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Systematic Review

Human factors in otorhinolaryngology: a systems engineering approach to patient safety, surgeon well-being and clinical excellence

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ABSTRACT

Otorhinolaryngology-head and neck surgery (ORL-HNS) is a high-acuity, technologically dense specialty in which surgical injuries account for approximately 80% of specialty-related patient harm, necessitating a shift from individual culpability toward a systems-based approach to safety. This systematic review synthesized the evidence on human factors in ORL-HNS using the Systems Engineering Initiative for Patient Safety (SEIPS) 2.0 framework. PubMed/MEDLINE, Scopus, Web of Science, Embase, the Cochrane Library and CINAHL were searched in January 2026 for English-language, peer-reviewed studies published between 2000 and 2026, with independent dual-reviewer screening and thematic narrative synthesis reported according to PRISMA 2020. Of 2,996 records identified, 46 studies were included. Technical errors were the most frequently reported error category (19.3%), and testing errors accounted for 10.4%. Never events such as wrong-site surgery were driven predominantly by cognitive and communication failures rather than individual incompetence. Work-related musculoskeletal disorders were reported by 79% of general otolaryngologists, most often affecting the neck (54%) and back (49%), yet most surgeons reported limited or no knowledge of ergonomic principles. The 3D exoscope permitted more neutral postures than the operating microscope, whereas image-guided navigation and robotic platforms could increase cognitive workload for inexperienced users. Failures of communication, teamwork and leadership underlay 70–80% of errors in crisis situations, and the effectiveness of surgical safety checklists (SSC) depended on organizational culture. Advancing clinical excellence requires multi-level redesign of work systems, formal ergonomic and simulation-based non-technical skills education, and a just culture that supports surgeon well-being.

Keywords: Otolaryngology, Ergonomics, Patient safety, System engineering, Medical errors

INTRODUCTION

The contemporary practice of otorhinolaryngology and head and neck surgery (ORL-HNS) is defined by an intricate convergence of high-acuity surgical interventions, technologically dense environments, and a reliance on micro-anatomical precision. Within this complex milieu, the discipline of human factors, frequently referred to as ergonomics, emerges not merely as a peripheral concern but as a foundational scientific pillar essential for optimizing clinical performance and ensuring patient safety. Human factors in healthcare is defined as the scientific study of the interactions between humans and the various elements of a system, specifically focusing on how teamwork, tasks, equipment, workspace design, organizational culture, and cognitive processes

influence human behaviour and abilities in clinical settings.[1,2] By acknowledging the inherent limitations and frailties of human performance, this discipline offers a structured methodology to minimize, mitigate, and manage medical error and its consequences.[1]

The evolution of patient safety in surgery has transitioned from a historical focus on individual clinician culpability toward a sophisticated systems-based paradigm. It is now understood that surgical safety incidents, which can account for up to 74.9% of all adverse events in hospitalized patients, are rarely the result of a single catastrophic failure by an individual.[2] Instead, these incidents are often the culmination of latent organizational failures and inadequately designed systems that permit predictable human errors to reach the patient.[3-5] In the specific context of otorhinolaryngology, surgical patient injuries constitute approximately 80% of all specialty-related patient injuries, necessitating a rigorous application of human factors principles to safeguard both patients and practitioners.[3,6]

Evidence on human factors in otorhinolaryngology is, however, dispersed across the ergonomic, cognitive-psychology, team-science and device-safety literature, and its implications for patient safety and for surgeon well-being are usually considered separately. The objective of this systematic review was therefore to identify and synthesize the published evidence on human factors in otorhinolaryngology and to interpret it within a single work-system framework, the SEIPS 2.0 model. Specifically, the review sought to characterize the epidemiology and taxonomy of error in the specialty, to describe the physical and cognitive workload borne by otorhinolaryngologists, and to examine the organizational, non-technical, procedural and design-based measures that mitigate these risks.

METHODS

This systematic narrative review was conducted in accordance with the PRISMA 2020 reporting standards to analyse the impact of human factors and systems engineering on patient safety and surgeon well-being in otorhinolaryngology. A narrative synthesis approach was selected rather than a quantitative meta-analysis due to the significant heterogeneity of the evidence base, which integrated randomized controlled trials, ergonomic surveys, and qualitative systems evaluations.

