Laryngoscope Investigative Otolaryngology

Identifying and Reducing Risks in Functional Endoscopic Sinus Surgery Through a Hierarchical Task Analysis

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Objective: To develop a hierarchical task listing of steps required to perform successful Functional Endoscopic Sinus Surgery (FESS). To complete a technical and human factor analysis of tasks resulting in the identification of errors, frequency of occurrence, severity, and reduction through remediation.

Methods: A triangulation of methods was used in order to derive the steps required to complete a FESS: 1) a literature review was carried out of published descriptions of FESS techniques; 2) observations of three FESS; 3) interviews with surgeons on FESS techniques. Data sets were combined to develop a task analysis of a correct approach to conducting FESS. A review by 12 surgeons, and observation of 25 FESS resulted in refinement of the task analysis. With input from five consultant surgeons and one consultant anesthetist, a Systematic Human Error Reduction and Prediction Approach (SHERPA) was used to identify the risks and mitigating steps in FESS.

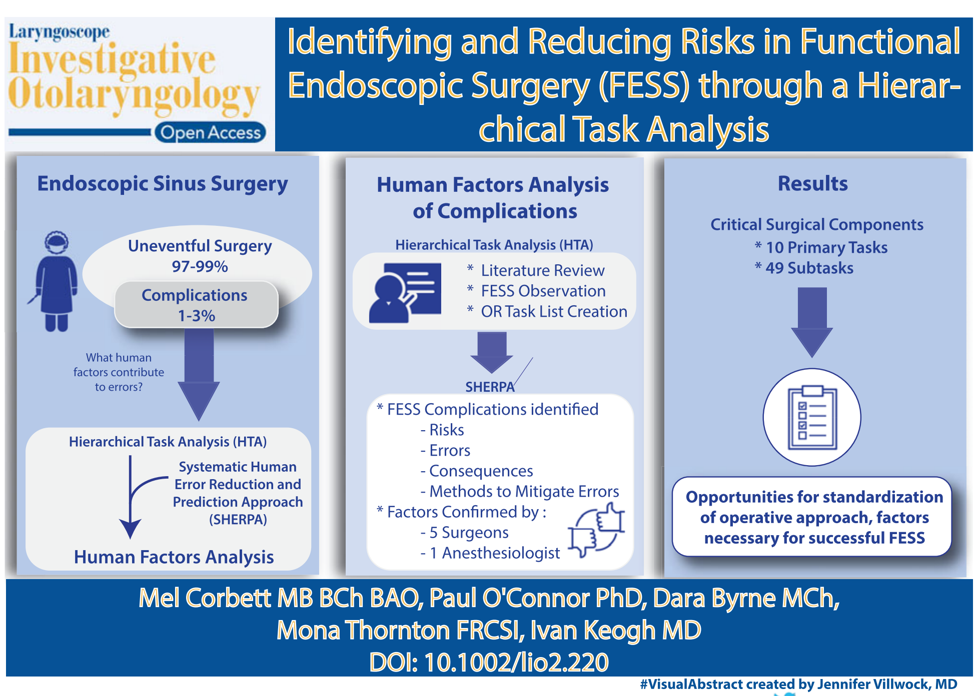
Results: Ten tasks and 49 subtasks required for a correct approach to completing FESS were identified based on literature review and expert consensus. A risk score for each subtask was calculated from a suitable risk matrix. Risk reduction methods at each subtask were detailed. High-scoring subtasks were evaluated and varying strategies examined to reduce the likelihood and mitigate the impact of error. The study demonstrates the usefulness of the HTA and SHERPA approach in standardization and optimization of clinical practice in order to improve patient safety.

Conclusion: Hierarchical Task Analysis and SHERPA are valuable tools to deconstruct expert performance and to highlight potential errors in FESS. The HTA and SHERPA approach to surgical procedures are useful learning and assessment tools for novice surgeons. The information derived offers the opportunity to improve surgical training and enhance patient safety by identifying high-risk steps in the procedure, and how risk can be mitigated.

