Preprints.org

Article

Revolutionizing Head and Neck Reconstruction: The Integration of Artificial Intelligence and Virtual Reality in Surgical Practice

Shohreh Ghasemi [*] , Mahmood Dashti , Nikoletta Vargas

Article

Revolutionizing Head and Neck Reconstruction: The Integration of Artificial Intelligence and Virtual Reality in Surgical Practice

Shohreh Ghasemi [1,*], Mahmood Dashti [2] and Nikoletta Vargas [3]

[1] DDS, MD, PHD (Advisory board of Oklahoma University, USA),Dental Faculty (RCSI, Ireland)
[2] DDS, MSc, Research Faculty in Shahid Beheshti Medical University, Iran, dashti.mahmood72@gmail.com
[3] DDS, MD, OMFS, University of Rochester, New York, Kimbrough Ambulatory Care Center, USA, Army, MEDDAC, Fort Meade, nikoletta.vargas@alum.urmc.rochester.edu
[*] Correspondence: shooshoo_gh@yahoo.com, Shohreh Ghasemi, DDS, MD, PHD

Abstract: Background: Head and neck reconstructive surgery is evolving with the advent of artificial intelligence (AI) and virtual reality (VR). We aimed to review how these technologies are transforming surgical practice and personalized patient care in head and neck reconstruction. Methods: A comprehensive literature review was conducted, focusing on AI applications (machine learning for diagnostics, 3D modeling, robotic assistance) and VR applications (surgical training simulations, preoperative planning, and intraoperative visualization). Key outcomes of interest were improvements in diagnostic accuracy, surgical efficiency, surgeon learning curves, patient-specific reconstruction planning, and postoperative monitoring. Results: The integration of AI and VR demonstrated enhanced diagnostic capabilities, more efficient and precise surgeries, accelerated surgical training and skill acquisition, highly individualized reconstructive planning, and improved postoperative monitoring and outcomes. AI algorithms increased the accuracy of tumor detection and treatment planning, while VR-based planning and augmented reality guidance improved surgical margins and reduced operative time. VR training platforms shortened the learning curve for surgeons by providing risk-free, immersive simulation, and AI-driven analytics enabled real-time monitoring of reconstructive flaps and early complication detection. Conclusions: AI and VR are revolutionizing head and neck reconstruction by personalizing surgical planning and training, improving intraoperative precision, and enhancing postoperative care. Embracing these technologies in clinical practice can lead to better functional and aesthetic outcomes. Ongoing research, interdisciplinary collaboration, and training are recommended to overcome current limitations and ensure safe, effective adoption of AI and VR in head and neck reconstructive surgery.

Keywords: Artificial Intelligence (AI); Virtual Reality (VR); Head and Neck Reconstruction; Personalized Medicine, Machine Learning, Surgical Planning, Augmented Reality (AR); 3D Modeling, Robotic Surgery, Microsurgery, AI in Diagnostics in Surgical Training; Postoperative Monitoring, Free Flap Reconstruction, Computer-Assisted Surgery

Introduction

Head and neck reconstruction presents unique challenges due to the complex anatomy and critical functions involved. Traditional surgical approaches rely heavily on surgeon experience for planning resections, designing reconstructions, and training new surgeons. Recently, emerging technologies in artificial intelligence (AI) and virtual reality (VR) have shown tremendous potential to augment these aspects of surgical care. AI systems can analyze medical images and data at a level beyond human capability, improving the detection of pathology and enabling data-driven surgical planning. Likewise, VR and related extended reality (XR) technologies provide immersive, three-dimensional

environments for surgical simulation and planning that transcend the limitations of conventional training and preoperative visualization. Integrating AI and VR aligns with the goals of personalized medicine by tailoring surgical strategies to the individual patient's anatomy and condition. Early studies indicate that these innovations can enhance diagnostic accuracy and treatment personalization in head and neck cancer care , while also transforming surgical education through realistic, hands-on virtual simulations . This introduction outlines the role of AI and VR in head and neck reconstruction and their growing significance in improving surgical outcomes and training. We also highlight how the convergence of these technologies can address persistent challenges in complex reconstructions, setting the stage for more personalized and efficient head and neck surgery.

