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Totally endoscopic cartilage tympanoplasty: a hierarchical task analysis

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Abstract

Background. Totally endoscopic ear surgery is a novel method of conducting otological surgery. Hierarchical task analysis and the systematic human error reduction and prediction approach ('SHERPA') are valuable tools that can effectively deconstruct the technical and non-technical skills required to successfully complete a surgical procedure.

Methods. Twenty-five endoscopic tragal cartilage tympanoplasties were observed, to identify the tasks and subtasks required for completion of totally endoscopic tragal cartilage tympanoplasty. The systematic human error reduction and prediction approach was used to identify the potential risks and methods, to reduce or remediate these risks.

Results. A hierarchical task analysis was performed, identifying 8 tasks and 50 subtasks for a safe approach to completing totally endoscopic tragal cartilage tympanoplasty. A risk score for each subtask was calculated to produce a systematic human error reduction and prediction approach and to highlight potential errors.

Conclusion. This hierarchical task analysis allowed for quick reference to a correct method of endoscopic tympanoplasty. The systematic human error reduction and prediction approach was employed to reduce the risks associated with undergoing endoscopic tympanoplasty, to improve patient safety.

Introduction

Tragal cartilage tympanoplasty is a common surgical procedure in reconstructive otology.[1] In recent years, totally endoscopic ear surgery has offered a novel perspective on otological surgery, allowing improved access and alternative minimally invasive approaches for many operations, including tympanoplasty.[2] An endoscopic approach to tympanoplasty is comparable to traditional microscopic surgery, with similar outcomes and improved recovery times.[3] Totally endoscopic ear surgery is particularly suitable as a day-case procedure. Endoscopic tympanoplasty provides a unique set of challenges to otologists from a technical and human factors standpoint.[4] The learning curve is steep for this one-handed, 'heads-up' technique. This is offset against superb views and the minimally invasive nature of totally endoscopic ear surgery.

Alternative approaches to the traditional 'see one, do one, teach one' method of surgical training, such as surgical simulators, are being increasingly utilised to improve patient safety and prevent error.[5] Novel methods of ensuring trainee competency prior to performing surgery on patients have demonstrated the potential to reduce risk and mitigate error. The integration of human factors into surgical practice has shown the potential to reduce surgical error and improve patient safety.[6] Human factors approaches to optimising performance have been successfully adapted to medical and surgical practice, and can reduce complications associated with complex tasks.[7]

First pioneered in the aviation, military and nuclear power industries, hierarchical task analysis is an approach used to deconstruct expert performance.[8] Similar to surgery, the significant impact of errors in these high-risk professions precludes learning by trial and error.[9] In addition, a detailed and comprehensive knowledge of the subtasks required to complete a procedure, and the steps required to reduce and remediate error, are of significant importance prior to undertaking a new procedure or a new technique.

Hierarchical task analysis methodology has been used in anaesthesia,[10] and has shown promise as both an assessment and training tool in general surgery.[11] For new surgical procedures, hierarchical task analysis can identify a correct method to deconstruct each task, improve understanding, and be used to create subtasks required to successfully complete the procedure without error. The systematic human error reduction and prediction approach ('SHERPA') is a human factors approach to error management; it involves error identification, followed by quantification of the frequency and severity of errors, and the subsequent identification of methods to reduce or mitigate risk at each step of a procedure.[12]

Otolaryngology procedures have been analysed using hierarchical task analysis and the systematic human error reduction and prediction approach in the past, prior to the

Main Article

Dr R Fahy takes responsibility for the integrity of the content of the paper

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creation of simulation-based learning.[13] Similar to functional endoscopic sinus surgery, totally endoscopic ear surgery involves careful preparation and management of anaesthesia, operating theatre staff, and endoscopic equipment, and both operations are suited to hierarchical task analysis and the systematic human error reduction and prediction approach.[14] Functional endoscopic sinus surgery simulators have utilised task deconstruction methodology to standardise procedure and improve trainee performance.[15]

It is important to appreciate that no two surgeons perform the steps of any complicated surgical procedure in the same way. All surgeons, particularly otologists, have nuances and personal preferences. However, the primary steps, approach, aims and attitudes to outcomes are fundamental tenets. It is also important to recognise that many established otologists are moving towards totally endoscopic ear surgery as their primary option for otological surgery.