Level of Evidence: 2c Outcomes Research

Key Words: Hierarchical Task Analysis, Systematic Human Error Reduction and Prediction Approach, functional endoscopic sinus surgery, human factors.

A Special Visual Abstract has been developed for this paper. (Visual Abstract 1)



INTRODUCTION

Functional Endoscopic Sinus Surgery (FESS) is a common surgical procedure performed in many major ENT centers. FESS is indicated in the management of chronic rhinosinusitis and has been shown as a reliable treatment to restore physiologic drainage and ventilation of the paranasal sinuses.[1] There is large scope for error in Functional Endoscopic Sinus Surgery and overall complication rates of between 1 and 3 percent have been described in literature.[2] New technologies and techniques including 3D navigation technology, improved equipment, better techniques and surgical safety checklists have improved technical outcomes since early endoscopic sinus surgery,[3,4]

Current practice for surgical training has moved away from traditional methods of practicing and teaching on live patients. Novel methods of teaching trainees including simulation are increasingly being incorporated into surgical curricula and literature[5] in an attempt to improve patient safety.[6] Simulation based learning has shown promise in reducing error rates and improving time to achieving proficiency in surgical skills. Surgical simulators provide a risk-free, cost-effective environment to practice the skills required to develop proficiency in FESS. However, these approaches to training have not yet been subjected to large-scale studies.[7] Prior to commencement on patients or simulators, trainees should have a base knowledge of the methods and steps required to perform a successful FESS.

Human factors play a substantial role in errors during any surgery and as long as surgeons are holding instruments, errors will occur due to these factors.[8] Understanding the mechanisms behind these human errors has large potential to further reduce the possibility of adverse events and reduce the risks associated with FESS.[9]

Improvements in human factors training involve tackling such areas as communication teamwork, situational awareness checklists,[10] and error strategy management.[11] These factors are being incorporated into modern-day core surgical training as a means of avoiding risk and improving patient safety.[12] These methods have been described as a means of improving technique and assessing performance in surgery.[13] To date, the human factors which contribute to error in FESS have not been examined in literature.

Hierarchical Task Analysis has been well documented in many high-reliability organizations such as aviation, military specialties, and nuclear power leading to safer working environments.[14] These methodologies are being adapted in surgery and anesthesia as a means of improving patient safety and performance evaluation.[15,16] These analyses are dependent on subjective observations and variations in clinical practice to produce a single accepted optimum method for successful completion of a procedure. This study aims to examine the process of developing a hierarchical task analysis for FESS and to analyze identified errors using the Systematic Human Error Reduction and Prediction Approach (SHERPA) methodology.

METHODS

Hierarchical task analysis is a well-documented approach to systematic decomposition of a procedure into its component steps with specific focus on the human factors which contribute to a safe outcome.[17] We produced a hierarchical task analysis for an error-free FESS decomposed to a level of detail where failings in each subtask could produce a significant error.

SHERPA was first described as a guideline for human error reduction in human–machine system interactions in nuclear power.[18] This has since been adapted and used in medical specialties, including anesthesia,[16] as a means of identifying credible errors in the process and suggesting methods of error mitigation at each step.

Task analysis allows trainees to view the steps required to complete a safe and successful FESS. These are presented in a concise manner showing a sequential list and task breakdown to improve knowledge and facilitate an earlier time to competency.

Hierarchical task analysis serves as a framework for application of a SHERPA approach to identify the errors. Each unique error is scored based on the Health Service Executive risk matrix.[19] This stratifies the errors using a composite score calculated by impact of error (Table I) and frequency of error occurrence (Table II). Particular attention was given to documenting preventative techniques to ensure as safe a surgery as possible.[20]

Ethical approval was obtained from the University Hospital Galway Research Ethics Committee to conduct the research project and informed consent obtained from participants providing data. A Hierarchical Task Analysis was applied to functional endoscopic sinus surgeries, covering initial patient positioning to care of the patient postoperatively. Information required to produce the task analysis was collected in three stages.