A comprehensive search of PubMed/MEDLINE, Scopus, Web of Science, Embase, the Cochrane Library, and CINAHL was completed in January 2026. The search strategy employed high-sensitivity Boolean strings, such as ("human factors" OR "ergonomics") AND ("otorhinolaryngology" OR "ENT") AND ("patient safety" OR "simulation training"). Eligibility criteria were strictly applied to identify English-language, peer-reviewed studies published between 2000 and 2026 that focused on ENT surgeons, operating room teams, and perioperative safety. Inclusion favoured studies utilizing validated human factors tools, such as the NASA Task Load Index (NASA-TLX) for cognitive workload or the Rapid Upper Limb Assessment (RULA) for physical ergonomics, while excluding non-medical literature and editorials lacking empirical grounding.

Study selection was performed via a dual-reviewer independent screening protocol, with discrepancies resolved through third-party adjudication. Data extraction focused on the specific human factor's domains identified, measurement instruments, and clinical or ergonomic outcomes. The findings were synthesized through a thematic approach, which mapped work system redesigns, technical and non-technical skill acquisition, and the prevalence of work-related musculoskeletal disorders (Figure 1).

The PRISMA selection process identified 2,782 records through database searches and 214 through manual screening and grey literature (n=2,996). Following the removal of 603 duplicates, 2,393 records were screened, resulting in the exclusion of 1,927 reports. Of the 466 full-text articles assessed for eligibility, 420 were excluded: 118 were not specific to the specialty, 94 did not focus on human factors engineering, 86 lacked measurable safety or ergonomic outcomes, 47 were conference abstracts only, and 29 were non-English. Consequently, 46 studies met all criteria and were incorporated into the final synthesis, providing the evidentiary foundation for the systems engineering approach to clinical excellence and professional resilience in the specialty.

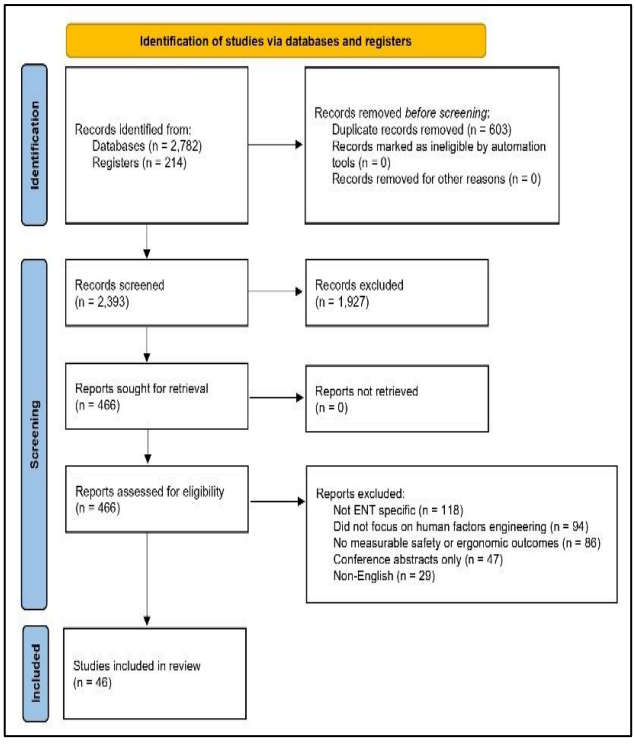

Figure 1: PRISMA flow diagram.

RESULTS

The included studies comprised randomized controlled trials, cross-sectional ergonomic and error-reporting surveys, observational and simulation-based studies, qualitative and Delphi studies, systematic reviews, and analyses of adverse-event and device-safety databases. The findings are presented below under the nine synthesis themes.

Organizational, managerial and sociotechnical factors

The application of human factors in otorhinolaryngology requires an organizing framework that accounts for the multiplicity of variables influencing surgical outcomes. A robust and widely accepted model categorizes these factors into four primary domains: Organizational and Managerial, Team, Individual, and Work Environment.[7,8] These domains do not operate in isolation; rather, they form a complex sociotechnical system characterized by non-linear and often unpredictable interactions.[2,9]

At the highest level of the system, organizational culture and managerial leadership dictate the prioritization of safety over competing demands such as throughput and efficiency. A positive safety culture reflects the shared attitudes and values of the workforce regarding risk management and error reporting.[7] Key dimensions include management's commitment to safety, rigorous adherence to safety protocols, and the presence of a "just culture" where errors are viewed as opportunities for system learning rather than grounds for individual punishment.[8]