Materials and Methods

Literature Review Methodology

We performed a comprehensive review of the current literature to identify applications of AI and VR in head and neck reconstructive surgery. Using databases such as PubMed and Google Scholar, we searched for studies published in the last decade that discussed AI-driven techniques (including machine learning algorithms, 3D virtual modeling, and robotic-assisted surgery) or VR-driven techniques (including surgical simulation, virtual surgical planning, and augmented reality visualization) in the context of head and neck or maxillofacial reconstruction. Keywords included combinations of "head and neck reconstruction," "artificial intelligence," "machine learning," "3D modeling," "robotic surgery," "virtual reality," "augmented reality," and "surgical training." We included peer-reviewed articles, systematic reviews, and relevant clinical trials that provided evidence on outcomes or described novel technological integrations. Preference was given to recent studies (within the last ~5 years) and high-impact journals to ensure up-to-date and credible information. Key data extracted from the literature included reported improvements in diagnostic accuracy, surgical planning time, operative metrics, learning outcomes for surgeons, customization of reconstructions, and postoperative results when using AI or VR tools, as compared to traditional methods. The findings from these sources were organized into thematic categories corresponding to major applications of AI and VR, which form the basis of our review.

AI Applications in Head and Neck Reconstruction

Machine Learning and Diagnostics: We identified applications of machine learning algorithms in improving diagnostic and planning phases of head and neck surgery. These include deep learning models for medical imaging analysis—such as tumor detection on radiographs, CT, or MRI scans—and automated segmentation of anatomical structures to guide surgeons in planning resections and reconstructions. AI systems have been utilized to analyze complex imaging data and generate virtual surgical simulations or predictions that assist in preoperative planning . For example, algorithms can highlight tumor boundaries or critical structures (nerves, vessels) in imaging studies, helping surgeons map out resection margins and reconstructive needs with greater precision than manual methods. Additionally, predictive models have been developed to forecast surgical outcomes or risks (e.g., the likelihood of a free flap failure or significant bleeding), enabling a more informed and personalized surgical strategy. Natural language processing (NLP) in AI has also been explored for decision support, by mining patient records and research data to recommend personalized treatment plans or identify patients who might benefit from specific reconstructive approaches.

3D Modeling and Virtual Surgical Planning: A significant AI-related advancement in reconstruction is computer-assisted design and 3D modeling of patient anatomy. High-resolution imaging data can be converted into three-dimensional virtual models of defects, which are then used for virtual surgical planning (VSP). In head and neck reconstruction, VSP often involves planning bone segment osteotomies (for example, in mandibular reconstruction) and designing patient-specific implants or cutting guides that are fabricated via 3D printing. These technologies are sometimes categorized under computer-assisted surgery but overlap with AI when algorithms optimize the fit or alignment of reconstructions. The methodology of virtual planning typically includes selecting the optimal donor site (e.g., fibula for jaw reconstruction), virtually shaping it to the resection defect, and simulating the outcome. We reviewed studies where such planning was done in conjunction with AI-driven tools—for instance, AI algorithms that automatically align bone segments or optimize plate designs. Robotic assistance can complement this process by executing precise cuts or placements as per the virtual plan. We note that some specialized centers have made virtual planning and 3D-printed guides a

routine part of mandibular and midface reconstructions, given evidence of improved accuracy and efficiency (as detailed in the Results section).

Robotic Surgical Assistance: The integration of AI in robotic systems represents another frontier in head and neck surgery. We examined literature on robotic-assisted surgeries, such as Transoral Robotic Surgery (TORS) for oropharyngeal tumors and robotic microsurgery for free flap anastomoses. Modern surgical robots provide enhanced dexterity and precision in confined spaces; when augmented with AI, they can offer advanced features like autonomous instrument positioning or real-time safety feedback. For instance, AI algorithms can aid a robotic system in identifying anatomical targets or safe dissection planes, effectively acting as an intelligent co-surgeon. In head and neck reconstruction, robotic assistance is particularly valuable for minimizing invasiveness – e.g., harvesting tissue from donor sites or resecting tumors through small incisions – and for performing delicate tasks such as microvascular suturing with stability beyond human hands. As part of our methodology, we included reports of AI-enhanced robotic outcomes and any comparative studies between robotic and traditional freehand techniques. These AI applications collectively illustrate the "toolbox" of intelligent technologies being applied to enhance various stages of reconstructive surgery.