Literature review

In order to first appreciate a theoretical background to FESS the relevant literature was appraised including books[21,22] and relevant papers examining various techniques and approaches to sinus surgery. Databases consulted included Scopus, Pubmed, Medline, and Uptodate. A provisional list of tasks required to complete a successful FESS was produced based on available literature.

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Editor's Note: This Manuscript was accepted for publication 28 September 2018.

This paper was presented as an oral presentation format at 58th annual conference of the Irish Otorhinolaryngology Society in Co. Mayo, Ireland on October 13, 2017.

The authors report no conflicts of interest.

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DOI: 10.1002/lio2.220

TABLE I. Impact Table					
Impact Table	Negligible	Minor	Moderate	Major	Extreme
Injury	Adverse event leading to minor injury not requiring first aid.	Minor injury or illness, first aid treatment required. <3 days absence. <3 days extended hospital stay.	Significant injury requiring medical treatment. >3 days absence. 3–8 days extended hospital stay	Major injury/long term disability requiring medical treatment	Incident leading to death or major permanent incapacity.

TABLE II.
Likelihood Scoring

Rare/Remote (1)		Unlikely (2)		Possible (3)		Likely (4)		Almost Certain (5)	
Actual Frequency	Probability	Actual Frequency	Probability	Actual Frequency	Probability	Actual Frequency	Probability	Actual Frequency	Probability
Occurs every 5 years or more.	1%	Occurs every 2–5 years	10%	Occurs every 1–2 years	10%	Bimonthly	75%	At least Monthly	99%

Observation was undertaken of 25 FESS cases in University Hospital Galway from July to October 2017. Steps taken to complete the surgeries were recorded. Variation in practices and steps were documented and used to refine the task list.

Structured interviews took place with five consultant attending surgeons and one consultant attending anesthetist. Each consultant was individually asked for input into the task analysis until a single agreed correct method was identified. Each subtask was analyzed for potential errors and each suggested error scored out of a maximum of 25 points.

Having identified the task goal as a successful surgical outcome, each task step was described in chronological order. Each task step was further divided into subtasks and the process continued until sufficient detail indicated that further subdivision became irrelevant or non-impacting on the task goal of successful surgical outcome.

Subtask steps derived from the HTA were evaluated using the SHERPA method. This method involves the following steps[23]:

TABLE III.
Top Level Task List (HTA)

	Task
1.	Prepare patient
2.	Anesthesia
3.	ENT preparation
4.	Uncinectomy
5.	Maxillary antrostomy
6.	Anterior ethmoidectomy
7.	Posterior ethmoidectomy
8.	Sphenoid osteotomy
9.	Frontal sinus work
10.	Postoperative care

1. Describing the step according to the action taken or the behavior required;
2. Classifying the errors to determine what can occur;
3. Detailing the consequences of each error;
4. Determining if there are measures that may be taken to recover or prevent the error;
5. Rating the probability and criticality of each identified error; and
6. Suggesting remediation and preventative measures to reduce error frequency and criticality.

Error types were classified from frequency of occurrence, severity, or criticality of impact and remedial and preventative actions. The consultant surgeon interviewees formed the consensus group for inclusion of high-risk errors.

RESULTS

Twenty-five FESS, performed by three consultant ENT surgeons were observed for the purposes of the study. Differences in technique from the provisional task analysis were documented and used to edit the task analysis upon consultation with the surgeons. No serious adverse events occurred during these surgeries. Variations existed between surgeons' techniques and between steps required to successfully perform FESS among patients with varying severity of disease. The proposed HTA was modified by each surgeon until a single correct method was agreed upon by the participants. The method agreed upon was deemed appropriate as a means of familiarizing trainees with the correct steps and means of reducing risks.