Evidence suggests that organizational-level factors are often the most precarious and difficult to modify, yet they exert a profound influence on staff morale and likelihood of preventable medical errors.[9] When management provides strong support and clear expectations, the resulting organizational dimensions can help reverse poor communication patterns and foster a learning environment.[10] Conversely, hierarchical intimidation or lack of senior support can lead to the failure of safety interventions such as surgical checklists.[11]

The SEIPS model, and its evolution into SEIPS 2.0, provides a comprehensive framework for analysing the work system.[12] This model emphasizes that any change to one system element whether the introduction of a new Electronic Health Record system, a change in operating room layout, or a shift in staffing ratios can have unpredictable ripple effects throughout the entire care process.[13] In perioperative and outpatient ENT settings, the SEIPS framework identifies five core elements that must be aligned to ensure optimal outcomes (Table 1).

The epidemiology and taxonomy of error in OTL-HNS

The frequency and nature of medical errors in otorhinolaryngology differ significantly from other surgical specialties. ENT departments experience a statistically higher frequency of perioperative and airway management errors compared to other inpatient and outpatient departments.[3,14,15] In a national survey of 466 otolaryngologists, 45% reported an error in their practice during the preceding six months; technical errors formed the largest single category (19.3%), with medication, testing (10.4%) and surgical-planning errors also prominent.[3] Extrapolating from these data, more than 2,600 episodes of major morbidity and 165 deaths related to medical error may occur annually among otolaryngology patients in the United States. Errors span all practice components, including history and physical examination, diagnosis, testing, and surgical planning, with consequences ranging from minor setbacks to catastrophic sentinel events (Table 2).[3]

"Never events" in otorhinolaryngology

"Never events" are serious reportable healthcare events considered largely preventable through established systems and protocols, including wrong-site/wrong-procedure surgery and unintended retention of foreign objects. Surgeons operating on bilateral structures a frequent occurrence in ENT for ears, sinuses, and thyroid surgery face a 25% lifetime risk of involvement in a wrong-site surgery event.[4]

Systems safety research indicates that these events are predominantly driven by cognitive factors such as channelled attention, overconfidence, and inadequate vigilance, rather than individual incompetence. Personnel factors, particularly inadequate communication, contribute to approximately 23% of the preconditions for these unsafe actions.[4] Technological factors, such as insufficient interface between electronic systems or a lack of automation in tracking surgical items, also play a significant role in the aetiology of never events.[5]

The impact of surgical expertise and experience

The aetiology of surgical pitfalls correlates closely with the practitioner's level of training. At the residency level, inexperience is the primary driver of complications, with nearly 60% of intraoperative errors attributed to unfamiliarity with complex anatomy or misjudgement of anatomical relationships.[16,17] During fellowship and early attending years, the risk profile shifts toward overconfidence and complacency, where surgeons may deviate from standard protocols or underestimate risks.[18]

Even for highly experienced senior surgeons, cognitive biases remain a persistent threat. Confirmation bias (seeking information that supports a preconceived diagnosis while ignoring contradictory evidence) and anchoring (giving excessive weight to initial information), can lead to diagnostic and intraoperative misjudgements. These cognitive traps are exacerbated by stressors such as high workload and fatigue, which erode even well-established technical skills.[19]

Ergonomics and musculoskeletal health

Otorhinolaryngology is widely recognized as a surgical specialty with a high degree of ergonomic risk.[20,21] The requirement for prolonged static postures while utilizing head-mounted lighting, loupe magnification, operating microscopes, and endoscopes places immense physical strain on the surgeon. Work-related musculoskeletal disorders (WRMD) are prevalent, with up to 79% of general otolaryngologists reporting some form of work-related musculoskeletal discomfort.[22] The prevalence of neck symptoms is estimated at 54%, back symptoms at 49%, and shoulder symptoms at 33% (Table 3).[20]

Approximately 23-84% of otolaryngologists require medical treatment for WRMD, and a significant portion believe these conditions negatively impact surgical performance.[22] Despite the high prevalence, 62% of surgeons report no knowledge and 31% report limited knowledge of ergonomic best practices.[20]

The choice of visualization technology has direct implications for surgeon posture and fatigue. Studies using the Rapid Upper Limb Assessment (RULA) tool have demonstrated that microscopic surgery is associated with higher ergonomic risk compared to newer platforms such as the 3D exoscope. The 3D exoscope offers a more "heads-up" neutral posture, as surgeon views operative field on a monitor rather than through fixed eyepieces, with comparative studies showing faster completion times and significantly improved ergonomics.[20]