A hierarchical task analysis and systematic human error reduction and prediction approach for a totally endoscopic ear surgical procedure have not, to our knowledge, been described in published medical literature to date. We hope that the publication and presentation of this research will stimulate discussion and raise awareness of these approaches for the training and safe performance of totally endoscopic ear surgery.

Materials and methods

A hierarchical task analysis was created to describe the steps required to perform totally endoscopic push-through tragal cartilage tympanoplasty. A literature review of published techniques and methods was conducted, to better understand the goals of totally endoscopic ear surgery. The databases searched included Scopus, PubMed, Medline and UpToDate. Available methods of microscopic[16] and endoscopic[17] tympanoplasty were condensed into a task and subtask listing suitable to complete a successful, error-free operation.

Push-through tragal cartilage tympanoplasty was chosen given its suitability for hierarchical task analysis, a systematic human error reduction and prediction approach, and totally endoscopic ear surgery.[18] It was considered an appropriate entry-level totally endoscopic ear surgical procedure for the trainee surgeon. It allows for tragal cartilage harvesting and plenty of endoscopic manipulation, without the added difficulty of raising tympanomeatal flaps and the challenges associated with managing bleeding. Supervision is easy and operation times are short. Proficiency allows progress to more complex totally endoscopic ear surgical procedures.

All totally endoscopic ear surgical procedures were categorised according to Cohen's classification system.[19] All procedures included were Cohen class 3, totally endoscopic. All procedures were performed under general anaesthetic, with informed consent obtained and all risks discussed. A variety of tympanic membrane perforation sizes were treated, but they were primarily of small to medium size.

Twenty-five endoscopic tragal cartilage tympanoplasties were observed over a 12-month period in order to identify the tasks and subtasks required for the successful completion of totally endoscopic ear surgery. Expert opinion included that of three consultant otologists and one consultant anaesthetist. Structured interviews were carried out with the participants to identify a single acceptable method for each step for an otolaryngologist with no prior experience of totally endoscopic ear surgery. Semi-structured interviews with three otolaryngology resident trainees were conducted to identify areas of difficulty and concern. The consultant otologists and trainees were interviewed independently. Through the help of these participants, accurate arrangement of the subtasks required for successful, error-free totally endoscopic tragal cartilage tympanoplasty was created in the form of a hierarchical task analysis. Each step was described in chronological order, and in sufficient detail such that a trainee could follow the task list. These participants also identified areas of risk and poor patient outcomes for the systematic human error reduction and prediction approach.

The task list was refined and edited at each procedure until a single suitable method was agreed upon. The three consultant otologists were involved with refining and editing these steps by consensus. Subtask steps derived from the hierarchical task analysis were evaluated using the systematic human error reduction and prediction approach method.[20] This method involves the following steps: (1) describing the step according to the action required to perform the subtask; (2) classifying the tasks to identify what errors can occur; (3) considering the consequences of each error identified; (4) discovering the measures required to recover or prevent the error; (5) rating the probability and severity of each identified error; (6) identifying critical errors that would lead to a serious incident; and (7) suggesting error reduction strategies. These are the changes used to prevent the errors from occurring or to reduce the consequences of the errors.

A suitable risk matrix was adapted from the Irish Health Services Executive risk matrix in order to quantify the frequency and severity of each potential error.[21] All 25 tympanoplasty procedures were carried out by a consultant otologist. The three otolaryngology resident trainees undertook independent scoring based on direct observation and experience of these procedures. The final score was reached by consensus with the trainees and consultant, and based on review of the literature where applicable. Each error was scored from 1 to 25 based on criticality and likelihood (Tables 1 and 2). Each error was analysed to determine the suitable steps required to reduce the chance or mitigate the consequence of risk.

The research was carried out at the University Hospital Galway with associated personnel. The otolaryngology department of the University Hospital Galway is experienced in totally endoscopic ear surgery, and has been using the technique since 2013 for a broad range of procedures. Ethical approval was obtained from the clinical research ethical committee at the University Hospital Galway.