A task list was derived from the steps involved in performing a successful FESS. Steps were characterized using a HTA approach which resulted in a task and subtask schedule consistent with successful surgical outcomes (Table III). A SHERPA methodology was used to identify potential errors, rate their significance, and suggest both remedial and preventative actions to reduce or eliminate errors. This task analysis was modified and

TABLE IV.
Sub-Tasks (HTA)

1.1	Complete pre-op checklist / time out twice
1.2	Equipment check
1.3	Ensure appropriate staff present
2.1	Pre-oxygenate patient with 100% oxygen
2.2	Administer hypnotic agent, inhalational agent, analgesic agent, and neuromuscular block anesthesia
2.3	Intubate patient
2.4	Position patient supine with head up at 30°
2.5	Insert throat pack above cuffed ET tube
2.6	Maintain MAP approx. 65 mmHg, heart rate low normal <60 bpm using Remifentanil and half-dose volatile Isofluorane. Maintain end tidal CO_2 low to normal
2.7	Administer Dexamethasone 5 mg IV
2.8	Administer Tranexamic acid 25 mg/kg IV
3.1	Prepare endoscopes, navigation, and CT scans
3.2	Scrub in
3.3	Drape patient and note eye position checking for asymmetry before taping eyes closed
3.4	Inject Lignocaine 2% and 1:10,000 into area above middle turbinate near sphenopalatine artery using dental syringe with endoscopic guidance
3.5	Inject 2 ml Lignocaine 2% and 1:80,000 into pterygopalatine fossa through mouth
3.6	Insert Cocaine/Oxymetazoline pattes into nasal cavity, 1 in each sphenoethmoidal recess under middle turbinate and over axilla of middle turbinate
3.7	Calibrate navigation system prior to operation
4.1	Remove patties prior to operation
4.2	Visualize uncinate using endoscope and CT scan
4.3	Make superior incision axilla medial turbinate
4.4	Incise mid-part uncinate superiorly and inferiorly
4.5	Introduce pediatric back biter to hiatus semilunaris. Cut uncinate posterior to anterior in sequential bites
4.6	Fracture uncinate at insertion to lateral nasal wall using ball probe or curette.
4.7	Remove middle section uncinate flush with lateral nasal wall
4.8	Visualize middle meatus and dissect bone from horizontal portion of uncinate
5.1	Use microdebrider to expose and enlarge maxillary ostium to posterior fontanelle
5.2	Use 30°/70° telescope to view maxillary sinus
6.1	Fracture middle turbinate medially to ensure clear visuals of medial aspect of bulla ethmoidalis using 0° telescope
6.2	Locate the natural ostium of bulla ethmoidalis between bulla and middle turbinate using right angled probe
6.3	Rotate tip of probe laterally into natural ostium
6.4	Pull probe forward to fracture medial and anterior walls in continuity with natural ostium
6.5	Open bulla ethmoidalis using microdebrider in fractured area to enlarge ostium, removing medial and anterior walls
7.1	Enter superior meatus using microdebrider or Blakesly through ground lamella at the point where it turns vertically adjacent to middle turbinate
7.2	Sequentially enter and dissect remaining ethmoid cells
8.1	Identify the posterior ethmoid skull base
8.2	Visualize sphenoethmoidal recess, sphenoidotomy
8.3	Remove lower 1/3 superior turbinate and use microdebrider to give access to front face of sphenoid/sphenoid ostium
9.1	Use Hajek Koeffler punch to remove the anterior wall of agger nasi cell
9.2	Remove cells obstructing drainage pathway using probe or curette in a posterior to anterior method placing instrument in definite spaces
9.3	Pull axillary flap forward so that it partially rolls under the edge of the bone of the agger nasi cell
10.1	Achieve hemostasis using hemostatic agent
10.2	Insert sinofoam dressing in each nostril
10.3	Insert nasal splints
10.5	Emergence reverse anesthetic
10.5	Remove throat pack
10.6	Extubate patient
10.7	Postoperative antibiotics and decongestants
10.8	Remove packing after 24 hours. Nurse patient in head up position

ET, endotracheal; MAP, mean arterial pressure; bpm, beats per minute; CO_2, Carbon dioxide.

