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ORIGINAL CONTRIBUTION

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Low-cost simulation training program for endoscopic sinus surgery: optimizing the basic skills level*

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Abstract

Background: The purpose of this study is to develop and validate a low-cost simulation model and training program for the acquisition of basic skills in endoscopic sinus surgery.

Methodology: Experimental study. An eight-task low-cost simulation model was developed based on feeding bottles. Junior residents, general otolaryngologists, and fellowship-trained rhinologists (experts) were recorded performing each task. Operative time and number of errors were measured. Videos were evaluated by two blinded experts using a validated global rating scale (GRS) and a specific rating scale (SRS). A group of residents completed a six-session training program 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 operative time and errors at higher levels of expertise were found. A significant correlation between SRS and GRS was found. Seven residents completed the training program. A significant improvement of SRS and GRS scores and reduction of operative time and errors were observed after training. Moreover, compared to experts, statistically significant fewer errors were made by residents after training, and no significant differences were found in terms of performance quality and operative time among these groups.

Conclusions: 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.

Key words: rhinosurgery, otorhinolatyngologic surgical procedures, simulation training, medical education

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 requires a long and rigorous period of training[6]. However, surgical exposure of trainees during their residency program has been diminishing over the past decade due to multiple factors including work hour restrictions, and the increased emphasis on patient 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 been 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].

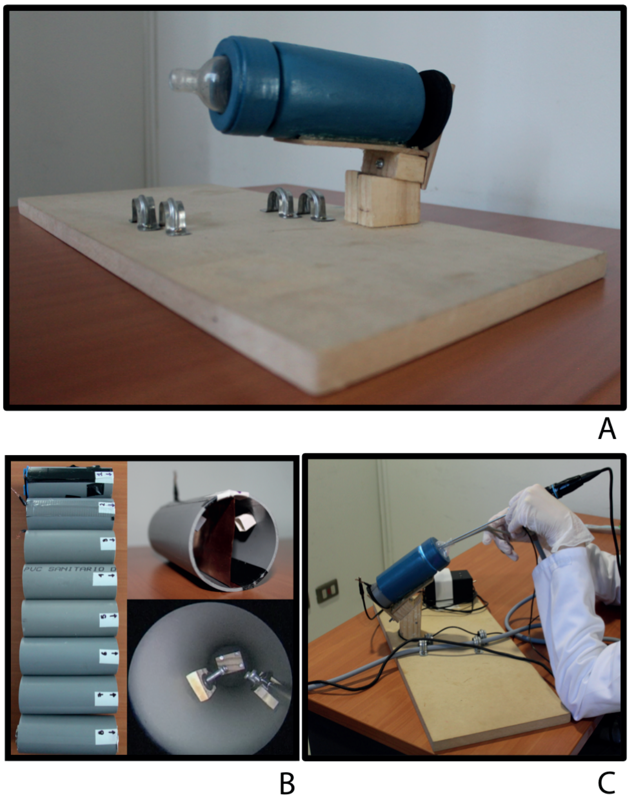

Figure 1. A) 15º inclination wooden base supporting feeding bottle; B) Eight PVC task tubes to be situated inside the bottle; C) 60º inclination and electrical circuit during performance.

There are many FESS training models described in the literature. In recent years several high-fidelity simulators such as virtual reality simulators have been validated, but their cost and availability limit their use[7,12-15]. Also, 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].

The 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.

Materials and methods

Model design and development

A low-cost simulation model for the 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 15º and 60º of inclination. (Figure 1A). The base of the feeding bottle was removed, in order to insert interchangeable polyvinyl chloride (PVC) tubes with different tasks (Figure 1B). The PVC tube was held in place by an adjustable posterior support and the internal diameter of the bottle. A simple electrical circuit was incorporated by using a battery, a light, a buzzer, and two cables. One cable was connected to a PVC internally coated with a copper strip and the other to the endoscope. One cable was connected to a 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 cooper plaque strategically positioned depending on the evaluated task (Figure 1C). Additionally, 0º and 45º 4mm 18cm rigid endoscopes (Karl Storz) connected to a telepack (Karl Storz), a 0º and 45º 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 0º and 45º endoscope.