Results

Twenty-five endoscopic tragal cartilage tympanoplasties were observed for the purpose of the study; 14 were performed on

Table 1. Error impact scoring

Impact	Complication
Negligible (1)	Adverse event leading to minor injury not requiring first aid
Minor (2)	Minor injury or illness; first aid treatment required. <3 days absence, <3 days extended hospital stay
Moderate (3)	Significant injury requiring medical treatment. >3 days absence, 3–8 days extended hospital stay
Major (4)	Major injury or long–term disability requiring medical treatment
Extreme (5)	Incident leading to death or major permanent incapacity

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Table 2. Error likelihood scoring

Likelihood	Actual frequency	Probability (%)
Rare or remote (1)	Occurs every 5+ yrs	1
Unlikely (2)	Occurs every 2–5 yrs	10
Possible (3)	Occurs every 1–2 yrs	10
Likely (4)	Bimonthly	75
Almost certain (5)	At least monthly	99

Yrs = years

males and 11 on females. All tympanoplasties were successful and no adverse events were identified. Patients' ages ranged from 12 to 68 years.

A top-level task analysis was conducted, detailing eight tasks required to successfully complete the operation and ensure patient safety (Table 3). A subtask analysis of each task was produced (Table 4). Systematic human error reduction and prediction approach analysis was performed to identify errors and methods of controlling risk (Table 4). For each subtask, a measurable error was identified. Each error was scored in terms of frequency and severity according to the risk matrix. Three otolaryngology resident trainees undertook independent scoring based on direct observation and experience of these procedures. The final score was reached by consensus with trainees and consultant, and based on a review of the literature where applicable. The agreed method was deemed suitable by senior authors for familiarising any surgeon new to the procedure with each step and error. Each potential error was examined, and suitable methods of error prevention and remediation were suggested.

Eight principal tasks and 50 subtasks of totally endoscopic tragal cartilage tympanoplasty were identified. Error impact ranged from negligible to major. Error likelihood ranged from rare to likely. Scoring was calculated by multiplying the impact by the likelihood. Of the errors at each subtask, the highest score was eight. Seven subtasks scored eight points or higher, indicating a probability of 10 per cent with the potential for major consequences to patient safety.

Highlighting the subtask steps associated with high-risk and high frequency error was the most important part of the analysis. The subtasks with the potential for major impact included inserting and handling the endoscope, tympanic membrane manipulation, and inserting and positioning the graft. Remediation included the active management and prevention of these errors. Active management included haemostasis, irrigation and topical adrenaline application. Prevention focused on observation of the endoscope progress via the monitor.

A few of the subtask steps were associated with errors considered likely or almost certain to happen. These errors resulted in poor quality images and were deemed negligible because of the ability for swift correction; that is, endoscope cleaning and reinsertion. Some ergonomic steps were deemed likely to those unfamiliar with totally endoscopic ear surgery, such as holding the endoscope in the non-dominant hand and not resting the endoscope against the side of the external auditory meatus. These can be improved by education and practice, and remediation is uncomplicated.

Table 3. Top-level task list*

Task number	Task
1	Pre-operative preparation
2	Otoendoscopy
3	Graft harvest
4	Graft preparation
5	Tympanic membrane preparation
6	Graft placement
7	Closure
8	Post-operative care

*Determined via hierarchical task analysis

Discussion

This hierarchical task analysis highlighted a number of surgical steps in totally endoscopic tragal cartilage tympanoplasty that have human factors and safety issues for the patient. These complications can involve damage to the outer ear or middle-ear structures, requiring further operative intervention. Trauma to the external auditory canal, tympanic membrane, ossicular chain, middle-ear mucosa and facial nerve are possible, and can significantly affect a patient's quality of life.[22] The hierarchical task analysis raises awareness of the surgical steps with the potential to damage these structures, allowing surgeons to focus on these areas to improve both technical and human factors based performance.

