



## Low-Cost Simulation Training Program for Endoscopic Sinus Surgery: Optimizing the Basic Skills Level

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### Abstract

**Purpose:** To develop and validate a low-cost simulation model and training program for the acquisition of basic skills in endoscopic sinus surgery, and a Specific Rating Scale (SRS) for the tasks performed in the model.

**Materials and Methods:** Experimental study. An eight-task low-cost simulation model was developed based on feeding bottles. Junior residents (R1), general otolaryngologists (ENT) and fellowship trained rhinologists (FSH) were recorded performing each task. Operative Time (OT) and number of errors (ERR) were measured. Videos were evaluated by two blinded experts using a validated Global Rating Scale (GRS) and SRS. A group of residents completed a six-session training program *via* deliberate practice and then were recorded and evaluated using the same methodology.

**Results:** Twenty-five participants were recruited. Statistically significant higher scores in the GRS and SRS, and lower OT and ERR at higher levels of expertise were found. A significant correlation between SRS and GRS was found. Seven R1 completed the training program. A significant median improvement of SRS and GRS scores, and a significant median reduction of OT and ERR were observed after training. Moreover, significant fewer ERR were made by R1 after training compared with experts, and no significant differences were found among these groups in terms of performance quality and OT.

**Conclusion:** Our low-cost simulation model can be accurately used as a validated objective assessment and training tool for basic endoscopic skills necessary for FESS, and can be potentially used in any otolaryngology surgical training program for residents.

**Keywords:** Endoscopic sinus surgery; Simulation training; Validation; Medical education

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### Introduction

Functional Endoscopic Sinus Surgery (FESS) is among the most performed surgeries in otolaryngology [1,2]. It is performed in a reduced and complex anatomical space, in close relation to important structures, resulting in iatrogenic complications in 1% of patients [3]. Specific technical skills and coordination of hand movements with endoscopic visualization must be developed by any otolaryngology trainee to achieve competence in this procedure and reduce the risk of error [4,5].

Acquisition of these skills require a long and rigorous period of training [6]. However, surgical exposure of trainees during their residency program have been diminishing over the past decade due to multiple factors including work hour restrictions, and the increased emphasis on patient's safety [4,6]. Therefore, traditional surgical training, which consists of intraoperative observation followed by practice under supervision, has been limited [7]. In this scenario, surgical simulation has demonstrated to be an efficient and effective tool in surgical skills acquisition [8]. It offers a safe environment where residents can repeatedly practice and improve their surgical skills, reducing the patient's risk [9,10]. Additionally, simulation models allow the deliberate practice of an objective and structured form of training, with real-time feedback and unbiased evaluation, improving the trainees' confidence and performance [7,11].

There are many FESS training models described in the literature. On recent years a number of

high-fidelity simulators such as virtual reality simulators have been validated, but their cost and availability limit their use [7,12-15]. In addition, virtual reality simulators have the drawback of suboptimal haptic feedback, if present at all. Ovine cadaveric models have also been recently validated [16,17]. Low-cost models reproducing anatomy such as silicone models were developed as a widespread alternative for novice surgeons [5,7]. Also, low-cost sinus surgery task trainers have been created and validated [18,19].

Validation process of any simulation training model requires to demonstrate face validity (similarity to a real scenario), content validity (relevance or usefulness of the model), construct validity (ability to detect different skill levels) and concurrent validity (comparison to a gold standard tool) [20].

The purpose of this study is to develop a low-cost task training simulation model for the acquisition of basic skills in FESS and a specific rating scale, assessing its face, content, construct and concurrent validities. Secondly, to evaluate skill acquisition by otolaryngology residents during simulation training using this model to warrant its incorporation into their curriculum.

## Methods

### Model design and development

A low-cost simulation model for acquisition of basic endoscopic competences was created using feeding bottles. The main objective was to recreate the small working space of the nose and narrow entrance of the nostrils with a consistency resembling the nasal vestibule. Two support bases were developed by fixing the bottles to a wooden structure, with 15° and 60° of inclination. The base of the feeding bottle was removed, in order to insert interchangeable Polyvinyl Chloride (PVC) tubes with different tasks. The PVC tube was held in place by an adjustable posterior support and the internal diameter of the bottle (Figure 1). A simple electrical circuit was incorporated by using a battery, a light, a buzzer, and two cables. One cable was connected to PVC internally coated with a copper strip and the other to the endoscope. One cable was connected to PVC internally coated with a copper strip and the other to the endoscope. This allowed the circuit to be closed turning the buzzer and light on when the endoscope touched the copper plaque strategically positioned depending on the evaluated task. Additionally, 0° and 45° 4 mm 18 cm rigid endoscopes (Karl Storz) connected to a telepack (Karl Storz), a 0° and 45° up biting non-cutting Blakesley nasal forceps (Karl Storz) and a needle holder were used to perform the tasks.