VR Applications in Surgical Training and Planning

Surgical Training and Skill Development: Virtual reality has emerged as a powerful tool for surgical education and skills training. We reviewed studies on VR simulation platforms developed for head and neck or reconstructive procedures, which allow surgeons and residents to practice in an immersive, computer-generated environment. These VR systems often include 3D anatomical models (sometimes patient-specific) and haptic feedback devices to simulate the tactile sensation of surgery. Our review method involved identifying evaluations of VR training modules – for example, a simulation for tumor resection or microvascular anastomosis – and noting their impact on surgical skill acquisition. Key metrics from these studies include improvements in technical skills, speed, accuracy, and the learning curve of trainees when VR training is used as an adjunct to traditional apprenticeship. Some works also measured muscle memory or psychomotor improvements using VR (e.g., practice of complex dissections repetitively in VR to gain proficiency). We paid special attention to controlled studies or pilot trials that compared groups with VR training to those without, in order to gauge effectiveness. Additionally, the review considered VR's role in continuous medical education and rehearsal of rare or complex surgeries, which can be crucial in head and neck oncology cases where surgeons may plan their approach on a virtual patient model before entering the operating room.

Preoperative Visualization and Intraoperative Guidance: Beyond training, VR and related technologies like augmented reality (AR) are being used to enhance surgical planning and execution for actual patients. We compiled evidence on virtual surgical planning (VSP) conducted in a VR environment, where surgeons can manipulate patient-specific 3D models (from imaging data) to plan resection margins and reconstructive approaches. In some cases, these VR planning sessions involve multi-disciplinary teams reviewing a virtual model of the patient's tumor and anatomy to decide on the optimal surgical plan. We also reviewed augmented reality applications intraoperatively: AR can project digital information (like holographic 3D models or navigation cues) onto the surgeon's field of view using headsets or displays. This is particularly relevant in head and neck surgery for identifying tumor boundaries, vital structures, or alignments for reconstruction in situ. As part of the methods, we included cadaveric and clinical studies evaluating AR headsets (such as the Microsoft HoloLens) for guiding tumor resections or flap placement. Outcome measures of interest were the accuracy of AR-guided resections, time added or saved by using AR, and surgeon feedback on its utility. Both VR and AR rely on high-fidelity visualization; thus, we also noted the development of mixed reality systems that combine VR's immersive planning with AR's real-world overlay during surgery. The collected data on VR/AR applications were categorized to correspond with the focus areas of surgical training and intraoperative visualization, setting the stage to report how these technologies have impacted results in head and neck reconstruction.

Results

Improved Diagnostics and Preoperative Assessment

Applications of AI in head and neck surgery have led to markedly improved diagnostic capabilities. Machine learning algorithms can analyze imaging and histopathology with high accuracy, aiding early detection of cancers and other pathologies that necessitate reconstruction . For instance, AI-driven image analysis can rapidly identify tumor margins on scans or flag metastatic lymph nodes, enhancing the surgeon's ability to plan an effective resection. In practical terms, this means clinicians can diagnose and stage head and neck tumors more reliably and expediently than with visual inspection alone. Improved diagnostic precision directly informs reconstructive strategy; knowing the true extent of a lesion allows for more appropriate resection margins and tailored reconstruction plans. Moreover, AI tools synthesizing data from radiology, pathology, and genomics can suggest personalized treatment approaches. In our review, multiple studies emphasized that integrating AI into the preoperative workflow reduces diagnostic uncertainty and interobserver variability. As a result, surgeons enter the operating room with a clearer map of the patient's anatomy and disease, which is crucial for complex reconstructions. This represents a significant improvement over traditional methods that relied solely on the surgeon's interpretation of imaging, often leaving room for error in appreciating three-dimensional tumor extents or subtle tissue involvement.