The majority of the errors are rare or unlikely to occur, and cause minor complications. Totally endoscopic ear surgery is a safe procedure when performed by an appropriately trained surgeon, and is an effective method with comparable outcomes to traditional otological surgery.[23]

The surgical approach is minimally invasive, performed via the external auditory canal, with a small incision on the tragus. This allows for a quicker patient recovery time and avoids a post-auricular scar.[24] High-quality images of the ear canal and middle ear allow the operation to be conducted transcanal in all but the most challenging anatomy cases, for all tympanic membrane perforation sizes.[25]

The impaired depth perception during totally endoscopic ear surgery can lead to an 'endoscopic plunge'; this can cause trauma to structures such as the external auditory canal, tympanic membrane and ossicular chain. Tympanoplasty performed with the microscope allows for both hands to be used and enables better depth perception. This reduces the risk of unintentional trauma, but at the cost of decreased visualisation when compared to the endoscope.

Other complications of totally endoscopic ear surgery include excessive heat dissipation from the endoscope itself.[26] Awareness of the nature of the light source and the heat produced, setting the light intensity at a minimal accepted level (e.g. less than 50 per cent), and inclusion of the complication in the surgical 'timeout' process can mitigate this. Anti-fog has been found to be ototoxic[27] and should be wiped clean after each application.

The widespread introduction of totally endoscopic ear surgery has been questioned by some because of the technique's steep learning curve[28] and the potential for damage by untrained operators. Totally endoscopic ear surgery is a 'heads-up' procedure, requiring a one-handed technique. It is a heads-up procedure with improved ergonomics, thereby reducing the chronic neck and back issues frequently suffered by many otologists.[29] Ergonomics are important for successful surgery, and can be improved by familiarity with equipment

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Table 4. Subtasks and systematic human error reduction and prediction approach

Step	Subtask	Error	Frequency	Severity	Risk score	Remediation
1.1	Complete pre-op checklist & timeout twice	Wrong patient, wrong procedure	Rare 1	Moderate 3	3	Reschedule surgery
1.2	Equipment check	Incorrect equipment	Unlikely 2	Negligible 1	2	Obtain correct equipment
1.3	Ensure appropriate staff present	Incorrect staff	Unlikely 2	Minor 2	4	Wait for appropriate staff
1.4	Avoid N_2O in pre-op anaesthetic regimen	N_2O can increase middle-ear pressure & displace graft	Rare 1	Moderate 3	3	Stop N_2O. Use alternate anaesthesia. Good communication with anaesthesia team
1.5	Prepare 0°, 3 mm Hopkin's rod endoscope & video equipment	Endoscopes incorrectly positioned	Possible 3	Minor 2	6	Reposition equipment, retrain staff on equipment use
1.6	Position patient with head tilted 30° away from operative ear	ET tube disconnected from oxygen machine	Rare 1	Negligible 1	1	Reconnect ET tube
1.7	Place endoscopy tower on opposite side of patient to operating surgeon, for ergonomic access	Difficulty in viewing images	Rare 1	Negligible 1	1	Improve equipment ergonomics
1.8	Trim ear hairs with iris scissors	Impaired view of EAC due to wax streaks on endoscope	Rare 1	Negligible 1	1	Trim ear hairs
1.9	Set up LED light source & set to 50% brightness	Brightness too high. Burns to TM or chorda tympani	Rare 1	Major 4	4	Decrease brightness. Be aware of light source type & include in timeout
1.10	Scrub in	Break in sterility	Possible 3	Minor 2	6	Re-scrub
1.11	Paint patient's ear with sterile solution & position sterile drapes over ear	Break in sterility	Unlikely 2	Minor 2	4	Re-drape patient
2.1	Drape endoscope & connect to endoscopy tower	Break in sterility	Unlikely 2	Minor 2	4	Re-drape endoscope
2.2	White balance endoscope	Poor quality images	Possible 3	Negligible 1	3	Re-perform white balance. Ensure triple-chip high-definition camera is being used
2.3	Record procedure or take pictures of pathology as required	No recorded evidence of pathology	Rare 1	Negligible 1	1	Ensure equipment is set up for intra-operative recording
2.4	Position anti-fog reservoir & saline-soaked gauze on sterile field within operating surgeon's reach	Poor quality images	Possible 3	Negligible 1	3	Allow access to anti-fog & gauze
2.5	Apply anti-fog to endoscope camera	Poor quality images	Almost certain 5	Negligible 1	5	Repeat steps 2.4 & 2.5
2.6	Use sterile gauze to remove excess anti-fog solution	Excess anti-fog is possibly ototoxic	Rare 1	Major 4	4	Remove excess anti-fog
2.7	Hold endoscope in non-dominant hand	Dissection is difficult with non-dominant hand	Likely 4	Negligible 1	4	Use non-dominant hand to hold endoscope
2.8	Rest endoscope against side of external auditory meatus to prevent shaking & reduce risk of plunge	Damage to ear canal with endoscope	Likely 4	Negligible 1	4	Haemostasis with time, irrigation & topical adrenaline. Observe endoscope progress using monitor
2.9	Insert endoscope into EAC & observe progress on endoscopy tower monitor	Damage to ear canal with endoscope	Likely 4	Negligible 1	4	Haemostasis with time, irrigation & topical adrenaline. Observe endoscope progress using monitor
2.10	Advance endoscope into EAC to obtain clear view of TM	Damage to middle-ear structures	Unlikely 2	Major 4	8	Haemostasis with time, irrigation & topical adrenaline. Observe endoscope progress using monitor