- Focus maintenance and navigation with 0º endoscope (Figure 2A). A copper septum, which should not be touched during the task, separated the right and left cavity. Using a 0º endoscope, three small balls labeled from A to C should be focused and defocused on each side.
- Focus maintenance and navigation with 45º endoscope (Figure 2B). Similarly, using a 45º 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 45º endoscope with obstacles (Figure 2C). A copper wall with three holes of 1.5 cm in diameter was placed before three boxes with labels inside them from A to C. The 45º 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 0º endoscope (Figure 2D). Using a 0º endoscope and a straight Blakesley nasal forceps, four small plastic rings should be moved from the anterior to the posterior nails.
- Lentils transfer with 0º endoscope (Figure 2E). Using a 0º endoscope and straight Blakesley nasal forceps, five lentils should be moved from an anterior to a posterior receptacle.

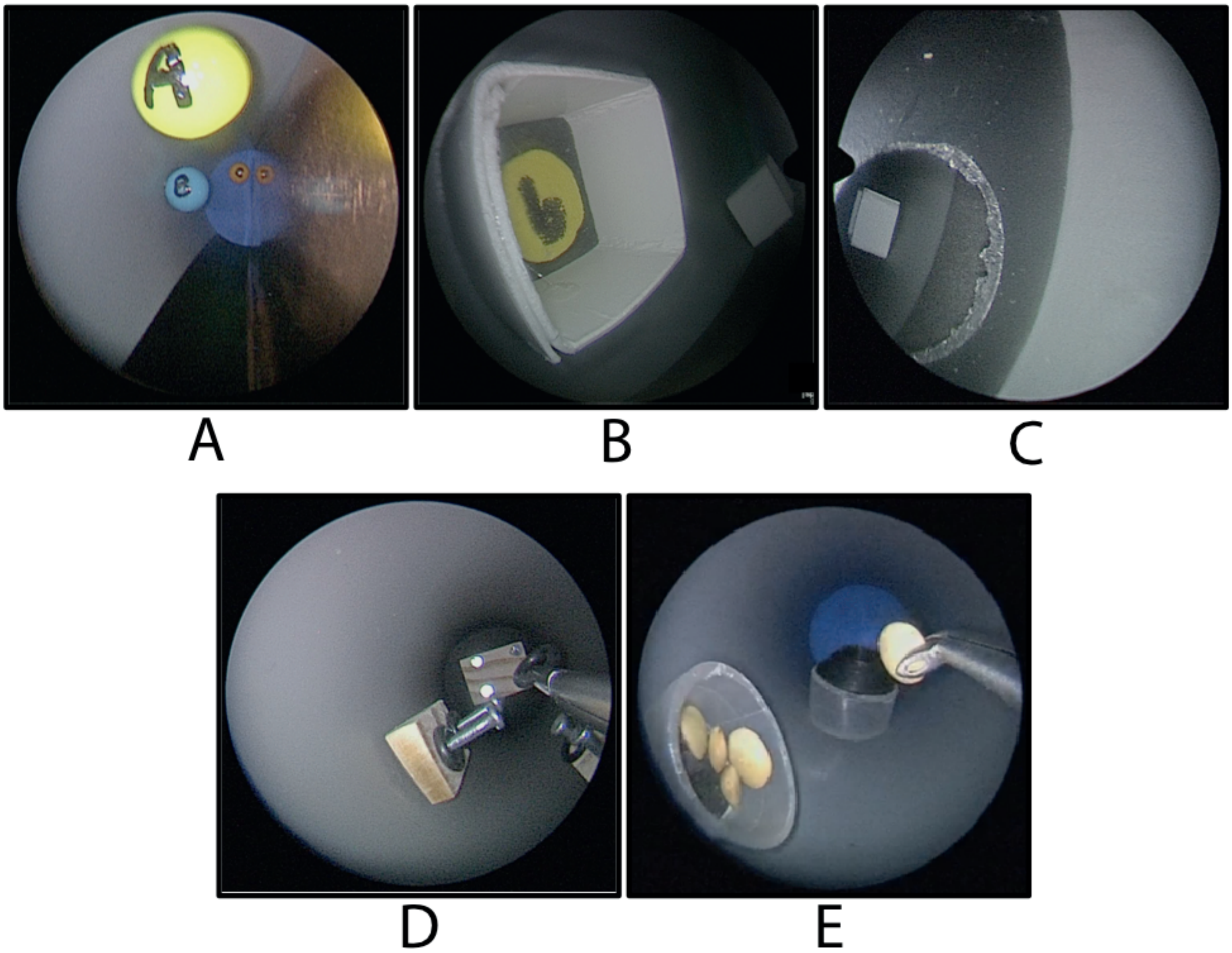

Figure 2. Endoscopic view during tasks performance: A) Focus with 0º scope, B) 45º scope and C) 45º scope & obstacles; D) transference of rings, and E) lentils with 0º scope.

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 45º endoscope. Using a 45º endoscope and a 45º 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 45º endoscope. Similarly, using a 45º endoscope and a 45º 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 0º 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

The entire team of the otolaryngology department of the Pontifical Catholic University of Chile was invited to participate in this study. First, informed consent was obtained, explaining to each participant that their performance would be videotaped and

Table 1. Specific rating scale.

	Not Achieved				Easily Achieved
Task 1. Focus with 0º endoscope					
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
Task 2. Focus with 45º endoscope					
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