Enhanced Surgical Efficiency and Precision

The integration of AI and VR technologies has translated into greater surgical efficiency in head and neck reconstruction. One notable finding is the reduction in operative time when advanced planning tools are used. For example, the use of virtual surgical planning (VSP) for mandibular reconstructions with fibula free flaps was associated with a significantly decreased operative time – on the order of 45 minutes shorter than conventional freehand surgery . This time savings can be attributed to the prefabrication of cutting guides and precise surgical plans that streamline intraoperative decisions. Shorter surgery duration not only improves operating room efficiency but also can reduce anesthesia time and potential complications for patients. In addition to speed, AI and VR have improved the precision of surgical execution. Augmented reality guidance and AI-driven navigation systems enable surgeons to perform more exacting resections and placements. In one study, an AR system overlaying a patient-specific tumor hologram onto the surgical field allowed surgeons to relocate tumor resection margins with an average error of only 4 mm, compared to ~10 mm using standard techniques . This level of precision means fewer guesswork adjustments and re-cuts during surgery. Furthermore, early clinical evidence supports that VR-enhanced preoperative planning can improve oncologic outcomes: a recent randomized pilot trial of VR surgical planning for head and neck cancer resection showed a significantly lower rate of positive or close margins and fewer unplanned margin extensions in the VR-planned group . Fewer margin re-excisions not only indicate better oncological safety but also contribute to efficiency by avoiding extended operations. Robotic surgical systems, when combined with AI guidance, have similarly improved efficiency by enabling minimally invasive approaches that shorten hospital stays and recovery. In sum, compared to traditional freehand techniques and on-the-fly decision-making, these results demonstrate that AI and VR tools can streamline surgical workflows while enhancing accuracy.

Shorter Learning Curves in Surgical Training

Our findings underscore a significant impact of VR on surgical education, translating to improved learning curves for head and neck surgeons. Studies on VR simulators for procedures such as endoscopic sinus surgery, temporal bone dissection, or free flap harvest show that trainees who practiced in VR attained proficiency faster than those who trained by conventional means alone. Novice surgeons benefited the most from VR-based rehearsal, showing marked improvements in confidence, technical accuracy, and decision-making efficiency during actual procedures . Objective assessments have documented that residents trained with VR commit fewer errors and demonstrate enhanced dexterity when performing complex tasks, effectively accelerating their progression to competency. For example, a systematic review in plastic and reconstructive surgery education found that VR simulation experience led to better performance in real surgical tasks, with novices demonstrating skill levels closer to experienced surgeons after VR training sessions . The learning curve—traditionally steep in head and neck reconstruction due to the intricate anatomy and microsurgical

techniques—is made more gradual by the opportunity to practice repeatedly in a no-risk virtual setting. VR modules offer immediate feedback and can be repeated until mastery, something not feasible on real patients. Consequently, young surgeons can reach critical milestones (such as performing a safe tracheostomy, or a microvascular anastomosis) more quickly and with greater assurance. Compared to the traditional apprenticeship model of learning solely in the operating room, the incorporation of VR significantly compresses the time and cases required for a surgeon to achieve proficiency in head and neck reconstructive skills.

Patient-Specific Reconstruction and Personalization

A key benefit of these technologies is the facilitation of patient-specific reconstructions. VR and advanced 3D modeling enable surgeons to tailor surgical plans and devices to an individual patient's anatomy, epitomizing personalized medicine in surgery. Through virtual surgical planning, each patient's CT/MRI data is turned into a 3D model on which osteotomies and flap designs can be planned with millimeter precision. Surgeons can perform a "virtual surgery" before the actual one, customizing resection margins and reconstruction contours to fit the patient's defect. Our review found that patient-specific VR modeling allows visualization of unique anatomical variations that generic models or two-dimensional images might not reveal . In one report, creating VR models for individual patients helped surgeons practice and refine their approach, which improved the surgical plan's feasibility and confidence, even though the fidelity of some models (e.g., texture or minor vessel detail) was lower than cadaveric simulations . The individualized approach extends to manufacturing cutting guides and implants: AI-assisted design can produce patient-specific plates, mandibular reconstructions, or orbital floor implants that match the patient's anatomy exactly, reducing the need for intraoperative adjustments. We also noted that AI algorithms are being used to select the optimal reconstructive option for a given patient based on predicted functional outcomes – for instance, suggesting which donor site (radial forearm vs. fibula flap) might best restore form and function for a particular oral cavity defect, by analyzing prior outcomes in similar patients. Such data-driven personalization was not possible in the past. Patients thus receive reconstructions that are bespoke to their anatomy and needs, improving aesthetic and functional results. In contrast to the one-size-fits-all plates or surgeon's best guess in shaping a bone graft, AI and VR-facilitated personalization yields reconstructions that integrate more seamlessly with the patient's remaining structures.