TABLE V.
SHERPA

	Error	Frequency	Severity	Risk Score	Remediation
1.1	Wrong patient, wrong procedure	Rare 1	Moderate 3	3	Reschedule surgery
1.2	Incorrect equipment	Unlikely 2	Negligible 1	2	Obtain correct equipment
1.3	Incorrect staff	Unlikely 2	Minor 2	4	Wait for appropriate staff
2.1	Failed to turn on O_2 Machine	Rare 1	Moderate 3	3	Re-ventilate patient with bag mask and O_2
2.2	Incorrect medicines/dosage	Unlikely 2	Moderate 3	6	Give appropriate dose.
2.3	Anesthetic risk; aspiration, cardiac decompensation	Rare 1	Extreme 5	5	Stabilize patient and reschedule surgery
2.4	Difficult or failed intubation	Unlikely 2	Major 4	8	Use video laryngoscope/bougie/advanced airway
2.5	Patient incorrectly positioned	Possible 3	Negligible 1	3	Reposition patient
2.6	Throat pack not inserted or insertion not documented	Rare 1	Moderate 3	3	Insert and document throat pack, verbal confirmation with theater staff.
2.7	MAP and heart rate incorrectly managed. Increased bleeding	Possible 3	Minor 2	6	Ensure appropriate communication with anesthetist
2.8	Medicine omitted / incorrect dose	Rare 1	Minor 2	2	Give correct dose
3.1	Endoscopes incorrectly positioned, navigation not working, CT scans incorrect	Possible 3	Minor 2	6	Reposition equipment, retrain staff on equipment use
3.2	Break in sterility	Possible 3	Minor 2	6	Rescrub
3.3	Eyes covered/ break in sterility	Unlikely 2	Minor 2	4	Re-drape and expose eyes
3.4	Bleed sphenopalatine artery / vein injury	Unlikely 2	Moderate 3	6	Cautery/packing/insert pattie
3.5	Local anesthetic systemic toxicity	Rare 1	Extreme 5	5	Abc intra lipid 1.5 ml/kg
3.6	Fail to monitor BP, fail to inform anesthetist	Unlikely 2	Moderate 3	6	Manage blood pressure
3.7	Failed to register equipment on navigation system	Possible 3	Moderate 3	9	Recalibrate/retrain on equipment
4.1	Failed to remove patties	Rare 1	Negligible1	1	Remove patties
4.2	Failed to visualize uncinated process/ mistake anatomy for bulla ethmoidalis	Unlikely 2	Moderate 3	6	Review anatomy on CT scan. Use navigation guidance to aid positioning.
4.3	Incorrect incision size, damage to orbit	Unlikely 2	Major 4	8	Stankewicz maneuver to assess orbital damage postoperatively. Review anatomy on CT scan with aid of navigation guidance
4.4	Damage to nasolacrimal sac	Unlikely 2	Moderate 3	6	Review anatomy on CT scan prior to action. Define anatomical landmarks prior to proceeding
4.5	Formation of accessory ostium	Unlikely 2	Minor 2	4	Join accessory ostium to natural ostium
4.6–4.8	Damage to nasolacrimal duct	Unlikely 2	Minor 2	4	Review anatomy on CT scan prior to action with aid of navigation guidance
5.1	Over enlarge/under enlarge ostium	Possible 3	Minor 2	6	Review anatomy on CT scan prior to action start with small bites and repeat step.
5.2	Infraorbital nerve injury	Rare 1	Moderate 3	3	Review anatomy on CT scan prior to action and use navigation guidance aid planning before proceeding
5.3	Sphenopalatine artery injury	Unlikely 2	Major 4	8	Stop bleed. Review anatomy on CT scan prior to action, navigation guidance aid planning before proceeding
6.1	Lamina papyra damage/medial rectus injury	Possible 3	Major 4	12	Inferomedial incision. Familiarity with anatomy, review CT scan prior to surgery. Use navigation guidance to aid position.
6.2	CSF leak	Unlikely 2	Extreme 5	10	Familiarity with anatomy/review CT scan prior to surgery. Use navigation guidance to aid step
6.3	Lamina papyra damage/medial rectus injury	Unlikely 2	Extreme 5	10	Inferomedial incision. Familiarity with anatomy/review CT scan prior to surgery.
6.4	Damage to cribiform plate	Unlikely 2	Major 4	8	Inferomedial incision. Familiarity with anatomy/review CT scan prior to surgery.