Task 3. Focus with 45º endoscope & obstacles					
Focus Nº1	1	2	3	4	5
Focus Nº2	1	2	3	4	5
Focus Nº3	1	2	3	4	5
Task 4. Rings transfer with 0º endoscope					
Transfers four rings	1	2	3	4	5
No rings drop	1	2	3	4	5
No instrument crossover	1	2	3	4	5
Task 5. Lentils transfer with 0º endoscope					
Transfers five lentils	1	2	3	4	5
No lentils drop	1	2	3	4	5
No instrument crossover	1	2	3	4	5
Task 6. Lentils transfer 45º endoscope (right side)					
Transfers five lentils	1	2	3	4	5
No lentils drop	1	2	3	4	5
No instrument crossover	1	2	3	4	5
Task 7. Lentils transfer 45º endoscope (left side)					
Transfers five lentils	1	2	3	4	5
No lentils drop	1	2	3	4	5
No instrument crossover	1	2	3	4	5
Task 8. Septum suture					
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

later evaluated while maintaining anonymity. Then, 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 Católica de Chile, Santiago, Chile (Project Number 16-198).

Model and SRS validation

After a standardized orientation was given by showing instructive videos, which considered the objectives for each task, each participant, one at a time, performed the eight tasks alone, unsupervised, in a quiet room. All participants were videotaped during their performance. Finally, a satisfaction survey (four areas, each with a score of 1 to 5) was completed by all participants (Table 3). Later, two blinded expert independently 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. Operative time (OT) and errors (ERR) such as touching the septum or dropping rings/lentils were also assessed. Face and content validity were assessed by analyzing satisfaction survey data and construct validity by comparing the group's performances. The concurrent validity of the newly SRS

Table 2. Participant 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 & Otorayngologists (ENT)	9	4/5	36 [29-40]	60 [30-80]	21 [10-30]
Fellowship-trained rhinologists (FSH)	3	2/1	38 [32-42]	>100 [>100]	>50 [40-60]

*Median [Range]. †During the last 12 months. Abbreviations: M, male; F, female.