### Tasks design

Two experts identified basic skills required for endoscopic sinus surgery. Three main competences were determined. Based on them, eight progressive tasks were developed on PVC tubes:

**Competence 1:** Orientation and focus with a 0° and 45° endoscope.

- Focus maintenance and navigation with 0° endoscope (Figure 2A). A copper septum, which should not be touched during the task, separated the right and left cavity. Using a 0° endoscope, three small balls labeled from A to C should be focused and defocused on each side at a close distance that allowed the balls being in first plane.

- Focus maintenance and navigation with 45° endoscope (Figure 2B). Similarly, using a 45° endoscope, three small boxes

containing labels from A to C inside them should be focused and defocused on each side, avoiding the central septum.

- Focus maintenance and navigation with 45° endoscope with obstacles (Figure 2C). A copper wall with three holes of 1.5 cm of diameter was placed before three boxes with labels inside them from A to C. The 45° endoscope should pass through holes, without touching their wall, to visualize labels inside each box, and then be focused and defocused.

**Competence 2:** Hand-eye coordination.

- Rings transfer with 0° endoscope (Figure 2D). Using a 0° endoscope and a straight Blakesley nasal forceps, four small plastic rings should be moved from the anterior to the posterior nails.

- Lentils transfer with 0° endoscope (Figure 2E). Using a 0° endoscope and straight Blakesley nasal forceps, five lentils should be moved from an anterior to a posterior receptacle. The posterior receptacle has an opening slightly wider than the lentils diameter to make the task more difficult.

- Lentils transfer to the right model wall with 45° endoscope. Using a 45° endoscope and a 45° up biting Blakesley nasal forceps, five lentils should be moved from an anterior to a posterior receptacle located over the right lateral wall of the model. The posterior receptacle has an opening slightly wider than the lentils diameter to make the task more difficult.

- Lentils transfer to the left model wall with 45° endoscope. Similarly, using a 45° endoscope and a 45° up biting Blakesley nasal forceps, five lentils should be moved from an anterior to a posterior receptacle located over the left lateral wall of the model. The posterior receptacle has an opening slightly wider than the lentils diameter to make the task more difficult.

**Competence 3:** Suture in a reduced space.

- Septum suture. A septum made of corrugated cardboard and sponge, separated the right and left cavity. Using a 0° endoscope, a suture (4-0 vicryl PS2 needle) should be passed from one side through the septum to the other a total of four times. A knot should be made at the end of the suture to recreate a real septal quilting suture.

### SRS development

Two FESS experts constructed a Specific Rating Scale (SRS) considering a list of fundamental objectives for each task. This scale had eight sections (one per task), each one with three items to be evaluated with a Likert score from 1 to 5, with a maximum possible score of 120 points (Table 1). Based on the SRS, instructive videos for each task were recorded and then shown to the participants before training.

### Subjects

Before performance, informed consent was obtained, standardized orientation was given, and an initial demographic survey was applied to all participants. According to the initial demographic survey, three groups were formed among enrolled subjects: junior residents (R1), general otolaryngologists (ENT), and fellowship trained rhinologists (FSH). Two senior residents on their last year of training, and who completed their rhinology rotation were included in the ENT group. Participants' baseline characteristics are shown in Table 2. This project was formally reviewed and approved by the Scientific Ethics Committee of the Faculty of Medicine at Pontificia Universidad