(Continues)

TABLE V.
Continued

	Error	Frequency	Severity	Risk Score	Remediation
7.1	Injury to skull base	Rare 1	Extreme 5	5	Review anatomy on CT scan prior to action and use navigation guidance. Approach posterior cells low and medially, frequently checking of CT scan and navigation
7.2	Anterior ethmoidal artery damage	Rare 1	Major 4	4	Review anatomy on CT scan prior to action and use navigation guidance to aid step
7.3	Lamina Papyra damage	Unlikely 2	Extreme 5	10	Inferomedial incision. Familiarity with anatomy/review CT scan prior to surgery.
8.1	Internal carotid artery damage	Unlikely 2	Extreme 5	10	Pack and suction to achieve hemostasis.
8.2	Optic nerve damage	Unlikely 2	Extreme 5	10	Review anatomy on CT scan prior to action and use navigation guidance to confirm location prior to incision.
9.1	Anterior ethmoidal artery damage	Rare 1	Major 4	4	Stop bleeding. Review anatomy on CT scan. Use navigation guidance to aid instrument positioning
9.2	CSF leak	Unlikely 2	Extreme 5	10	Review anatomy on CT scan. Use navigation guidance to aid planning
9.3	Sphenopalatine artery injury	Possible 3	Moderate 3	9	Review anatomy on CT scan. Use landmarks to identify vessels.
9.4	Scarring/obstruction of frontal recess	Possible 3	Moderate 3	9	Review anatomy on CT scan.
10.1/10.2	Failure to control bleeding	Rare 1	Extreme 5	5	Adrenaline, nasal packing, cautery, tranexamic acid
10.3	Splints not inserted/not inserted correctly	Rare 1	Negligible 1	1	Re insert splints
10.4	Failure to rouse patient	Rare 1	Extreme 5	5	ABC and maintain vitals
10.5	Throat pack not removed	Possible 3	Extreme 5	15	Airway management laryngoscopy and remove throat pack, Clear communication on insertion and removal

O_2, oxygen; MAP, mean arterial pressure; CT, computed tomography; BP, blood pressure; CSF, cereberospinal fluid.

edited based on consultation with a consensus group of eight surgeons and one anesthetist all familiar with the procedure.

Ten principal tasks and 49 subtasks were identified. Of the errors at each subtask nine scored 10 points or higher with the two highest subtasks scoring 12 and 15 points, respectively. These two subtasks were "possible" on frequency score and "major or extreme" on the severity score. An overview of the HTA is represented in Tables III and IV. SHERPA output for each subtask step is detailed in Table V.

DISCUSSION

This HTA highlights a number of important steps in FESS that were judged to have the potential for serious adverse events. Failure to remove the throat pack was identified by surgeon and anesthetists as a possible error with extreme impact. Methods to mitigate this risk can include: tying or suturing the pack to the airway equipment, leaving some of the pack outside of the patient's mouth, Leaving a sticker on the patients forehead, and a wearable band to remind anesthetic staff.[24] Variation in practice existed within the hospital and this was the most significant risk to patient safety. Regardless of surgeon's or anesthetist's preference one standardized protocol will remove the uncertainty of responsibility regarding a key subtask which relies on human interaction and effective communication in the team.

Other risks with extreme impact include arterial bleeds, skull base injury, and optic nerve damage. As a result of the HTA the steps in which these errors occur can be focused on to target improvements in trainees technical skills. In addition to this, other risks can occur during multiple subtasks (Table V) drawing attention to the need for measures to avoid these potential adverse events.

