DESCRIPTION OF THE MSESS

### Identification of Core Technical Skills

Experts in the field of rhinology, performance assessment, skull base surgery, and education evaluation identified the most important core technical skills needed to perform ESS. Their findings were cross-referenced with the work of Bakker,[8] who reported survey results from a panel of otolaryngologists on the skill requirements of ESS. This led to the identification of three core skills, *viz.*, recognition of the complex anatomy through an endoscopic view, learning to handle an endoscope and a tool with bimanual dexterity, and learning to perform discrete surgical steps in a safe and effective manner.

### Simulator Hardware

The simulator's physical setup consists of a monitor to visualize the surgical field, two haptic tools (endoscope and microdebrider), and two pedals (microdebrider and endonasal wash) (Fig. 1); a more detailed explanation of each part of the simulator follows. There is

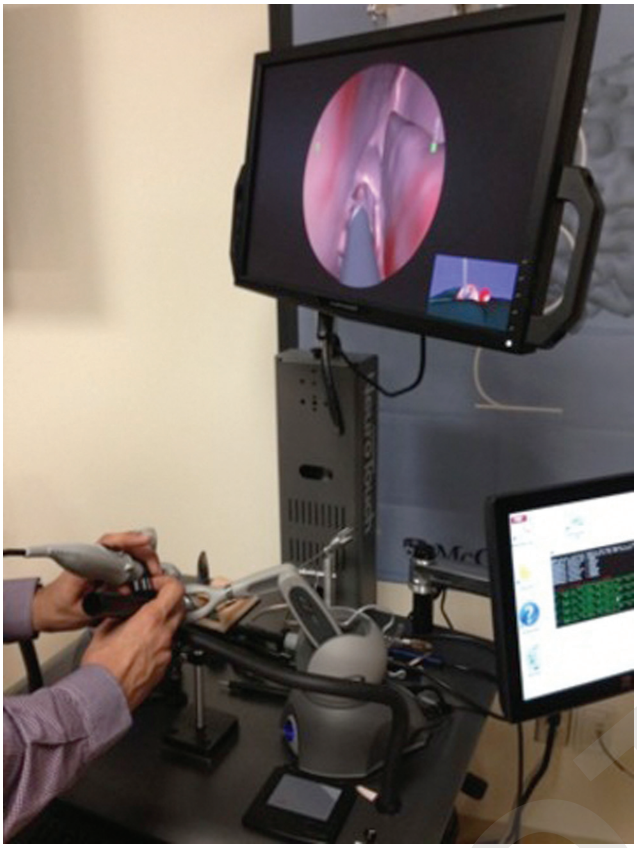

*Figure 1. McGill simulator for endoscopic sinus surgery (MSESS) with the user placing the endoscope and the microdebrider within the nasal cavity. The user visualizes the surgical field on a high-definition monitor as would be seen through a routine 0°, rigid Hopkins rod-lens endoscope.*

also a touch screen, which allows navigation of the user interface and selection of various simulation tasks.

## Nasal and Paranasal Sinus Software Model

The MSESS was developed on the NeuroTouch platform, a neurosurgical simulator previously developed by the National Research Council of Canada (NRC).[9,10] NeuroTouch is based on the NRC's software simulation engine, Blade, which consists of three asynchronous processes for the computation of tissue mechanics, graphics, and haptic feedback. The finite element method with explicit time integration computes tissue deformation and topology change in response to tissue rupture, cutting, or erosion. The tissues are modeled as viscoelastic solids using a quasilinear viscoelastic constitutive model for the viscous part[11] and a compressible form of the generalized Rivlin constitutive model[11,12] for the elastic part.