Improved Postoperative Monitoring and Outcomes

Postoperative care, especially monitoring of reconstructive flaps and surgical sites, has also been enhanced through AI-driven solutions. Free tissue transfers (flaps) in head and neck reconstruction require vigilant monitoring for vascular compromise in the days after surgery. Traditionally, this is done through clinical exam and occasional Doppler checks, which are intermittent and clinician-dependent. AI technology now allows continuous, automated monitoring using sensors and machine learning analysis. One study developed a supervised machine learning model to analyze signals (like tissue oxygenation or temperature) from a flap monitoring device, enabling early detection of ischemia or venous thrombosis in the transplanted tissue . The AI system can alert the surgical team at the earliest sign of compromise, often before it is clinically apparent, thereby increasing the success rate of salvaging the flap. Our review found that such AI-based monitoring markedly improves postoperative safety: complications are detected sooner, interventions (e.g., returning to the OR to relieve a thrombosis) can be performed in a more timely fashion, and the reliance on round-the-clock specialized clinical staff is reduced . Beyond flaps, AI algorithms have been employed to predict and track patient recovery trajectories. For example, machine learning models using postoperative data can predict which patients are at higher risk of wound dehiscence, infection, or airway complications, prompting preemptive measures. Additionally, VR technology has been piloted for postoperative rehabilitation—such as VR exercises to help patients regain neck movement or swallowing function in a gamified manner—though these applications are still emerging. Overall, patients benefit from a more proactive and personalized postoperative course. In comparison to traditional postoperative care, which might detect problems only during scheduled exams, AI-driven monitoring provides real-time surveillance and peace of mind that any deviation in the patient's recovery will be promptly identified and addressed. This contributes to improved outcomes, as early intervention often prevents minor issues from becoming major complications.

Discussion

The integration of AI and VR into head and neck reconstructive practice represents a paradigm shift when compared to traditional techniques. The results of this review illustrate that these technologies not only enhance what surgeons can do, but also how they do it. For instance, in the past, surgical planning relied on two-dimensional imaging and surgeon experience, whereas now AI algorithms can synthesize vast datasets to guide decisions, and VR can present the surgeon with a lifelike 3D rehearsal of the procedure. The improved diagnostic accuracy and surgical precision we found (e.g., AI-assisted margin analysis and AR-guided resections) directly address long-standing challenges in oncologic surgery – namely, how to completely remove a tumor while sparing healthy tissue. Traditional methods often required a surgeon to make educated guesses about margin sufficiency, sometimes resulting in either positive margins or unnecessary removal of healthy tissue. In contrast, technologies like augmented reality provide a visual roadmap during surgery, reducing uncertainty. When comparing outcomes, the emerging tech-assisted approaches show at least equivalent if not superior oncologic safety and functional results relative to conventional methods, with the added benefits of efficiency and personalization. For example, a conventional freehand jaw reconstruction might achieve good results in experienced hands, but with AI-driven planning and cutting guides, even less experienced surgeons can achieve highly accurate reconstructions consistently.

Despite these advantages, there are important limitations and considerations in the current state of AI and VR application. One major challenge is the learning curve and accessibility of the technology itself. Surgeons and trainees must be educated not only in surgical technique but also in how to effectively use VR simulators or interpret AI outputs. There can be an initial time and resource investment to incorporate these tools into practice. Moreover, some VR systems still lack realism in certain aspects – notably haptic feedback. For example, replicating the feel of soft tissue manipulation or micro-suturing tension in a VR simulator remains difficult . This means that while VR can greatly enhance certain skills (like understanding anatomy or practicing instrument handling), it may not yet fully substitute all aspects of hands-on experience. Another limitation is the quality and bias of data feeding AI systems. AI models are only as good as the data and training they receive; if there are biases or gaps in the dataset (say, underrepresentation of certain tumor types or patient demographics), the AI's guidance might be less reliable. There are also concerns about the interpretability of AI "black box" algorithms – surgeons may be hesitant to trust a recommendation or detection if they do not understand how the AI arrived at that result. Ensuring that AI tools are explainable and validated in diverse clinical scenarios is an ongoing need. Additionally, the cost and infrastructure required for advanced surgical robotics, VR labs, and computing power for AI can be significant, which may limit availability to well-funded centers initially. Traditional techniques, in contrast, require less technology and thus remain the mainstay in resource-limited settings.