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Table 4. (*Continued.*)

Step	Subtask	Error	Frequency	Severity	Risk score	Remediation
2.11	Gently remove debris from EAC using microsuction or Hartmann crocodile forceps	Damage to ear canal from instrumentation	Likely 4	Negligible 1	4	Haemostasis with time, irrigation & topical adrenaline
2.12	Clean endoscope intermittently using sterile gauze & anti-fog when necessary	Poor quality images	Likely 4	Negligible 1	4	Clean endoscope
2.13	Obtain clear view of TM	Damage to middle-ear structures e.g. ossicular chain	Unlikely 2	Major 4	8	Haemostasis with time, irrigation & topical adrenaline. Observe endoscope progress using monitor
2.14	Avoid sudden movements that would result in endoscopic plunge	Damage to middle-ear structures e.g. ossicular chain	Unlikely 2	Major 4	8	Haemostasis with time, irrigation & topical adrenaline. Observe endoscope progress using monitor. Avoid plunge
2.15	Take pictures of pathology with help of assistant at endoscopy tower	Poor quality images	Likely 4	Negligible 1	4	Clean endoscope. Retake images
2.16	Remove endoscope from ear canal	Damage to ear canal	Unlikely 2	Negligible 1	2	Haemostasis with time, irrigation & topical adrenaline. Observe endoscope progress using monitor
3.1	Using a number 15 blade scalpel, incise skin above tragal cartilage, posteriorly & medially at base of tragal dome	Visible scar on tragus	Rare 1	Minor 2	2	Ensure incision is 5 mm medial from tragus tip
3.2	Use assistant & skin hooks to retract incised tragus	Damage to anterior tragus	Rare 1	Minor 2	2	Haemostasis with time, irrigation & topical adrenaline. Gently retract tragus
3.3	Dissect along perichondrium with blunt dissection & mosquito forceps	Damage to potential graft	Unlikely 2	Minor 2	4	Use atraumatic instruments on cartilage
3.4	Use 6 mm skin punch biopsy to harvest tragal cartilage graft with perichondrium on one side	Damage to tragus	Unlikely 2	Minor 2	4	Haemostasis with time, irrigation & topical adrenaline
3.5	Haemostasis, if necessary, by bipolar diathermy	Damage to tragus	Unlikely 2	Minor 2	4	Haemostasis with time, irrigation & topical adrenaline
3.6	Close tragal incision using simple interrupted (size 4-0) Vicryl Rapide™ sutures	Tragal haematoma	Unlikely 2	Moderate 3	6	Ensure haemostasis with bipolar diathermy
4.1	Using a Kurz® Precise Cartilage Knife & number 15 blade scalpel, shape & thin the graft to match TM perforation	Graft too thin & damaged	Unlikely 2	Minor 2	4	Use different part of cartilage sample as graft
4.2	Size the graft to replace TM defect	Incorrect graft shape	Unlikely 2	Minor 2	4	Use different part of cartilage sample as graft
4.3	Store graft in normal saline	Graft is dry	Rare 1	Negligible 1	1	Store in saline
5.1	Insert endoscope into ear canal & visualise affected TM	Damage to viable TM	Unlikely 2	Minor 2	4	Repair damage
5.2	Freshen TM edges using sharp needle	Damage to middle-ear structures	Unlikely 2	Major 4	8	Haemostasis with time, irrigation & topical adrenaline. Observe endoscope progress using monitor. Avoid plunge
5.3	Assess for debris in middle ear & clean as required	Damage to middle-ear structures	Unlikely 2	Major 4	8	Haemostasis with time, irrigation & topical adrenaline. Observe endoscope progress using monitor
5.4	Layer Gelfoam® absorbable dressing into middle ear to support graft	Graft not supported	Rare 1	Negligible 1	1	Insert Gelfoam