Modeling endoscopic procedures is particularly difficult with constitutive model-based finite element methods because of the relatively large volume over which the surgeries occur. Furthermore, partial volume effects in medical images and the small size of nasal passages make it difficult to construct highly accurate models from imaging using purely automated methods. Therefore, a multistage method was used. A set of clinical computed tomography images were first manually segmented using a 3D slicer (www.slicer.org)[13] to define both the extent of the simulated volume and the different tissues that would be tracked by the performance metrics. Then, a 3D model of the nasal cavity walls was constructed from the segmentation. Thereafter, the graphics software Blender (Blender Foundation, Amsterdam, Netherlands) was used to correct any artifacts. Finally, with the visible anatomy defined, a finite element mesh capable of reproducing the visible anatomy was constructed by placing a thin layer of finite elements surrounding the visible surfaces. Realistic-feeling tissue properties were assigned to the elements, which were held in place by Dirichlet boundary conditions placed on the outer boundary of the finite element mesh.

Table 1 **Different anatomical structures coded separately**

| **Coded anatomical structures** |
|---|
| 1. Nasal septum |
| 2. Inferior turbinate |
| 3. Middle turbinate |
| 4. Superior turbinate |
| 5. Lamina papyracea |
| 6. Orbital fat |
| 7. Anterior ethmoids |
| 8. Posterior ethmoids |
| 9. Skull base |
| 10. Basal lamella |
| 11. Fontanelle |
| 12. Optic nerve |
| 13. Carotid artery |
| 14. Sphenoid sinus anterior face |
| 15. Sphenoid sinus posterior wall |
| 16. Sphenoid intersinus septum |
| 17. Planum sphenoidale |
| 18. Clivus |

*Note: Items 14–18 relate to extended endoscopic approaches to the skull base.*

Extensive work was performed to match tissue characteristics, including color and mobility, to enhance realism. This is of particular importance given that anatomic recognition through an endoscopic view is one of the most challenging tasks of ESS.[8] Recent advancements in software design have allowed previous models to include tissue deformability and mobility of the turbinates, which are also included in our model. This surmounts a major drawback of currently available silicone or plaster models: the inability to easily move tissues.[14]

Each anatomic nasal structure was coded with a specific label to allow measurements of performance metrics. For example, the simulator can calculate the percentage of each anatomic structure removed by the microdebrider. In addition, this individualized labeling allows specific tissue characteristics for each structure. A list of all the labeled structures is found in Table 1.

## Haptic Tools

The user visualizes the surgical field on a high-definition monitor as would be seen through a routine 0°, rigid Hopkins rod-lens endoscope. To create a lifelike feel to the surgery, the handle of the endoscope is akin to a real rod endoscope camera head (Fig. 2). Furthermore, a novel aspect of the MSESS is the ability for the endoscope to become soiled and thus blurry when the tip virtually contacts nasal mucosa, as would be expected during real-life surgery. The endonasal wash function, which is activated using a foot pedal, is used to clean the endoscope. Although the simulated nasal mucosa does not bleed, the latter feature of the simulator encourages the user to carefully position the endoscope tip during the virtual procedure.

The microdebrider is the tool used to complete the tasks on the simulator and is also activated using a pedal. The handle is similar to a commonly used pen-grip tool and harbors a wheel on the handle to rotate the cutting edge of the microdebrider (Fig. 2). It has a 4.0-mm outer diameter and a double serrating rotating tip. The tip moves at 5000 rpm and has the ability to suction and remove tissue. The decision to create a simulated microdebrider was based on the fact


*Figure 2.* *The tool handles for the endoscope and the microdebrider. (A) Endoscope handle; (B) microdebrider handle; (C) virtual view of the microdebrider's double serrating rotating tip.*