**Table 1:** Specific rating scale.

	Not Achieved	Achieved with difficulty			Easily Achieved
<b>Task 1. Focus with 0° endoscope</b>					
Focus A, B and C (left side)	1	2	3	4	5
Focus A, B and C (right side)	1	2	3	4	5
No touching septum or balls	1	2	3	4	5
<b>Task 2. Focus with 45° endoscope</b>					
Focus A, B and C (left side)	1	2	3	4	5
Focus A, B and C (right side)	1	2	3	4	5
No touching septum or boxes	1	2	3	4	5
<b>Task 3. Focus with 45° endoscope and obstacles</b>					
Focus N°1	1	2	3	4	5
Focus N°2	1	2	3	4	5
Focus N°3	1	2	3	4	5
<b>Task 4. Rings transfer with 0° endoscope</b>					
Transfers four rings	1	2	3	4	5
No rings drop	1	2	3	4	5
No instrument crossover	1	2	3	4	5
<b>Task 5. Lentils transfer with 0° endoscope</b>					
Transfers five lentils	1	2	3	4	5
No lentils drop	1	2	3	4	5
No instrument crossover	1	2	3	4	5
<b>Task 6. Lentils transfer 45° endoscope (right side)</b>					
Transfers five lentils	1	2	3	4	5
No lentils drop	1	2	3	4	5
No instrument crossover	1	2	3	4	5
<b>Task 7. Lentils transfer 45° endoscope (left side)</b>					
Transfers five lentils	1	2	3	4	5
No lentils drop	1	2	3	4	5
No instrument crossover	1	2	3	4	5
<b>Task 8. Septum suture</b>					
Crosses septum four times	1	2	3	4	5
Needle crosses perpendicular to septum	1	2	3	4	5
No needle deterioration	1	2	3	4	5

Católica de Chile, Santiago, Chile (Project Number 16-198).

**Model and SRS validation**

Each participant performed the eight tasks. All participants were videotaped during their performance, assessing their Operative Time (OT) and Errors (ERR) such as touching the septum or dropping rings/lentils. Two blinded experts then assessed the videos with the Global Rating Scale (GRS) from the Objective Structured Assessment of Technical Skills (OSATS) [21], and with the SRS created to assess competence in the tasks performed in this model. Finally, a satisfaction survey (four areas, each with a score of 1 to 5) was completed by all participants (Table 3). Face and content validity were assessed by analyzing satisfaction survey data, and construct validity by comparing group’s performances. Concurrent validity of the newly SRS was assessed by making a correlation analysis with the validated GRS from the OSATS.

**Training program development and assessment**

A training program for otolaryngology residents was developed

using the simulation model. It consisted of a six-session personalized program of one hour each, where residents could train endoscopic skills using the simulation model *via* deliberate practice and receiving constructive feedback [11]. To evaluate the skills acquisition, once the training program was completed, participants were video-recorded performing the eight tasks for one last time, assessing their OT and ERR. The final videos were evaluated by the same two blinded experts using the GRS and SRS.

**Statistical analysis**

The data was analyzed with the STATA® version 13.0. Median and range were used for descriptive statics. Mann-Whitney and Kruskal-Wallis test (non-parametric) were used to assess differences among independent groups. Dunn’s test (non-parametric) was performed to assess pair wise comparisons among subgroups. Signed rank test was used to assess differences on the same group before and after training (non-parametric). The correlation between SRS and GRS was assessed with Spearman’s rank correlation coefficient. A P value <0.05 was considered statistically significant. The sample size and power

**Table 2:** Participants characteristics.

	n	Sex (M/F)	Age*	Clinic endoscopies*†	FESS*†
Junior Residents (R1)	13	6-7	26 (25-36)	0 (0-2)	0 (0)
Senior residents and Otolaryngologists (ENT)	9	4-5	36 (29-40)	60(30-80)	21 (10-30)
Fellowship trained rhinologists (FSH)	3	1-2	38 (32-42)	>100 (>100)	>50 (40-60)

\*Median (Range); †: During the last 12 months  
M: Male; F: Female

analysis were calculated based on data from a recent publication of a simulator validation (Standard Deviation 3.1, and a mean difference of 13.5) [22], obtaining a minimum of 3 experts, and other 3 non-experts.

## Results

Twenty-five participants were recruited (13 junior residents, 9 general otolaryngologists, and 3 fellowship trained rhinologists).

### Model and SRS validation

The Global Rating Scale from the OSATS showed significantly better scores at a higher level of expertise, with a median score of 12 points out of 35 (range, 9.5 to 29) for R1, 22 points (range, 15.5 to 30.5) for the ENT, and 33.5 (range, 28.5 to 35) for the FSH group (P=0.0009) (Figure 3A).