In endoscopic sinus surgery, monitor placement is a critical ergonomic variable; monitors should be positioned directly in front of the surgeon at eye level to prevent neck flexion exceeding 20°, and never beyond 40°. (Table 4) Objective assessment of surgeon posture, and the use of posture-training devices, has also been evaluated during otolaryngology procedures.[23] Beyond equipment adjustments, behavioural interventions such as "microbreaks" (one- to two-minute exercise-guided stretching breaks every 20 to 40 minutes) have been shown to activate dormant muscle groups and reduce fatigue. Strengthening joint and core muscles through targeted exercise is also recommended to improve intraoperative endurance.[24]

Cognitive human factors: workload, situation awareness, and automaticity

The mental demands placed on a surgeon during complex ENT procedures are substantial. Cognitive Workload (CWL) is defined as the mental strain and effort required by working memory to complete a task, and in high-demand environments, cognitive overload can occur, impairing decision-making and performance.[25-27] Cognitive load theory divides the total load into three types: intrinsic load (the inherent difficulty of the task), extraneous load (mental effort imposed by environmental factors and poor equipment design), and germane load (resources dedicated to learning and schema development).[25] A hallmark of surgical expertise is the ability to balance these demands through "automaticity," whereby routine tasks require fewer cognitive resources, allowing the expert to dedicate more working memory to non-routine situations such as emergencies or unexpected anatomical variants.[25,27]

Situation awareness (SA) is a critical non-technical skill defined as the perception of environmental elements, comprehension of their meaning, and projection of their future status.[28,29] In the operating room, SA involves maintaining an accurate mental model of the procedure amidst a constant stream of information. Loss of SA is a significant factor in medical errors, particularly during airway crises.[16,30] Technological advancements such as Image-Guided Navigation (IGN) and robotic-assisted surgery have a complex impact on cognitive workload. While IGN provides improved spatial orientation, it can also increase mental demand, particularly for inexperienced users.[31-33] Robotic-assisted surgery offers physical ergonomic benefits but may reduce situation awareness through the physical separation of the surgeon from the team and the loss of haptic feedback.[34] However, once proficiency is achieved, robotic platforms can significantly reduce mental workload subdomains of effort and frustration compared to traditional approaches, as demonstrated by NASA-TLX (Table 5).[35]

Non-technical skills and interdisciplinary teamwork

While technical proficiency remains the traditional focus of surgical training, non-technical skills (NTS) are increasingly recognized as essential for safe and efficient performance.[36] NTS encompass the cognitive and social skills that complement technical expertise, and 70–80% of medical errors in crisis situations are attributed to failures in communication, teamwork, and leadership rather than technical deficiency.[30,31,36] The categories and elements of non-technical skills, as operationalized in crew resource management, are summarized in Table 6.

Nurses play a pivotal role in non-technical environment of the operating room. Empirical studies have identified NTS specific to scrub and circulating nurses, including independent decision-making and proactive problem-solving. The tacit knowledge of experienced nurses such as anticipating instrument needs or identifying a break in sterile field before it occurs is a critical component of system resilience.[37,38] Ineffective communication is well-represented theme in literature as primary contributor to patient harm, while transparent communication regarding adverse events supports organizational learning and shared sense of accountability.[9]

SSCs: protocols and the human factor

The introduction of the WHO SSC in 2008 marked a transformative moment in patient safety, designed to reduce major complications and mortality by ensuring

critical tasks are performed consistently while encouraging a non-hierarchical, team-based approach. The checklist is divided into three phases: Sign-In, Time-Out, and Sign-Out (Table 7).[39-41] Effective implementation, however, depends heavily on the organizational and cultural factors described throughout this discussion, underscoring that protocols alone are insufficient without sustained institutional commitment to safety culture and team-based practice.[42]

Human factors in the outpatient ENT clinic

While the operating room is the focus of much research, the outpatient clinic is a high-volume environment where 10-15% of patients experience adverse events, many of which are preventable.[43-45] Rhinolaryngoscopes are among the most widely used instruments in otolaryngological practice. An analysis of the United States Food and Drug Administration Manufacturer and User Facility Device Experience (MAUDE) database identified 2,591 rhinolaryngoscope-related reports between 2016 and 2023, comprising 2,534 device malfunctions, 56 patient injuries and one death (Table 8).[46] Breakage was the most frequent device problem (40.8%), followed by fluid leaks and poor image quality, while contamination or reprocessing problems accounted for 4.9% of reports. Bleeding was the most common patient-related adverse event, with root causes that included material deformation or wear, breakage and improper operation of the device.[46]

