Hybrid Robotics for Endoscopic Skull Base Surgery: Preclinical Evaluation and Surgeon First Impression

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■ BACKGROUND: **A robotic endoscope holder should theoretically provide various advantages in transnasal endoscopic skull base surgery, but only recently has a robotic system become commercially available. The objective of this study was to provide a preclinical evaluation of potential advantages and surgeon first impression of this robotic hybrid solution.**

■ METHODS: **Thirty skull base surgeons, attending the Joint European Diploma of Endoscopic Skull Base Surgery 2018–2019 in Paris, France, were enrolled. A questionnaire, mainly concerning personal surgical experience and habits, was administered. The test phase consisted of 2 different dry-lab tasks, performed with and without EndoscopeRobot, according to randomization and on 2 different days. A modified NASA Task Load Index test was subsequently administered via e-mail to all participants. Completion times and modified Global Evaluative Assessment of Robotic Skills in Endoscopy scores of the videotaped tasks were recorded.**

■ RESULTS: **Nineteen otorhinolaryngologic surgeons and 11 neurosurgeons, with different surgical habits and endoscopic experience, were enrolled. No one appeared unfavorable a priori to robotic endoscopic surgery. Although the robot did not provide an advantage in the simple grasping task 1, a trend toward better completion times and efficacy was evident in the bimanual task 2, when performed with the robot and bimanually. According to the modified NASA Task Load Index test, surgeons felt more successful with the robot in task 2, finding it less stressful and mentally demanding.**

■ CONCLUSIONS: **Endoscopic skull base surgeons seem to view a hybrid robotic solution positively. EndoscopeRobot seems to provide a benefit to the single surgeon with experience in bimanual endoscopic surgery. Further preclinical and clinical evaluation of this technology is necessary.**

INTRODUCTION

Robotics has already been applied to several surgical fields.[1,2] Different prototypes have been described for endoscopic transnasal skull base surgery,[3-5] with clinical applications limited to a robotic arm rest[6] or transoral robotic surgery.[7] Recently, a hybrid robotic system dedicated to endoscopic transnasal skull base surgery (EndoscopeRobot [Medineering Surgical Robotics, Munich, Germany]) has become available for clinical practice. The theoretical advantages of robotic systems include tremor filtration[8] and reduced fatigue for the surgical team, especially in case of long bimanual procedures. An additional benefit provided by a hybrid solution is the combination of robotic precision with the direct control of the endoscope movements by the surgeon.[9] Significant advances in surgical robotics have been made, but a role for robot-based

Key words
- Endoscope holder
- Endoscopy
- Preclinical
- Robotics
- Skull base surgery
- Transsphenoidal

Abbreviations and Acronyms
ENT: Otorhinolaryngologist
GEARS-E: Global Evaluative Assessment of Robotic Skills in Endoscopy
NS: Neurosurgeon

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applications in transnasal endoscopic skull base surgery has not yet been defined.[10] Furthermore, although surveys on robotics from both a neurosurgeon (NS) and otorhinolaryngologist (ENT) point of view are available,[11,12] they are not dedicated to skull base surgery, but rather other subspecialties from both disciplines. This study was therefore conceived to provide a preclinical evaluation of potential advantages and surgeon first impression of a hybrid robotic solution for transnasal endoscopic skull base surgery.

Video

Video available at www.sciencedirect.com

MATERIALS AND METHODS

All attendees of the Joint European Diploma of Endoscopic Skull Base Surgery 2018–2019 in Paris, France, were enrolled in the study. Each participant signed a study consent form and answered a questionnaire, mainly concerning personal surgical experience and habits (Supplementary Table 1).