Considering the time to complete all the tasks, the OT analysis showed shorter median time in the FSH group (15.29 minutes (range, 10.84 to 16.9)) compared to the ENT (20.64 min (range, 16.59 to 27.2)), and the R1 (31.53 (range, 18.92 to 34.3)) (P=0.0003) (Figure 3B).

Significant less errors were found in the fellowship trained rhinologists group, with a median of 26 errors (range, 7 to 36) compared to the general otolaryngologists (33 errors (range, 25 to 111)), and the junior residents groups (97 errors (range, 26 to 217)) (P=0.0154) (Figure 3C).

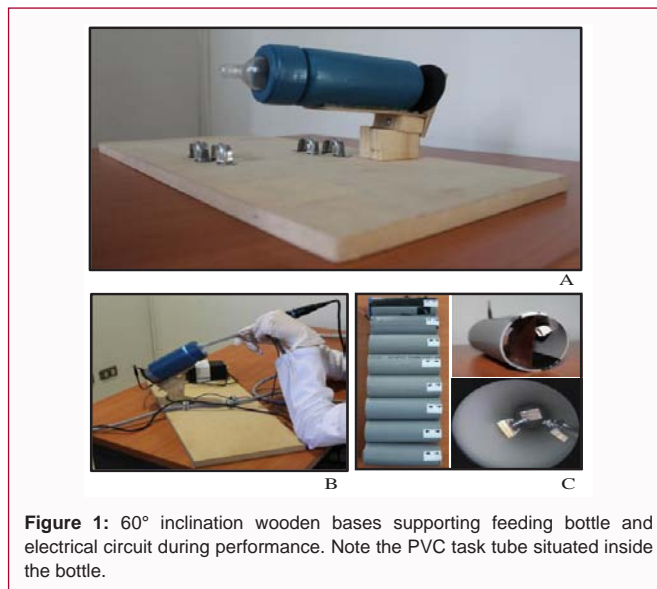
Finally, the newly SRS analysis demonstrated, similarly to GRS, significantly higher scores at an upper level of expertise, showing a mean score of 57 points out of 120 (range, 36 to 82) for the R1 group, 84.5 points (range, 71.5 to 101.5) for the ENT, and 106 points for the FSH group (92.5 to 118.5) (P=0.0002) (Figure 3D). A significant correlation (Rho=0.908, P<0.001) between the SRS and the GRS was found.

Pair wise comparison was obtained with Dunn’s test to determine how each subgroup differed from one another, showing that the FSH performed better than the R1 group in the GRS, OT, ERR and SRS (P=0.004, 0.002, 0.034, 0.002, respectively). Likewise, the ENT group performed better than the R1 in GRS, OT and SRS (P=0.016, 0.008, 0.003, respectively), but not in ERR (P=0.125).

Satisfaction survey analysis showed that 95% of participants agreed that the training in the simulation model is applicable to procedures in a real clinical environment and that it is useful for learning nasal endoscopic skills. All participants completely agreed

**Table 3:** Satisfaction survey applied to participants.

	Strongly Disagree				Strongly Agree
1. I believe that the simulation model is useful for learning nasal endoscopic skills	1	2	3	4	5
2. I believe that the training in the simulation model is applicable to procedures in a real clinical environment	1	2	3	4	5
3. I would recommend training in the simulation model to a colleague	1	2	3	4	5
4. I would like to have this training as part of my formal instruction in endoscopic sinus surgery	1	2	3	4	5



**Figure 1:** 60° inclination wooden bases supporting feeding bottle and electrical circuit during performance. Note the PVC task tube situated inside the bottle.

that they would recommend training in the simulation model to a colleague and it would be useful to have this training as part of a formal instruction in endoscopic sinus surgery.

### Training program results

Seven R1 completed the training program. Their performance data before and after training are shown in Table 4. A significant median improvement of 19.5 points (P=0.0178) and 40.5 points (P=0.0178), in the GRS and SRS respectively, was observed compared to their initial performance (Figure 4A, 4B). A significant median OT reduction of 18.2 min (P=0.018; Figure 4C) and median reduction of 53 errors (P=0.0178; Figure 4D) were also observed.

When compared to the FSH group, no statistically significant differences were found in the performance of R1 in terms of GRS (P=0.5664; Figure 4A), SRS (P=0.9093; Figure 4B) or OT (P=0.0874; Figure 4C). Moreover, the ERR analysis showed significant less errors in the R1 after training in the simulation model (P=0.0135; Figure 4D).