(*Continued*)

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Table 4. (*Continued.*)

Step	Subtask	Error	Frequency	Severity	Risk score	Remediation
6.1	Use Hartmann crocodile forceps to introduce graft into ear canal with aid of endoscope	Damage to outer ear & middle-ear structures	Unlikely 2	Major 4	8	Haemostasis with time, irrigation & topical adrenaline. Observe endoscope progress using monitor
6.2	Push graft through TM perforation in an underlay position. Ensure perichondrium-free surface faces into middle ear	Incorrect graft position	Unlikely 2	Minor 2	4	Reposition graft
6.3	Ensure there is no communication between outer & middle ear	Communication between middle & outer ear	Unlikely 2	Major 4	8	Reposition graft
6.4	Insert absorbable EpiDisc® dressing over tragal cartilage graft	Protect lateral surface of graft	Rare 1	Minor 2	2	Insert EpiDisc
6.5	Insert Gelfoam® into ear canal to stabilise graft	Graft moved out of place	Unlikely 2	Minor 2	4	Reposition graft
7.1	Apply BIPP to thin strips of ribbon gauze	BIPP paste not applied	Rare 1	Negligible 1	1	Apply BIPP
7.2	Insert gauze strips into ear canal	Damage to ear canal	Unlikely 2	Negligible 1	2	Haemostasis with time, irrigation & topical adrenaline. Repair of damage
7.3	Apply antibiotic-ointment-soaked cotton wool to outer-ear canal	Wound improperly dressed	Unlikely 2	Negligible 1	2	Redress wound
8.1	When patient awake, provide written post-op instructions regarding water precautions & caution against nose blowing	Graft infection or migration	Rare 1	Major 4	4	Post-op care instructions given prior to discharge from hospital
8.2	Review in out-patient clinic for removal of aural dressing at 3 weeks	Aural dressing not removed	Rare 1	Negligible 1	1	Review in next available out-patient clinic

Pre-op = pre-operative; N_2O = nitrous oxide; ET = endotracheal; EAC = external auditory canal; LED = light-emitting diode; TM = tympanic membrane; BIPP = bismuth iodoform paraffin paste; post-op = post-operative

and intuitive operating theatre layout. Totally endoscopic ear surgery also provides a high-definition record of pathology and surgical correction, allowing for progress to be monitored over time.

Even with its challenges, totally endoscopic ear surgery has proved useful in multiple procedures including: stapes surgery,[30] assessment of perilymphatic fistulas,[31] management of cholesteatoma[32] and paediatric middle-ear surgery.[33] Recently, totally endoscopic ear surgery has been used in the coronavirus disease 2019 pandemic to reduce the need for open ear surgery and the associated aerosols generated.[34]

The use of hierarchical task analysis in totally endoscopic ear surgery can increase an otolaryngologist's familiarity with the surgery. Hierarchical task analysis highlights areas of difficulty, which can be used to inform trainees who are inexperienced with totally endoscopic ear surgery. Increasing a trainee's familiarity with a new procedure can make the trainee more likely to safely attempt novel techniques, therefore providing more skills for the management of a wide range of pathologies. Hierarchical task analysis provides the steps required for error-free tragal cartilage tympanoplasty, allowing otolaryngologists of all levels to improve their skills.