The test phase was structured in a 2-day session and consisted of performing 2 different dry-lab tasks with a 0° endoscope (Karl Storz, Tuttlingen, Germany), with and without the EndoscopeRobot (Videos 1 and 2; further details are subsequently discussed). A modified NeuroEndoTrainer[13] was used to simulate the nasal cavity and skull base (Figure 1). An instructional video was shown to all participants before the tasks; surgeons were given 3 minutes before the task performance with the robot to familiarize themselves with EndoscopeRobot. Participants were randomized into 2 groups to partially control the effects of surgical learning (Figure 2).[14,15]

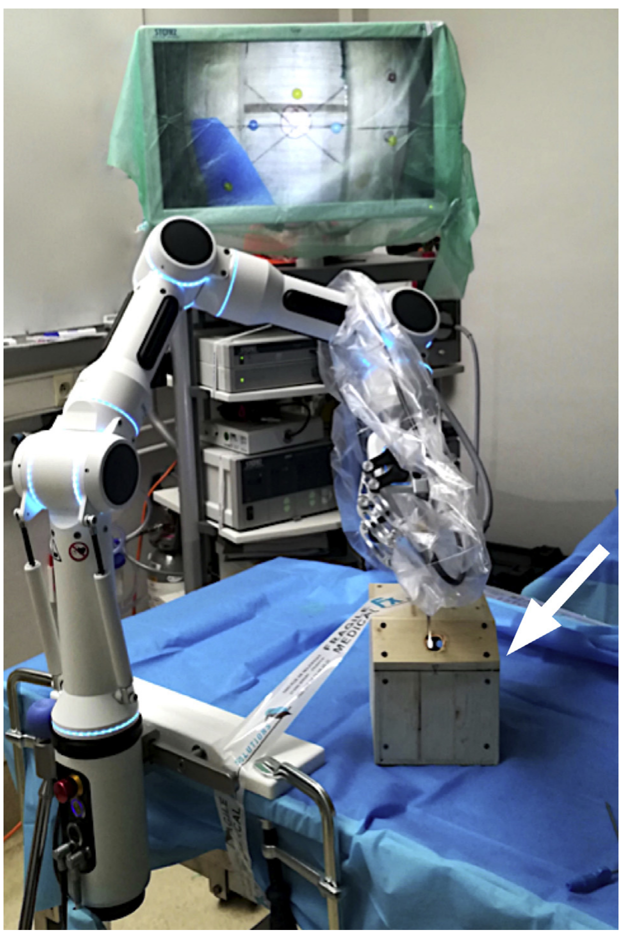

Figure 1. Robotic setup for task 1. The robotic arm and modified NeuroEndoTrainer (*arrow*) are fixed to the laboratory table; 2 entry ports can be seen on the model. The endoscope is introduced through the simulated right nostril. A semitransparent cover with a hole at the center is positioned over the screen.

EndoscopeRobot

EndoscopeRobot (Figures 1 and 3) is a compact robot specifically developed to work as an endoscope holder during transnasal interventions. It is made up of 4 components: a small, robotic, endoscope holder; the positioning arm; the control unit (foot pedal); and the power source. The positioning arm has 7 degrees of freedom; therefore, it can be driven in every position of space by simultaneous manual unlocking of 2 joints. At its base, it can be fixed directly to the operating room table; its superior end is connected to the endoscope robotic holder. Once attached to the holder and positioned inside the nasal cavity, the endoscope can be orientated upward, downward, or laterally by using the joystick on the foot pedal; furthermore, it can be moved in or out by pressing different pads on the foot pedal. Also, one particular button has the function to make the robot return to a previously saved home position in every moment during surgery.

Modified NeuroEndoTrainer

NeuroEndoTrainer, a low-cost training model, has been recently developed in India and validated.[13] It is a box containing an angled activity plate, replicating the dimensions of the surgical field in transnasal endoscopic skull base surgery. The original box has a single entry port. The model was modified to allow for the evaluation of bimanual tasks: 2 entry ports were therefore created (Figure 1). The activity plate was fixed at an angle of 45° and 9 cm from the entry point to simulate a relatively deep surgical field.