## Discussion

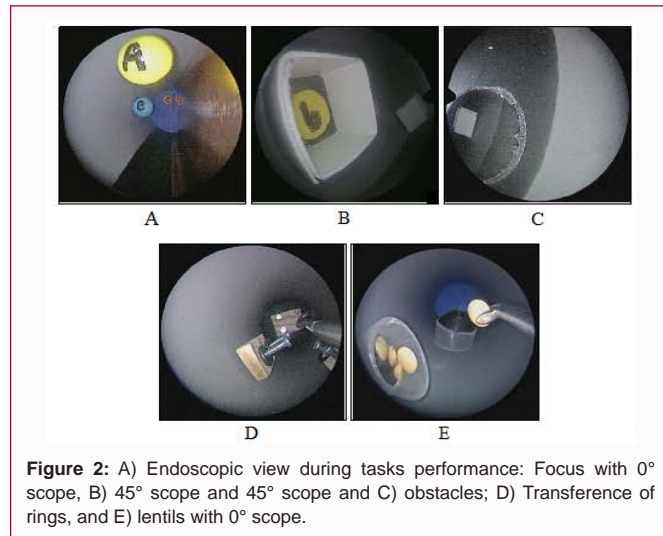
In this study we developed a low-cost task trainer simulation model for the acquisition of basic endoscopic skills. The model was constructed using feeding bottles, a wooden structure and PVC tubes with a total estimated cost of 15 USD. Likewise, a simple SRS for the



**Table 4:** R1 performance before and after training program.

	Before Training*	After Training*
Global Rating Scale (GRS)	12 (9.5-29) points	31.5 (28-35) points
Specific Rating Scale (SRS)	66.5 (52-82) points	107 (96.5-118) points
Operative Time (OT)	28.72 (18.92-32.66) min	10.52 (8.6-12.45) min
Errors (ERR)	52 (26-175) errors	0 (0-4) errors

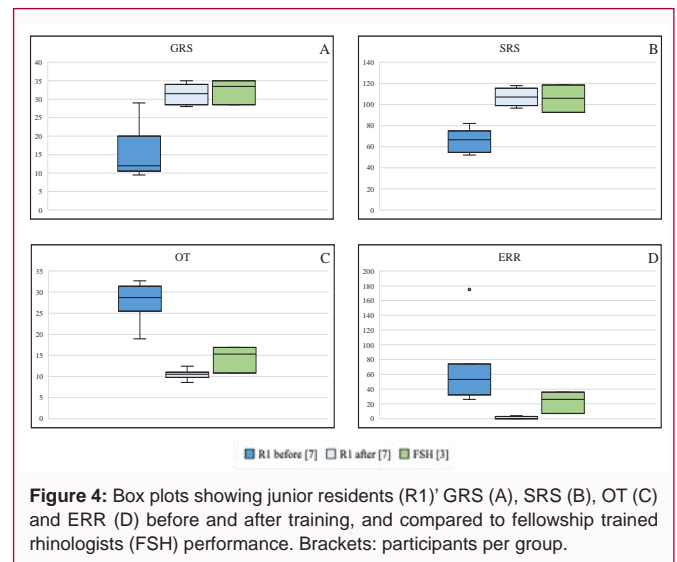
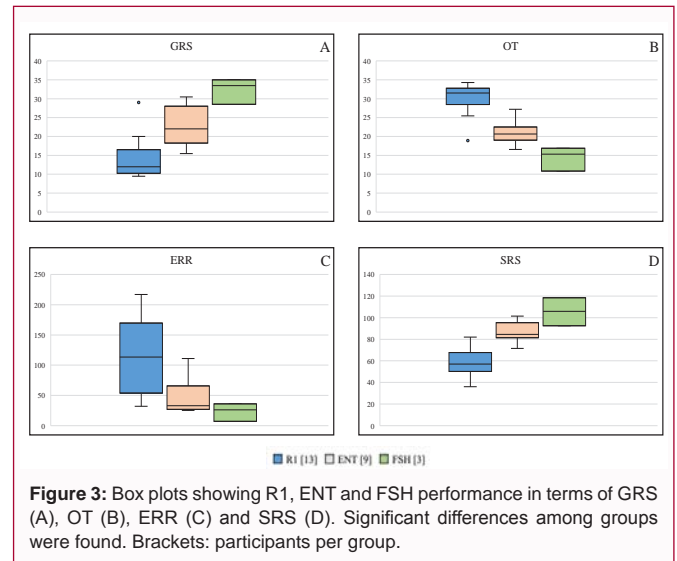
\*Median (Range) n=7



evaluation of tasks performed in the model was developed by experts and validated in this study. These accessible and straightforward easy to replicate tools allow the objective evaluation of basic endoscopic skills, a useful assessment in any training program.