Table 1: Elements of SEIPS.[6]

SEIPS work system element	Description and ENT context
People	The characteristics, knowledge, and psychological states of surgeons, nurses, anaesthetists, and patients
Tasks	The specific nature of surgical or diagnostic procedures, including cognitive demand, time pressure, and workload
Tools and technology	The design and usability of microscopes, lasers, robotic consoles, and EHR interfaces
Organization	The structural and cultural characteristics, including leadership, policies, and hierarchical levels
Environment	The physical and psychosocial workspace, including lighting, noise levels, and room layout

Table 2: Classification of errors.

Error classification	Percentage of total errors	Key human factors implications
Technical errors	19.3%	Relates to psychomotor skills, fine motor coordination, and inexperience[3,16]
Testing errors	10.4%	Involves the misinterpretation of imaging or laboratory data[3,16]
Surgical planning	9.9%	Linked to cognitive biases and failures in preoperative assessment[3,16]
Wrong-site surgery	6.1-7.3%	Represents a failure in site marking and preoperative verification[3,4]
Medication errors	3.8-12.7%	Often caused by labelling issues or communication breakdowns[3,19]
Anaesthesia-related	3.3%	Highly sensitive to the timing of safety checks and team coordination[3,19]

Table 3: Prevalence and distribution of chronic pain among otolaryngologists.

Anatomical site	Symptom prevalence	Impact on productivity and longevity
Neck	54%	Potential for chronic cervical pain and radiculopathy[21,22]
Shoulder	33%	Risk of rotator cuff injury and chronic bursitis[22]
Back	49%	Linked to prolonged standing and poor lumbar support[22]
Overall WRMD (Work-related musculoskeletal disorders)	79%	5-23% of surgeons take time off work; 1-6% stop operating[22]

Table 4: Ergonomic guidelines for the ENT operating room.[24]

Procedure category	Ergonomic recommendation	Physiological rationale
Seated procedures (Ear/Micro)	Chair should have adjustable armrests, lumbar support, and locking casters	Provides stability for fine motor tasks and reduces spinal load
Open surgery (Neck/ thyroid)	Neck flexion <20°; shoulder abduction <30°	Minimizes strain on cervical vertebrae and rotator cuff

Continued.

Procedure category	Ergonomic recommendation	Physiological rationale
Table height	Adjust for the tallest surgeon; others use step stools	Ensures neutral elbow flexion (90° - 120°) for all team members
Endoscopic/robotic	Monitor at eye level; console angle 15° below horizontal	Prevents "text neck" and computer vision syndrome
Standing support	Use of antifatigue mats and unlocked knee posture	Reduces lower extremity discomfort and improves circulation

Table 5: The NASA-TLX subscales and the corresponding surgical contexts.[34,35]

NASA-TLX subscale	Description in surgical context
Mental demand	Thinking, deciding, calculating, and remembering required
Physical demand	Amount of physical exertion, such as holding instruments
Temporal demand	Time pressure felt during the procedure
Effort	How hard the surgeon has to work to achieve their performance
Performance	The perceived success in meeting the goals of the surgery
Frustration	The level of irritation or insecurity felt during the task

Table 6: Non-technical skills categories and elements in crew resource management.[36]

Category	Elements
Situation awareness	Gathering information Interpreting information Anticipating future states
Decision-making	Defining problems Considering options Selecting and implementing option Outcome review
Communication	Sending information clearly and concisely Including context and intent Receiving information Identifying and addressing barriers to communication
Team working	Supporting others Solving conflicts Exchanging information Co-ordinating activities
Leadership	Using authority Maintaining standards Planning and prioritizing Managing workload and resources
Managing stress	Identifying symptoms of stress Recognizing effects of stress Implementing coping strategies
Coping with fatigue	Identifying symptoms of fatigue Recognizing effects of fatigue Implementing coping strategies

Table 7: Key items for confirmation of the various phases of the WHO SSC.[39,40]