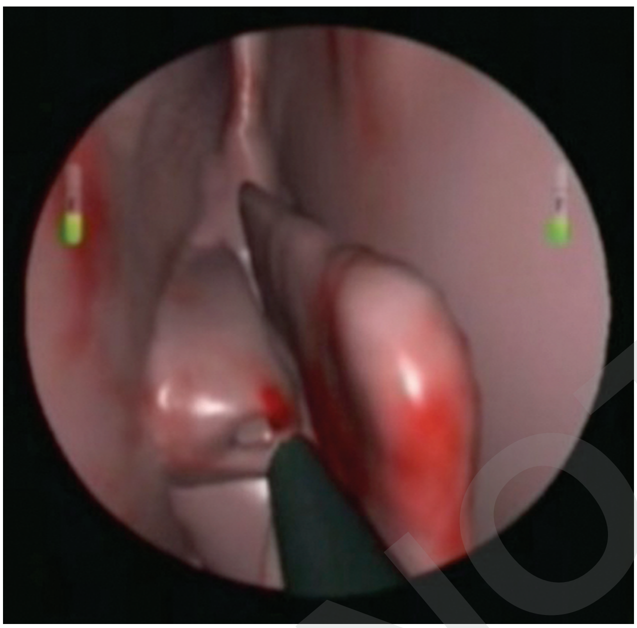

*Figure 3.* *Virtual view of user performing an anterior ethmoidectomy.*

*Figure 4.* *Virtual view of user performing a sphenoidotomy.*

that it is a particularly dangerous tool in ESS with potential complications of diplopia, blindness, carotid artery injury, cerebral spinal fluid leak, brain injury, and encephalocele.[15]

## Simulated Tasks

The five tasks that a user will perform on the simulator are as follows:

Task 1. Pass the endoscope from the nasal vestibule to the nasopharynx with minimal trauma to the nasal mucosa.
Task 2. Pass the endoscope and use the microdebrider to contact the maxillary ostium, sphenoid ostium, and nasopharynx.
Task 3. Complete anterior ethmoidectomy (Fig. 3).
Task 4. Complete posterior ethmoidectomy.
Task 5. Wide sphenoidotomy (Fig. 4).

Sinus surgery is a step-based intervention, beginning with the maxillary antrostomy, and then addressing the ethmoids, and finally the sphenoid sinus. The maxillary antrostomy is planned for future versions of the MSESS after the development of tools such as the sickle knife and the back-biter. Additionally, various angled scopes could be simulated. The five tasks were selected based on this stepwise approach. The tasks also increase in difficulty: tasks 1 and 2 are considered basic tasks; tasks 3 and 4 are more difficult; and task 5 is the most complex. Because there is a risk of severe complications with task 5 because of proximity of the carotid artery and optic nerve, simulation training is critically important for trainees before performing such a procedure in a live patient.

## Performance Metrics

The performance metrics collected by the MSESS can be thought of in three categories: safety, efficiency, and quality of final product. The metrics measured are quantitative data points created and exported by the simulator (transferred to a spreadsheet). Each structure within the nasal cavity has been labeled separately, which allows the measurement of metrics for each one. The metrics and their units are presented in Table 2. At the end of the simulation session, the trainee is provided with a series of scores for each performance metric.

# DISCUSSION

## Surgical Training in ESS

Surgical trainees commonly learn ESS on live patients, with significant patient safety concerns. Training on cadavers is limited because of the associated costs and availability,[8] along with the issue of inadequate tissue characteristics after embalmment.[16] Fortunately, simulation training provides a potential solution to the inadequacies of cadaver-based training and of patient safety concerns.

Using simulation based and virtual reality technologies, medical students, residents, and practicing physicians can learn and refine

Table 2 **Three spheres of performance metrics**

| Metric Sphere | Metric | Metric Measured (U) |
|---|---|---|
| Safety | Percentage of normal tissue removed | Percentage of total volume |
| | Contact with optic nerve | Yes or no |
| | Contact with carotid artery | Yes or no |
| | Force on each structure | mmHg |
| Efficiency | Duration of performance | s |
| | Average distance between endoscope and microdebrider | cm |
| | Distance travelled by microdebrider | cm |
| | Frequency of microdebrider activation | *n* |
| | Frequency of endonasal wash | *n* |
| Quality | Amount of residual ethmoids | Percentage of total volume |
| | Amount of residual sphenoid face | Percentage of total volume |