Task 1

A grasping maneuver was simulated in the first task (Figures 4A and B, and Video 1). The endoscope was introduced through the simulated right nostril and the grasping instrument through the left one. The surgeon had to move the endoscope in different consecutive positions, where pins were placed (Figures 4A and B, and Video 1); once the target was at the center of the screen (which was covered by a semitransparent cover) (Figure 1), the pins could be removed with Weil grasping forceps. Participants were asked to perform the task as quickly and precisely as possible; the endoscope was held with the nondominant hand or the robot, according to randomization.

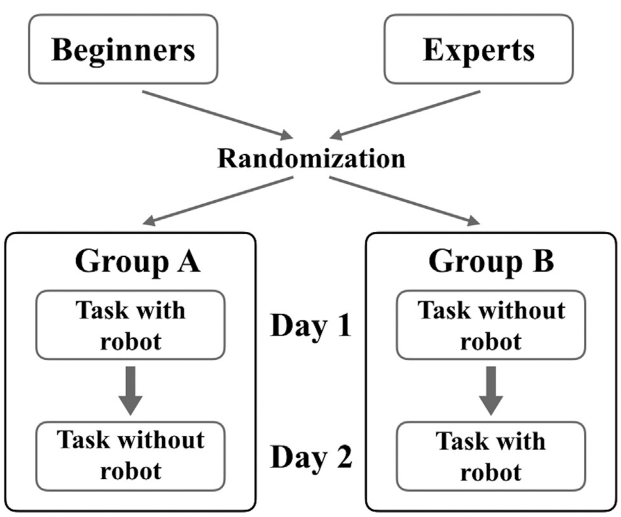

Figure 2. Randomization scheme. Group A started the test with the robot on day 1 and performed the tasks without the robot on day 2. Vice versa for group B.

Task 2

The placement of a nasoseptal flap was simulated in the second task (**Figures 4C** and **D**, and **Video 2**). Surgeons were asked to grasp a simulated flap with 2 small holes and position them over 2 separate pins. The endoscope was introduced through the simulated right nostril. In the robotic phase, surgeons moved the endoscope with EndoscopeRobot foot pedal and could use either both hands (2 grasping instruments) or just one to perform the task, according to preference. In the nonrobotic phase, the endoscope was held with the nondominant hand and the task was performed with the dominant hand.

All participants' tasks were video-recorded[16] and evaluated with the modified Global Evaluative Assessment of Robotic Skills in Endoscopy (GEARS-E) score[17] (**Supplementary Table 2**). Task completion times were also recorded.

At the end of the test phase, a modified NASA Task Load Index test[18] was administered to all participants via SurveyMonkey Europe UC (Dublin, Ireland) to evaluate the task load with a highly standardized tool (**Supplementary Table 3**).

RESULTS

A total of 30 participants were enrolled (**Supplementary Table 4**). Endoscopic experience was evaluated in terms of years of endoscopic surgery practice and number of procedures per year: 15 surgeons (50%) had performed endoscopic surgery for less than 5 years, 10 (33%) had performed surgery for about 5–10 years, and 5 (17%) had performed surgery for more than 10 years. Nine surgeons (30%) performed less than 30 procedures per year, 7 (23%) performed 30–60 procedures per year, 6 (20%) performed 60–100 procedures per year, and 8 (27%) performed more than 100 procedures per year.