Looking towards the future, the potential of AI and VR in this field is immense, and ongoing research is addressing current shortcomings. Interdisciplinary collaboration will be key – surgeons, engineers, data scientists, and educators working together can improve the fidelity of simulations and the accuracy of algorithms . For example, developers are already working on incorporating tactile feedback into VR (haptic gloves, advanced simulators) to better mimic real surgery. AI models are being refined with explainable AI techniques so that they can provide not just predictions but also reasoning (e.g., highlighting the image features that indicate a positive margin) . We anticipate more prospective clinical trials will be conducted, like the pilot we noted, to quantify the benefits of these technologies on patient outcomes and to convince broader surgical communities of their value. Future research is also exploring the synergy of combining multiple technologies – for instance, using AR guided by AI in real time, or VR training that adapts to the learner's performance via AI-driven feedback. The regulatory landscape is evolving in parallel; recent approvals of AR surgical navigation systems by authorities (e.g., FDA) show a path toward clinical adoption and standardization of these tools.

In terms of practical recommendations, surgical departments considering these innovations should start with high-yield areas: VR can be introduced in residency programs to supplement cadaver labs, and AI can be used to assist in preoperative planning for complex cases as a double-check to human planning. Initially, these should complement rather than replace traditional approaches to ensure patient safety. As confidence in technology grows, protocols can be updated to integrate, for example, routine use of VSP for eligible cases or mandatory VR training modules before performing

certain procedures. We also suggest establishing data registries for outcomes of AI/VR-assisted surgeries, which will help in continuously refining the technology and proving its efficacy.

In comparison to the traditional technique paradigm – which heavily relied on the individual surgeon's skill and experience – the new paradigm with AI and VR is more standardized, data-driven, and team-oriented. Surgeons of the future might collaborate with AI as an intelligent assistant that learns from every case worldwide, and with VR as a perpetual training ground for honing skills. Embracing these changes, while acknowledging their current limitations, can propel head and neck reconstruction into a new era of precision and personalized care. Ultimately, the goal is not to replace the surgeon, but to empower the surgeon with better tools. Our discussion reinforces that when used appropriately, AI and VR serve as extensions of the surgeon's mind and senses, leading to improvements that were difficult to achieve with traditional methods alone.

Conclusion

In conclusion, the integration of artificial intelligence and virtual reality is revolutionizing head and neck reconstructive surgery by enhancing each phase of care – from diagnosis and planning to execution and postoperative management. AI algorithms contribute to more accurate diagnoses, individualized treatment planning, and predictive insights that tailor reconstruction strategies to each patient's unique needs. VR and AR technologies offer immersive visualization and simulation capabilities that improve surgical precision, efficiency, and education in ways not previously possible with traditional techniques. The combined impact is seen in better surgical outcomes, such as more reliable tumor resections with safe margins, reduced operative times, and reconstructions that more closely restore patients' form and function. Patients are benefitting from these advancements through more personalized and effective treatments with potentially fewer complications and faster recoveries.

To fully realize the advantages of AI and VR in clinical practice, we recommend a proactive but measured adoption. Hospitals and surgical centers should invest in these technologies and related training for staff, beginning with high-impact applications like virtual surgical planning for complex reconstructions and VR-based rehearsal for surgeons. Multidisciplinary teamwork is essential – surgeons working alongside data scientists can ensure that AI tools are clinically relevant and reliable, while collaboration with engineers can further refine simulation realism. It is also important to develop guidelines and standards for using AI/VR in surgery, to ensure safety and consistency (for example, validating an AI's recommendations against expert tumor board decisions before acting on them). As more clinical trials and longitudinal studies emerge, they will provide evidence to refine best practices for implementation. We encourage the head and neck surgical community to engage with these innovations through research and training, as early adopters will shape how the technology evolves to meet clinical needs.