basic and advanced procedural skills before operating on patients.[17] Seymour *et al.* first established the benefit of simulation training on resident operating room performance and a possible reduction in complications.[18] Virtual reality training has since been used in many fields of medicine including laparoscopic surgery, gastroenterology, plastic surgery, ophthalmology, and dermatology.[3] In otolaryngology, there has been a great deal of work in the field of otology, with several simulation models having been created for temporal bone dissections.[19] There has also been some work in the field of rhinology with shown benefit of simulation training,[1,2,20] but currently there are no available virtual reality simulators with appropriate validity evidence supporting their integration into residency education. Compared with our otology colleagues, the advancements in the field of sinus surgery simulation remain underdeveloped, both in terms of the technology and in the ability to render patient-specific simulator models. The inherent difficulty in ESS relates to the mobility of nasal structures in a hollow space and the visualization of the surgical field through an endoscope.

The potential benefits of simulation training include objective measurements of surgical skill, reduction of patient risk, eventual simulation of complex procedures, and the standardization of residency training regardless of case load available at a particular institution.[20] Furthermore, the procedure can be practiced many times until proficiency is achieved, reducing the amount of time needed for a trainee to achieve comfort.[17]

## Educational Implications of MSESS

Traditionally, innovations in technology have driven the practice of teaching, whereas good teaching practices should drive technology.[21] There is, in fact, little standardization of metrics for the evaluation of a user's performance and minimal data on the integration of simulators into surgical educational curriculums.[21] The MSESS builds on previous simulator models to increase the educational value by providing users with advanced performance metrics in order for the trainee to identify specific areas requiring improvement. It also allows for objective comparison of their performance to those of experts, as well as to track their progression over time.

One of the innovative features of the MSESS is the large variety of performance metrics. A number of these metrics have already been validated for use in a neurosurgical model such as force, tool path length, and volume of tissue removed[22]; current work by our group aims to validate them in the sinus surgery model. As reported by Wiet and colleagues, a simulator can assess competency by objective measures, such as time of performance, rates of error, and economy of movement,[7] which have all been incorporated in the list of metrics currently being collected by the MSESS (Table 2). Although some metrics have been validated in neurosurgical simulators, all of the performance metrics are currently undergoing an extensive validation process with the MSESS. Here, we simply mention the measurement tools available to the user through the simulator.

Among the more novel component of the performance metrics is the measurement of force on various structures. Endoscopic surgeons are aware that certain areas of the nasal cavity such as the lamina papyracea are more sensitive to force; thus, it is important to be able to measure metrics with regard to these specific structures. The importance of force also highlights a downfall of cadaveric tissues, which may not allow for adequate estimation of the force necessary to perform endoscopic sinus procedures.[23] Furthermore, as described by Bakker *et al.*,[8] judging the location of the endoscope and the tool was one of the most challenging tasks of ESS. Thus, the MSESS allows measurement of bimanual dexterity, particularly the position of the endoscope relative to the microdebrider.

Currently, our technology only allows the use of the model based on one computed tomography scan, because each structure within the nasal cavity is labeled individually, which is an elaborate process to perform. Work is being performed to shorten this process to eventually allow patient-specific models. The use of 3D printing is a potential resource to help with patient-specific models for preoperative planning and education, as indicated by Waran *et al.*,[24] In contrast, virtual reality training has the additional benefits of providing a more realistic visual environment and providing feedback to the trainee through objective performance metrics. Future versions of the MSESS may be able to eventually address the issues of patient specificity.

## CONCLUSION

The MSESS incorporates novel technological advancements to create a realistic platform for trainees. To our knowledge, this is the first simulator to combine tools such as the endonasal wash and elaborate anatomic deformability with advanced performance metrics into a model that emulates real ESS. Research is continuing to collect evidence supporting the validity of the simulator, the performance metrics, and the validity of using this kind of educational technology within the current training curriculum.

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