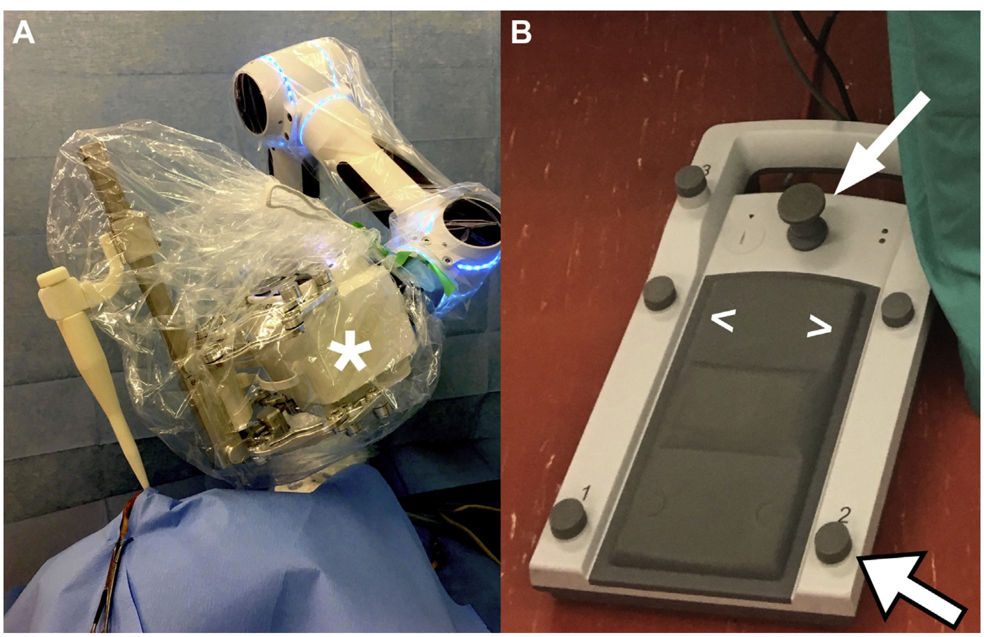

Figure 3. EndoscopeRobot components. (**A**) Endoscope holder (*asterisk*) and the robotic arm.(**B**) Foot pedal. The joystick (*thin arrow*) consents upward, downward, and lateral movements of the endoscope. Central buttons (< and >) allow zooming in and out movements, respectively. Lateral buttons (*thick arrow*) have the function, among others, to make the robot return to a previously saved home position.

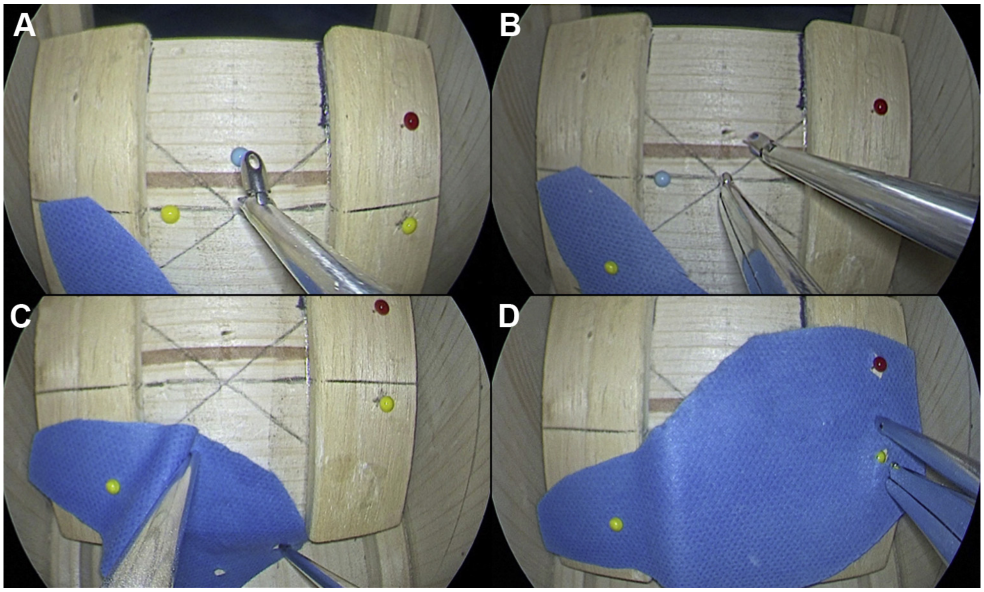

Figure 4. Endoscopic view of the tasks. (**A** and **B**) Task 1: the endoscope was positioned so that the center of the activity plate matched the center of the screen. The surgeon could remove the pins with Weil grasping forceps when the target was centered. (**C** and **D**) Task 2: the placement of a nasoseptal flap was simulated: surgeons were asked to grasp an artificial flap with 2 small holes and position them over 2 separate pins.