Table 3. Satisfaction survey applied to participants.

	Not Achieved				Easily Achieved
I believe that the simulation model is useful for learning nasal endoscopic skills	1	2	3	4	5
I believe that the training in the simulation model is applicable to procedures in a real clinical environment	1	2	3	4	5
I would recommend training in the simulation model to a colleague	1	2	3	4	5
I would like to have this training as part of my formal instruction in endoscopic sinus surgery	1	2	3	4	5

Table 4. Junior residents performance before and after the 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].

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 pairwise comparisons among subgroups. Signed rank test was used to assess differences in 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 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, 9.5-29] for R1, 22 points [range, 15.5-30.5] for the ENT, and 33.5 [range, 28.5-35] for the FSH group (P = 0.0009) (Figure 3A).

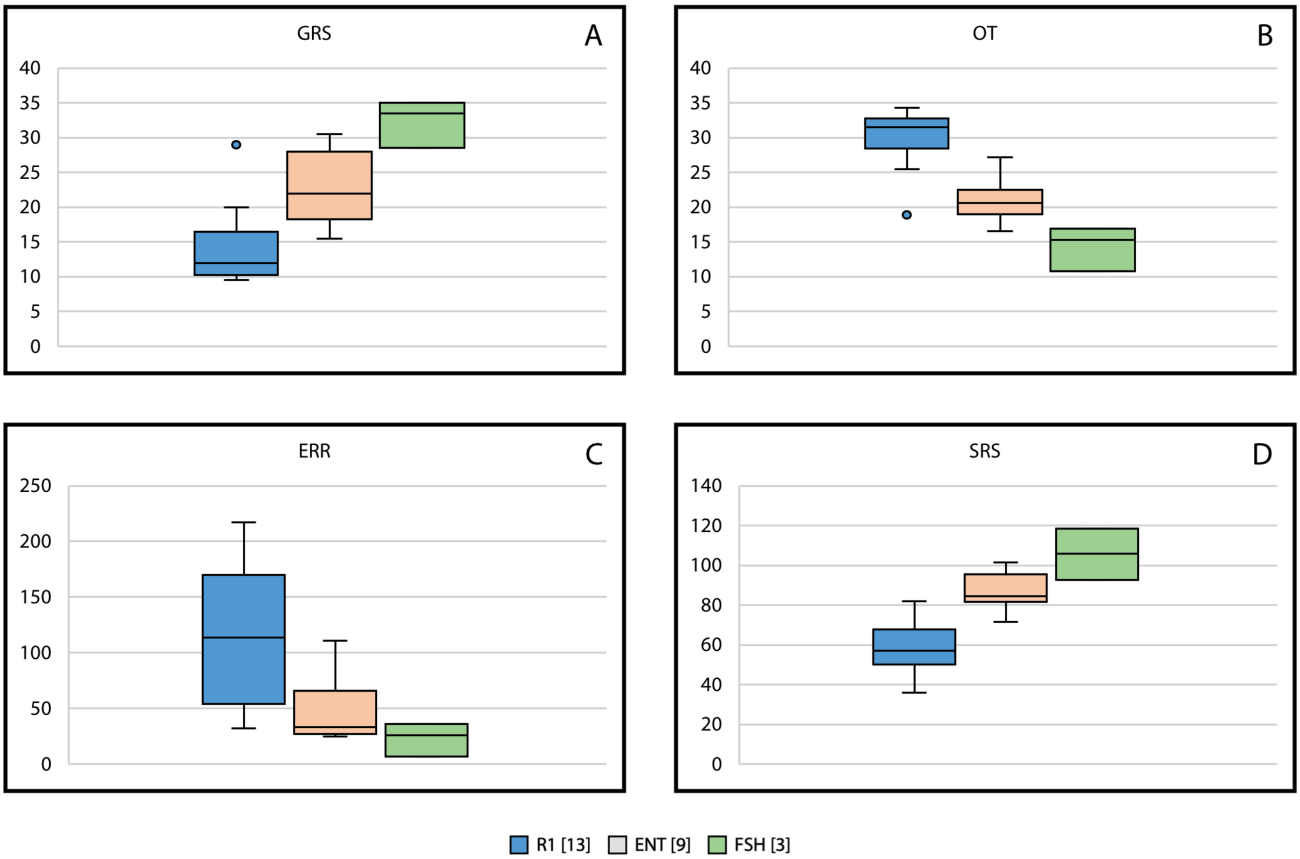

Figure 3. Boxplots showing R1, ENT and FSH performance in terms of GRS (A), OT (B), ERR (C) and SRS (D). Significant differences among groups were found. Brackets: participants per group.

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

Significant fewer errors were found in the fellowship-trained rhinologists group, with a median of 26 errors [range, 7-36] compared to the general otolaryngologists (33 errors [range, 25-111]), and the junior residents groups (97 errors [range, 26-217]) (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, 36-82] for the R1 group, 84.5 points [range, 71.5-101.5] for the ENT, and 106 points for the FSH group [92.5-118.5] ((P = 0.0002) (Figure 3D). A significant correlation (Rho=0.908, P < 0.001) between the SRS and the GRS was found.

A pairwise 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 applies to procedures in a real clinical environment and that it is useful for learning nasal endoscopic skills. All participants completely agreed that they would recommend training in the simulation model to a colleague and it would be useful to have this training as part of 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) in the GRS was observed compared to their initial performance (Figure 4A). A significant median OT reduction of 18.2 minutes (P =0.018; Figure 4B) and a median reduction of 53 errors (P =0.0178; Figure 4C) was also observed. Also, a significant median improvement of 40.5 points (P = 0.0178) in the SRS was observed after training in this group.

When compared to the FSH group, no statistically significant differences were found in the performance of R1 after training