SSC phase	Key items for confirmation
Sign-in	Patient identity, site marking, procedure, consent, anaesthesia machine check, pulse oximetry, airway or aspiration risk
Time-out	Team introductions, surgeon or anaesthesia or nursing review of critical concerns, antibiotic prophylaxis, sterility confirmation
Sign-out	Confirmation of procedure name, instrument/sponge/needle counts, specimen labelling, equipment issues

Table 8: Rhinolaryngoscopy device issues and patient adverse events as per the MAUDE database between 2016 and 2023.[46]

Device issue	Reports, (n=2591)	Common patient adverse events
Breakage	40.8%	Haemorrhage/bleeding (28%)
Fluid leakage	24.4%	Foreign body in patient (19%)
Poor image quality	18%	Discomfort/pain (16%)
Contamination	4.9%	Burns/thermal burns (14%)
Material deformation	4.8%	Anaphylactic shock or oedema (11%)

DISCUSSION

This systematic review of 46 studies indicates that the principal threats to patient safety and surgeon well-being in otorhinolaryngology arise from the design of the work system rather than from isolated individual failure. Errors were distributed across every phase of care, with technical errors predominating,[3] and never events were driven chiefly by cognitive and communication failures.[4,5] The physical burden of practice was substantial, with most otolaryngologists reporting work-related musculoskeletal symptoms despite limited ergonomic knowledge, and the cognitive burden of complex procedures was shaped by technology in ways that depended on the user's experience.[20,22,32,33] Failures of non-technical skills, rather than technical deficiency, underlay most crisis-related errors, and the benefit of safety protocols such as the WHO SSC depended on organizational culture and leadership.[11,36,42]

Interpreted through the SEIPS 2.0 model, these findings show that the components of the ENT work system (the person, tasks, tools and technology, organization, and environment) interact, and that improving one component can shift load onto another. The 3D exoscope reduces postural strain compared with the operating microscope, robotic platforms offer physical ergonomic benefits at a potential cost to situation awareness and haptic feedback, and image-guided navigation improves spatial orientation while increasing mental demand for inexperienced users.[20,32,33] New technology in otorhinolaryngology should therefore be evaluated against both physical and cognitive workload, using validated instruments such as RULA and the NASA-TLX, rather than against technical performance alone.[27] In the same way, the concentration of wrong-site risk in bilateral structures such as the ears, sinuses and thyroid is a task characteristic of the specialty, and cognitive failures such as channelled attention and overconfidence are more reliably countered by system-level barriers, including site marking, structured time-outs and automated tracking of surgical items, than by exhortations to individual vigilance.[4,5,39]

Several implications for practice and training follow. The finding that 62% of surgeons report no knowledge of ergonomic best practice identifies a correctable gap: ergonomic principles such as monitor positioning at eye level, neutral postures and scheduled microbreaks can be incorporated into residency curricula and operating room set-up protocols at little cost.[20,24] Because communication, teamwork and leadership failures dominate crisis-related errors, training in non-technical skills, including the skills of scrub and circulating nurses, and interprofessional simulation of high-risk scenarios such as the airway catastrophe merit formal inclusion in otolaryngology training alongside technical skills.[30-36-38] Checklists should be implemented as team interventions supported by leadership and a just culture, since hierarchy and lack of senior support can otherwise undermine them.[10,11] In the outpatient clinic, the pattern of rhinolaryngoscope failures supports the application of human factors engineering to device design, structured training in scope handling and reprocessing, and adverse-event reporting systems that extend beyond the operating room.[15,46]

The review also indicates that surgeon well-being and patient safety are interdependent rather than competing aims. Many otolaryngologists perceive that musculoskeletal symptoms impair their surgical performance, and high workload and fatigue erode even well-established technical skills.[19,22] Measures that protect the surgeon, including ergonomic workstation design, workload management as well as a just culture that treats error as an opportunity for the system learning, are therefore, patient-safety interventions in their own right.[8]

Much of the synthesized evidence derives from North American and European health systems. Its transferability to high-volume, resource-constrained settings, including many teaching hospitals in India, cannot be assumed, because staffing ratios, operating room infrastructure, device reprocessing practices and professional hierarchies may differ; the impact of safety interventions such as checklists should therefore be evaluated in these settings rather than extrapolated.[10]

Future research should prioritize prospective, ENT-specific studies using validated measures of physical workload, cognitive workload and non-technical performance; controlled evaluations of ergonomic and non-technical skills training; assessment of new visualization, navigation and robotic technologies across both physical and cognitive dimensions; systematic study of safety in the outpatient clinic; and studies from low- and middle-income countries.

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