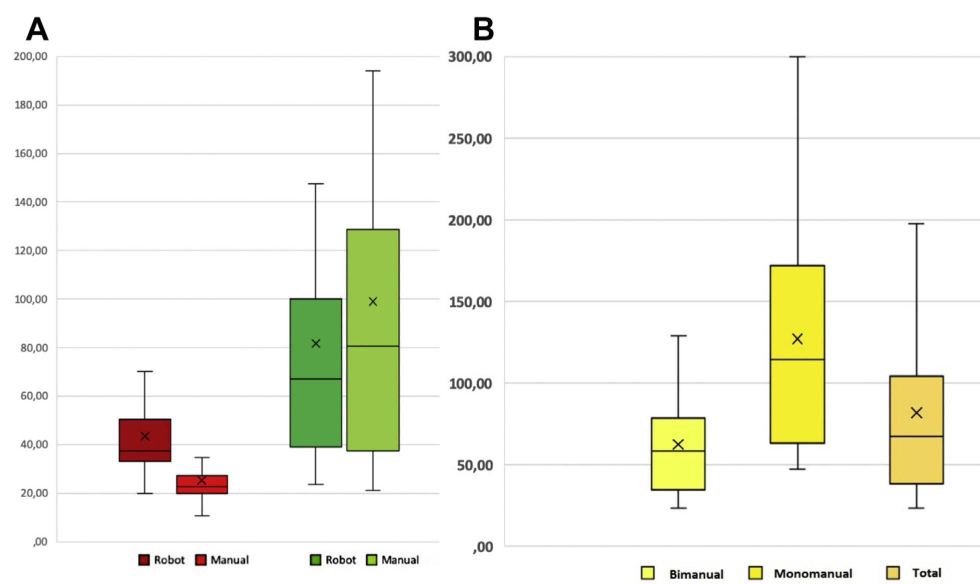

Figure 5. Boxplot representation of completion times. (**A**) Boxplot representation of completion times for task 1 (red) and task 2 (green) with and without the robot. Time is measured in seconds on the ordinates. The × symbols represent the mean values. (**B**) Completion times in robotic task 2 have been analyzed separately according to whether the surgeon uses both hands or just one to perform the task.

Participants were randomized into 2 groups, which were not significantly different in terms of demographic data and endoscopic experience.

In their clinical practice, during bimanual dissection, most surgeons (55% of NSs and 74% of ENT surgeons) reported holding the endoscope in the nondominant hand, 6 surgeons (36% of NSs and 10% of ENT surgeons) usually have a partner who holds the endoscope, and 4 surgeons (9% of NSs and 16% of ENT surgeons) use both strategies.

About half of the surgeons (53%) habitually use the operative microscope; of these, most of them do not use the foot pedal (88% of NSs and 100% of ENT surgeons).

Most participants (83%) did not have any experience with robotic surgery; some (18% of NSs and 16% of ENT surgeons) had experience with the DaVinci Robot (Intuitive Surgical, Sunnyvale, California, USA) (4 of 5, group A) or EndoscopeRobot (1 of 5 in group B, NS).

None of the participants were unfavorable a priori to robotic endoscopic surgery; most thought it could be a valid tool in clinical practice (73% of NSs and 79% of ENT surgeons).

Time recordings of the 2 tasks are summarized in Figures 5 and 6. Task 1 mean completion time was 25.3 seconds without the robot and 43.5 seconds with the robot. The mean time required to complete task 2 was 98.88 seconds without the robot and 81.79 seconds with the robot (Figure 5A). In robotic task 2, surgeons who used both hands to perform the task completed it in 62.32 seconds, whereas those (9 of 30) who used just one hand completed it in 83.8 seconds (Figure 5B).

Task 1 mean GEARS-E score was 4.45 without the robot and 4 with the robot. Task 2 mean modified GEARS-E scores were 3.95 and 3.85 without and with the robot, respectively. Differences were not statistically significant.