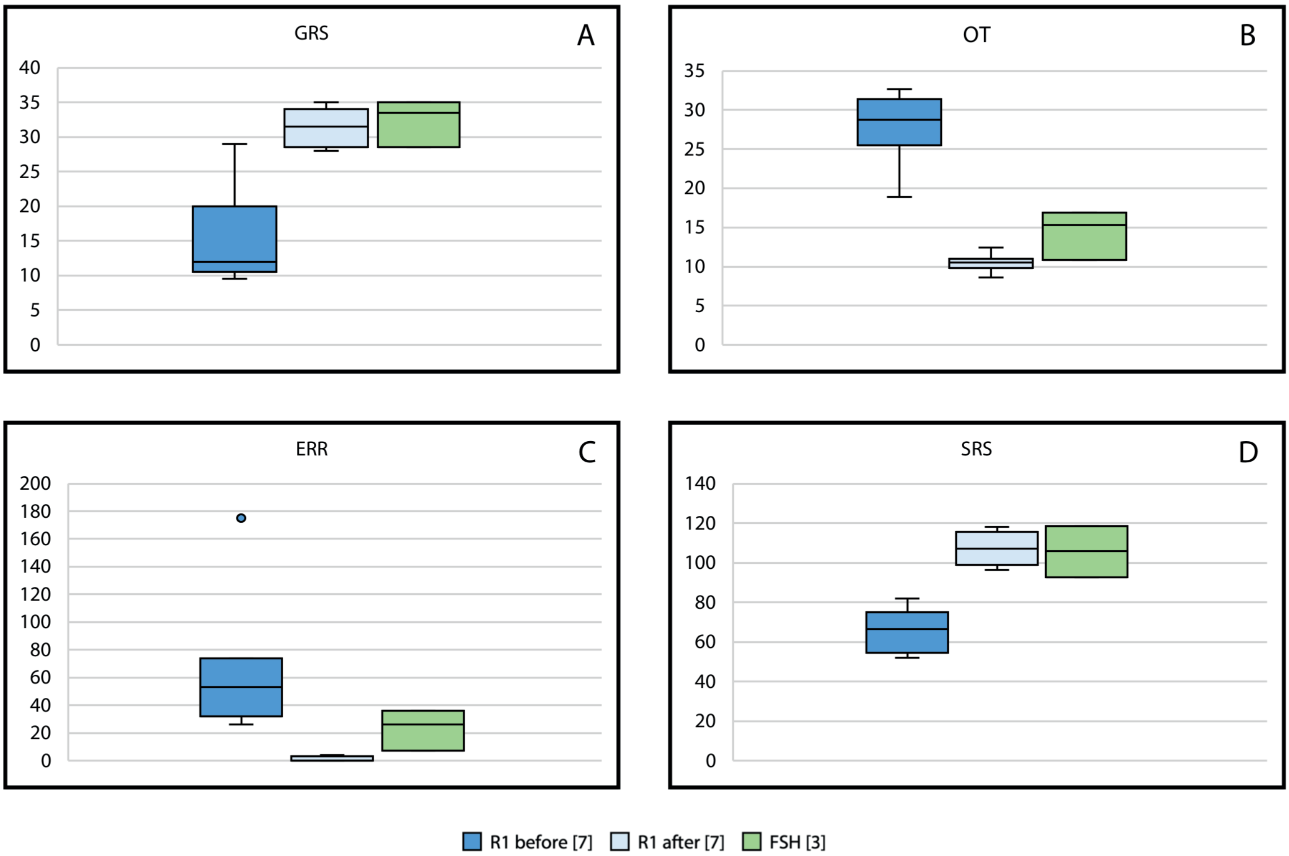

Figure 4. Boxplots showing junior residents (R1)' GRS (A), OT (B), ERR (C), and SRS (D), before and after training, and compared to fellowship-trained rhinologists (FSH) performance. Brackets: participants per group.

in terms of GRS (P = 0.5664; Figure 4A), OT (P = 0.0874; Figure 4B) or SRS (P = 0.9093; Figure 4D). Moreover, the ERR analysis showed significantly fewer errors in the R1 after training in the simulation model (P =0.0135; Figure 4C).

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 production cost of €15. Likewise, a simple SRS for the 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 applies 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 new 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, several high-fidelity simulators such as virtual reality simulators have been validated, becoming an essential part of training in medicine[24]. However, their high-cost limit their accessibility, and have the drawback of suboptimal haptic feedback.
Other low-cost task trainers have been described in the literature in the past years. Steehler et al.[18,25] developed and validated a biologic sinus surgery task trainer aimed at five main tasks: recess probing, targeted injections, removal of superior sutures, extraction of posterior beads, and antrostomy 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 0º nasal endoscope, a straight suction task, a sinus injection task, and pin removals using forceps with 0º and 30º 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. The reduced number of participants in the FSH group compared to the other groups was due to the availability of fellowship trained rhinologists to participate. However, we believe that this did not affect the study results as the sample size calculated was 3 participants in each group. 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 the 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.

Authorship contribution

AR: experiments performance, analysis and interpretation of data, manuscript writing. SP: study and model conception and development, drafting the article, final approval of article. TM: model development, experiments performance, analysis and interpretation of data, final approval of article. FGH: experiments performance, analysis and interpretation of data, final approval of article. CG: study and model conception, final approval of article. JV: study design, interpretation of the results, final approval of article. CC: project direction, study and model conception and development, implementation of the research, drafting the article, final approval of article.

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Ethics approval and consent to participate

This project was formally reviewed and approved by the Scientific Ethics Committee of the Faculty of Medicine at Pontificia Universidad Católica de Chile, Santiago, Chile (Project Number 16-198).

Consent for publication

Not applicable.

Availability of data and materials

Not applicable.

Conflict of interest

The authors declare no conflict of interest.

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