GRS, SRS, OT and ERR analysis, all showed statistically significant differences among groups, and therefore, the model was able to discriminate among different levels of endoscopic performance. Face and content validity were assessed using the satisfaction survey, where over 95% of participants agreed that the training in the simulation model is applicable to procedures in a real clinical environment, and that tasks performed in the model are useful for learning nasal endoscopic skills, respectively. The SRS concurrent validity was also assessed making a correlation analysis between this newly scale and the validated OSATS' GRS [21].

The resident's training assessment showed endoscopic skills acquisition by deliberate practice using the model and personalized feedback. In a short program of six-sessions, equivalent to six hours of practice, residents demonstrated a significant improvement in their quality of performance (GRS and SRS), OT, and ERR. All residents who completed the training improved their endoscopic skills. Interestingly, after training, even the worst performance was better than the best performance before the training, in terms of SRS, OT and ERR. Moreover, compared to the FSH group, residents after training performed similarly in terms of GRS, SRS and OT (no statistically significant differences were found), and even significantly better in terms of the ERR (Table 4 and Figure 4). All these results together, show that the training program enabled our residents the acquisition of basic endoscopic skills comparable to those of an experienced sinus surgeon in the simulation model. For this reason, it has been incorporated into our resident's formation program. This has allowed our residents to make the most of their surgical opportunities, being able to practice operative techniques from the



very beginning of their surgical exposure instead of wasting time acquiring basic endoscopic skills.

The main aim of any surgical simulation program is to accelerate the learning curve before a junior surgeon begins performing in a real clinical scenario [19]. In a context of increasingly limited surgical exposition, enhanced by the COVID-19 pandemic context where elective endoscopic procedures should be restricted [23], our training program and low-cost model serve as a task trainer of fine motor skills and endoscope handling, especially useful for junior residents who may achieve basic competence faster, and thus, take more advantage of surgical opportunities in the operating room. Other FESS simulation models have been developed and validated. During the last decade a number of high-fidelity simulators such as virtual reality simulators have been validated. However, they are mostly aimed for the training of surgical techniques and their high-cost limit their accessibility. In addition, virtual reality simulators have the drawback of suboptimal haptic feedback, if present at all.

Other low-cost task trainers have been described in the literature in the past years. Steehler et al. [18,24] developed and validated a biologic sinus surgery task trainer aimed to five main tasks: Recess

probing, targeted injections, removal of superior sutures, extraction of posterior beads, and anrostomy of an egg with removal of contents. After that, a relative paucity of these models occurred, until Harbison et al. [19] developed and validated a silicone rubber oriented to nine tasks that included two endoscopic visualization tasks using a 0° nasal endoscope, a straight suction task, a sinus injection task, and a pin removals using forceps with 0° and 30° endoscopes. Our simple to replicate feeding bottle-PVC model aims to develop basic endoscopic manual skills, including endoscopic navigation, eye-hand coordination, and fine motor dexterity. Future versions of our model could include anatomical orientation, suction tasks, and pin placement/removal along strategic anatomical locations.

A limitation of this model is that it aims to develop basic endoscopic skills. Tasks directed to develop anatomical orientation and learn specific surgical techniques are not included. Thus, although any resident can benefit from increasing or polishing his or her endoscopic basic skills set, this simulation model is mainly oriented to junior residents so they can start learning surgical techniques once they have acquired the minimum set of skills required. Another possible limitation of this study is that it represents a single institution experience, making face and content validation through satisfaction survey likely biased. Lastly, R1 final performance results are just limited to skills in the simulation model, and may not predict a real FESS performance. Further studies improving anatomical fidelity, including participants from outside institutions, and assessing transfer of these skills to the operating room are in progress.

## Conclusion

Our FESS training program including a low-cost model with easily applicable ratings scales can be applied for the objective assessment and training of basic endoscopic skills. This low-cost simulation training program can be potentially used in any otolaryngology surgical training program for residents.

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