Twenty-one surgeons completed the modified NASA Task Load Index test at the end of the course. As far as mental workload and stress are concerned, no significant differences were noted between tasks with and without the robot. On the contrary, the NASA Task Load Index test showed that surgeons felt significantly more successful in performing task 2 with the robot (3.9 of 5) compared with the same task without it (2.9 of 5) (Figure 6).

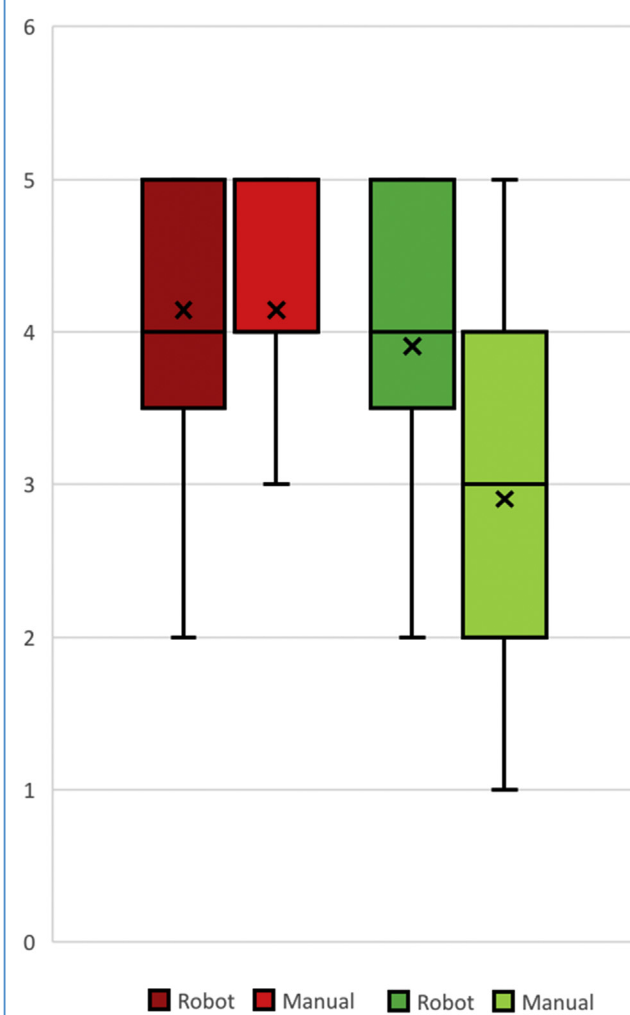

Figure 6. Boxplot representation of NASA Task Load Index test score, part 2 (How successful were you in performing the task?). Surgeons felt significantly more successful in performing task 2 with the robot (dark green) compared with the same task without it (light green), whereas they generally felt more successful without the robot in task 1 (red). The × symbols represent the mean values.

DISCUSSION

Significant advances in surgical robotics have been made, but a role for robot-based applications in skull base surgery has not been defined. A preclinical study was conceived to investigate surgeons' compliance with a new robotic system developed for endoscopic surgery.

Thirty surgeons attending the Joint European Diploma of Endoscopic Skull Base Surgery 2018–2019 in Paris, France, were asked to perform 2 different endoscopic tasks using a modified NeuroEndoTrainer, with and without EndoscopeRobot. Participants were randomized into 2 groups. As far as endoscopic experience is concerned, a preponderance of ENTs was observed in the expert group (7 of 8), whereas two thirds of beginners were NSs (6 of 9). This finding is coherent with the fact that ENT surgeons perform endoscopic transnasal procedures more frequently than NSs in their daily clinical practice.

About half of NSs (6 of 11) stated they habitually hold the endoscope in the nondominant hand without the aid of a partner; however, 5 of 6 are beginners. Analyzing bimanual dexterity, 9 of 30 scores on the modified GEARS-E were 2 or lower, 6 of 9 surgeons had an endoscopic surgery experience inferior to 60 procedures per year, and 4 of these 6 were NSs with no experience or less than 30 procedures per year, habitually holding the endoscope in the nondominant hand. These data might be explained by the fact that neurosurgical procedures usually require the use of both hands to perform finer and more precise movements often for a long time. Bimanual dexterity implicates a higher level of concentration and coordination (and therefore of mental stress) and requires specific training.