Highlighting the steps which require more supervision and guidance allows trainees to improve skills in a safe environment and can address the concerns in allowing trainees to perform technically challenging high-risk steps.[25]

Human factors training has been reported to make positive changes to clinical practice.[26] Mandatory programs to support this type of training have been introduced to core surgical trainees by the Royal College of Surgeons in Ireland and the United Kingdom.[27] HTA is a valuable tool used to provide a systematic description of the steps of an activity and this is of specific relevance to high-reliability organizations. As a tool this task analysis provides a step by step guide to the procedure that is valuable for surgical trainees. As a result of this task analysis trainees will have a better understanding of the procedure and team members will have an improved awareness of the high-risk steps and the potential errors.

Task analysis will allow trainees to record each step of a procedure completed for the purpose of demonstrating operative experience. Workplace-based assessment can be made by scoring each subtask. Once recognized and integrated into trainees portfolios and logbooks the task analysis for FESS can serve as the guideline for completion of an error free FESS. This would ensure trainees proficiencies and experiences are logged as component steps of the procedure performed rather than logging an operation as performed or assisted.

Because errors in FESS can have significant consequences, opportunity for learning by trial and error is no longer feasible. HTA and SHERPA are valuable tools to deconstruct expert performance and to highlight potential errors in FESS. Errors can involve any member of staff from any discipline during the procedure and a preoperative task analysis viewed prior to a surgery will increase the awareness of these errors among team members and improve the capacity of the theatre team to manage these risks. Future surgical training will rely more on simulation[28] and task analysis will facilitate the steps to build and improve simulation based tools. Task analysis in the operating theater has the potential to allow any observer to appreciate the organization and technical proficiency required during each step by following the steps with their observation. In addition a check list version of the steps and materials used has the potential to speed up work flow and accuracy of the operation note. This is of particular value prior to the construction of an electronic operation note.

The introduction of surgical checklists perioperatively has been demonstrated to reduce error, facilitate communication, and to improve patient safety.[29] This systematic approach to the perioperative period has the potential to have a similar impact on the intraoperative period. This method applied in multiple centers would further highlight differences in expert opinion and facilitate the analysis of groups of experts' differing opinions regarding how these steps are performed. If a universal consensus on an algorithmic approach to FESS could be agreed upon, this could standardize patient care across centers and improve safety in centers, which fall below this standard.

The HTA and SHERPA approach to surgical procedures are useful learning and assessment tools for novice surgeons, In addition assessments of both operative and nonoperative performance can be based upon analysis of performance at the sublevels from this task analysis. The information derived from this task analysis of FESS offers the opportunity to improve surgical training and enhance patient safety by identifying high-risk steps in the procedure, and how risk can be mitigated. The agreed upon steps can be used to identify where trainees have difficulty with technical aspects and emphasize improvement in these areas. A scoring system at each task or subtask will allow trainees to be assessed in a standardized manner and feedback will facilitate improvement.

HTA and SHERPA can be more difficult to apply to emergency cases or cases where major variations in technique and setup may occur perioperatively. In addition, in circumstances where human resources are limited another checklist can represent an additional burden to theater staff. For FESS an algorithmic standardized approach is an iterative process and can be updated as novel technologies and advancements are made available. Surgical task analyses will need updating as novel strategies techniques and methods of reducing error are introduced.

HTA and SHERPA have the potential to be applied to any procedure and a standardized accepted method could ensure that surgeons are less frequently dealing with an unfamiliar task. Ultimately a rigorous method and the standardization of method will have the ability to reduce error and improve patient safety.

CONCLUSION

The HTA and SHERPA approach to task decomposition is a valuable tool in understanding the factors necessary to successfully carry out a FESS. This tool has been relatively underutilized in literature and modern surgical training. Human errors in surgery can be better recognized and sooner addressed. With wider uptake and usage these approaches have the potential to mitigate and reduce error in high-risk surgeries such as FESS. With identification and recognition of areas of concern improved efforts can be made to minimize the opportunities for errors. These analyses have the potential to improve trainees understanding of the surgery and also to facilitate evaluation and standardization of current practice across centers.

Our HTA and SHERPA of FESS has demonstrated the potential use of this tool for education, evaluation of practice and defining a standard of care with the aim of reducing risks and improving patient safety.

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