Human factors and simulation teaching has been increasing in recent years, with mandatory training for core surgical trainees in the Royal College of Surgeons in Ireland and the UK.[35,36] Learning through trial and error is no longer feasible given the potential for patient harm, and simulation teaching with manikins and task trainers is being used to bridge the gap in surgical training.[37] Hierarchical task analysis and the systematic human error reduction and prediction approach are valuable tools for surgical training. The creation of a standardised procedure allows trainees to follow a step-by-step guide to a surgical operation, with the potential to reduce performance variation among surgeons. Human error is thought to be the cause of most adverse surgical events.[38] This systematic human error reduction and prediction approach highlights areas of potential danger, and guides trainees and trainers to focus on these areas, improve surgical skills and improve patient safety.

Hierarchical task analysis can also be used for the assessment of surgical trainees, by evaluating a trainee's ability to adhere to a previously devised pathway for a surgical procedure. The trainee's performance can be compared to the agreed standard. Hierarchical task analysis and the systematic human error reduction and prediction approach are particularly useful for novel or technically challenging procedures such as totally endoscopic ear surgery. The validity of hierarchical task analysis and the systematic human error reduction and prediction approach, as applied to totally endoscopic ear surgery as a teaching tool, will need to be assessed in the future through further research.

This study had a number of limitations. Our hierarchical task analysis and systematic human error reduction and prediction approach are specific to push-through cartilage tympanoplasty, and there are multiple other methods available. Our steps would benefit users of different methods, but would not

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be comprehensive. Three consultant otologists were selected as experts because this is a single-institution study. These experts were selected as they are experienced in endoscopic ear surgery and are members of the institution's otolaryngology department. Another panel of experts may have assessed the important tasks and evaluated errors of this procedure differently.

- Totally endoscopic ear surgery is a novel method that can offer a unique perspective of operative and non-operative challenges
- Hierarchical task analysis is an approach used to deconstruct expert performance
- The systematic human error reduction and prediction approach involves error identification, error frequency and severity quantification, for error reduction
- These methods have not previously been described in medical literature for totally endoscopic ear surgery
- Hierarchical task analysis was used to describe the steps required for error-free totally endoscopic push-through tragal cartilage tympanoplasty
- The systematic human error reduction and prediction approach identified potential surgical errors, enabling error reduction mechanisms to mitigate these risks

It is recognised that deconstructing any surgical procedure into tasks and subtasks will result in many individual steps. This can act as a starting point to design a more efficient, trainee-focused aid, individual to each operating surgeon, which highlights key surgical steps, particularly those considered high risk. A handful of steps, such as those involving taking pictures, are not mandatory and instead reflect the preferences of this department's otologists. A tympanomeatal flap was not raised. This can be a difficult step for early-stage trainees and those migrating from microscopic techniques. Proficiency at entry-level totally endoscopic ear surgery allows smooth progression to more complex procedures. Breakdown of the steps required for raising a tympanomeatal flap would benefit trainees, but this was outside the scope of this paper. Assessment of outcomes for trainees using this hierarchical task analysis and systematic human error reduction and prediction approach has not yet been performed. We hope to undertake this research in the future.

Conclusion

The hierarchical task analysis and systematic human error reduction and prediction approach methods are valuable tools, which, through standardisation of practice, allow errors in surgery to be better recognised and more promptly addressed. Our hierarchical task analysis allows for quick reference to a correct method of endoscopic tympanoplasty and enables evaluation of a standard technique. The systematic human error reduction and prediction approach identified numerous potential errors in the completion of totally endoscopic tragal cartilage tympanoplasty; this enabled the identification of error reduction mechanisms to mitigate the risks of undergoing totally endoscopic ear surgery. We are not aware of these methods being applied to totally endoscopic ear surgery to date.

Competing interests. None declared.

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