Task Completion Times

As expected, execution times in task 1 with the robot were longer than without it. Task 1 indeed does not require the use of both hands, but rather needs rapid movements in different directions of space. Modified GEARS-E scores confirmed that surgeons were more efficient in performing task 1 without the robot.

On the contrary, performing task 2 is a bimanual task (Video 2): this is well reflected by task completion times, which were lower in both groups when the robot was used. Interestingly, they were higher when surgeons performed the task with just one hand (Figure 5). Nonetheless, these differences were not statistically different, probably because of an underpowered sample.

Previous Robotic Experience

Only 5 surgeons had previous robotic experience; therefore, no statistical analysis could be made, but it seems that in this particular subgroup, execution times were generally better than those of the rest of the participants. Two of these surgeons were also the only participants familiar with the use of a foot pedal in microscopic surgery. This finding may suggest that appropriate training in robotic surgery is necessary and useful.

Survey

According to answers on the pretest questionnaire, 23 surgeons thought that robotics represents a valid tool in surgical practice; no one appeared a priori unfavorable toward this new technology (the remaining 7 surgeons answered do not know). None of the participants reported using an endoscope holder in clinical practice. In a pilot survey focused on endoscope holders and involving 28 NSs,[11] Paraskevopoulos et al.[11] reported that comments such as "the best scope holders are surgeon's or assistant's hands" were not uncommon; 75% of surgeons did not routinely use an endoscope holder, and the remaining 25% used it mainly for intraventricular procedures (only 18% for skull base surgery). Notwithstanding, in a more extensive survey by the same author,[12] though the preference for a cosurgeon was confirmed, 82.7% of interviewed NSs stated they were interested in the further development of holding systems, especially robotic ones. In this survey,[12] 54% of surgeons did not use endoscope holders, but among procedures in which they could be useful, most of the surgeons indicated bimanual and lengthy procedures.

Psychometric Test

At the end of the test, a modified NASA Task Load Index test[18] was administered via e-mail to all participants; 21 surgeons answered the survey. This psychometric test represents a highly standardized tool, which evaluates the level of mental stress while performing a task. It confirmed that in task 1, the robot not only is not useful, but also it could be more mentally demanding and stressful for the operator. In task 2, however, even if controlling the robot movements adds a further variable to deal with, the use of the robot seems to reduce mental stress by allowing bimanual surgery, therefore making surgeons feel more successful in performing the task ($P < 0.02$).

Limits of the Study

This is a preclinical study involving a relatively limited number of participants. No thorough statistical analysis has been performed, but we provide a rather qualitative evaluation of surgeons' attitudes and impressions toward this novel hybrid robotic system. The aim of the study was not to compare robotic surgery with team surgery. This preclinical assessment should be followed by an in-detailed analysis of possible advantages of robotic surgery, especially in long tasks that need small, precise endoscope movements, and potential advantages of training in bimanual surgery, robotics, foot pedal use, and other factors that influence the surgeon's efficiency in using a robotic system. Furthermore, it should also be integrated with clinical studies.

CONCLUSIONS

Significant advances in surgical robotics have been made, but a role for robotic skull base surgery has not been defined yet. Surgeons are not against a possible robotic solution for transnasal endoscopic skull base surgery. The EndoscopeRobot seems to provide a benefit to the single surgeon with experience in bimanual endoscopic surgery. Further preclinical and clinical evaluation of this novel technology is necessary.