In summary, AI and VR have proven their potential to transform head and neck reconstruction, making surgeries more precise, efficient, and patient-specific than ever before. These tools are aligning surgical practice with the principles of personalized medicine, as reconstructions can be custom fit to the patient and surgical training can be tailored to the surgeon. Continued advancements and thoughtful integration of AI and VR into routine practice will likely yield further improvements in outcomes and pave the way for a future where highly complex head and neck reconstructions can be performed with greater confidence, safety, and success. The evidence to date strongly supports moving beyond traditional boundaries and embracing these technologies as valuable adjuncts in the quest for optimal patient care in head and neck surgery.

References

1. Holmes S. et al. Artificial intelligence in head and neck cancer: Innovations, applications, and future directions. J. Pers. Med. 2024; 14(??): 388. (Demonstrates AI-driven improvements in diagnostic accuracy and personalized treatment planning in HNC, discusses challenges and future prospects.)
2. De Luca P. et al. 3-D virtual reality surgery training to improve muscle memory and surgical skills in head and neck residents. Eur Arch Otorhinolaryngol. 2024; 281(5): 2767-2770. (Shows implementation of VR training for head and neck surgery education; no abstract available in this text, but title indicates focus on skill improvement with VR.)

3. Toro B. et al. Extended reality applications in otolaryngology beyond the operating room: A scoping review. J. Clin. Med. 2023; 13(21): 6295. (Highlights use of VR/AR for patient education, simulation, and preoperative planning in ENT, noting benefits of patient-specific virtual models.)

4. Barr M.L. et al. Virtual surgical planning for mandibular reconstruction with the fibula free flap: A systematic review and meta-analysis. Surg. Plast. Reconstr. 2020; ?: ??. (Meta-analysis showing VSP-guided mandible reconstruction significantly reduces operative time (~45 minutes) and suggests shorter hospital stay compared to traditional methods.)

5. Nunes K.L. et al. A randomized pilot trial of virtual reality surgical planning for head and neck oncologic resection. Laryngoscope. 2025; 135(3): 1090-1097. (RCT demonstrating feasibility of VR planning and finding fewer margin events and defect-driven expansions in VR-planned surgeries versus standard planning.)

6. Prasad K. et al. Augmented reality in head and neck oncology: guiding re-resection using 3D specimen models (Author Reflections). Ann. Surg. Oncol. 2023; 30(8): 4833-4835. (Cadaveric study showing AR can reduce tumor margin relocation error from ~10 mm to ~4 mm, indicating improved resection accuracy with AR guidance.)

7. Kapila A.K. et al. Decoding the impact of AI on microsurgery: Systematic review and classification of six subdomains for future development. Plast. Reconstr. Surg. 2024; ??: ePub. (Systematic review of AI in microsurgery outlining applications including training, preoperative planning, intraoperative navigation, flap monitoring, and outcome prediction; notes that AI-based flap monitoring enables early complication detection and less reliance on specialist monitoring.)

8. Sagar P. et al. Characterizing the untapped potential of virtual reality in plastic and reconstructive surgical training: A systematic review on skill transferability. J. Surg. Educ. 2023; (Systematic review finding that VR simulation improves knowledge and technical skill acquisition in surgical training, especially for novice surgeons, and noting challenges like haptic realism in plastic surgery simulation.)

9. Chen X. et al. Editorial: Virtual surgical planning and 3D printing in head and neck tumor resection and reconstruction. Front. Oncol. 2022; 12:960545. (Summarizes advances in computer-assisted surgery for head and neck reconstruction, including the combination of VSP with emerging technologies like AI, VR/AR and reporting improvements in surgical accuracy and oncologic safety.)

10. Armand M. et al. Enhancing surgical vision: Augmented reality in otolaryngology – Head and Neck Surgery. J. Med. Extended Reality. 2024;: ePub. (Review of AR technology in otolaryngology, describing how real-time overlays of critical anatomical information can improve surgical accuracy and reduce complications in head and neck procedures.)