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Supplementary Table 1. Pretest Questionnaire

Questions	Answers		
1 What is your age?			
2 What is your sex?	Male/Female		
3 Are you left-handed, right-handed, or ambidextrous?	Left-handed	Right-handed	Ambidextrous
4 Are you a neurosurgeon, ENT surgeon, or other surgeon?	Neurosurgeon	ENT	Other surgeon
5 Do you routinely perform endoscopic surgery?	Yes/no		
	If yes, how long have you been doing this? How many endoscopic procedures have you performed in 2017? <30; 30—60; 60—100; >100		
6 How do you handle the endoscope during bimanual dissection? Please choose 1 or 2 answers that best describe your practice.	I usually hold the scope in my nondominant hand and my partner helps with a surgical instrument (suction or grasping forceps).	I usually have a partner holding the scope.	I usually use an endoscope holder.
7 Do you use the surgical microscope?	Yes/no		
	If yes, do you use it with a foot pedal? Yes/no		
8 Do you already have experience with surgical robotic systems?	Yes/no		
	If yes, please specify which		
9 Do you think the robot could be a valid tool in endoscopic skull base surgery?	Yes/no/maybe		

ENT, otorhinolaryngologist.

Supplementary Table 2. Modified Global Evaluative Assessment of Robotic Skills in Endoscopy Score

Evaluated Skill	1	2	3	4	5
Endoscope control and depth perception	Consistently does not optimize view and scope position and/or overshoots the target, slow to correct		View and scope position sometimes are not optimal and/or some overshooting or missing of target, but quick to correct		Controls view and scope position optimally and independently and/or accurately directs instruments in the correct plane to target
Bimanual dexterity	Unable to use both instruments in a fluid way without interfering with the optics		Unable to use the instruments always in a fluid way, sometimes the optics must be repositioned		Able to use both instruments in a fluid way without interfering with the optics
Tissue handling	Rough movements, injures tissues		Minor trauma to tissues		Negligible injury to tissue
Efficiency	Inefficient efforts, many uncertain movements, many errors		Slow, but planned movements are reasonably organized		Confident, efficient, and safe conduct

The Global Evaluative Assessment of Robotic Skills in Endoscopy score has been developed and validated for evaluation of skills in transluminal endoscopic robotics. It was adapted to allow the evaluation of endoscopic transnasal surgery skills.
Modified from Takeshita et al.[17]

Supplementary Table 3. Modified NASA Task Load Index Test

Question
How mentally demanding was
Task 1 with/without the robot?
Task 2 with/without the robot?
How successful were you in accomplishing
Task 1 with/without the robot?
Task 2 with/without the robot?
How insecure, stressed, and/or annoyed were you in
Task 1 with/without the robot?
Task 2 with/without the robot?

Participants were asked to grade with a number, from 1 (very low) to 5 (very high), their impressions of both tasks, without and with the robot.
Modified from Dixon et al.[18]

Supplementary Table 4. Summary of Participant Features, as Recorded by the Pretest Questionnaire

Characteristic	Value			
Sex	Male: 25 (83)	Female: 5 (17)		
Age (years)	<35: 11 (37)	35–45: 13 (43)	>45: 6 (20)	
Surgical specialty	ENT: 19 (63)	Neurosurgeon: 11 (37)		
Endoscopic experience (years)	<5: 15 (50)	5–10: 10 (33)	>10: 5 (17)	
Endoscopic experience, number of procedures per year	<30: 9 (30)	30–60: 7 (23)	60–100: 6 (20)	>100: 8 (27)
Handedness	Right: 28 (94)	Left: 1 (3)	Ambidextrous: 1 (3)	
During bimanual dissection	Holds the scope with nondominant hand: 20 (67)	Partner holds the scope: 6 (20)	Both nondominant and partner: 4 (13)	Uses endoscope holder: 0 (0)
Uses surgical microscope	Yes: 16 (53)		No: 14 (47)	
Uses surgical microscope foot pedal	Yes: 2/16 (12.5)		No: 14/16 (87.5)	
Any experience with surgical robots	Yes: 5 (17)		No: 25 (83)	
Thinks robotics can be a valid tool for endoscopic skull base surgery	Yes: 23 (77)	Uncertain: 7 (23)	No: 0 (0)	

Values are number of patients (%) or number of patients/total number of patients (%).
ENT, otorhinolaryngologist.