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Decoding the Impact of AI on Microsurgery: Systematic Review and Classification of Six Subdomains for Future Development

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Background: The advent of artificial intelligence (AI) in microsurgery has tremendous potential in plastic and reconstructive surgery, with possibilities to elevate surgical precision, planning, and patient outcomes. This systematic review seeks to summarize available studies on the implementation of AI in microsurgery and classify these into subdomains where AI can revolutionize our field.
Methods: Adhering to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, a meticulous search strategy was used across multiple databases. The inclusion criteria encompassed articles that explicitly discussed AI's integration in microsurgical practices. Our aim was to analyze and classify these studies across subdomains for future development.
Results: The search yielded 2377 articles, with 571 abstracts eligible for screening. After shortlisting and reviewing 86 full-text articles, 29 studies met inclusion criteria. Detailed analysis led to the classification of 6 subdomains within AI applications in microsurgery, including information and knowledge delivery, microsurgical skills training, preoperative planning, intraoperative navigational aids and automated surgical tool control, flap monitoring, and postoperative predictive analytics for patient outcomes. Each subtheme showcased the multifaceted impact of AI on enhancing microsurgical procedures, from preoperative planning to postoperative recovery.
Conclusions: The integration of AI into microsurgery signals a new dawn of surgical innovation, albeit with the caution warranted by its nascent stage and application diversity. The authors present a systematic review and 6 clear subdomains across which AI will likely play a role within microsurgery. Continuous research, ethical diligence, and cross-disciplinary cooperation is necessary for its successful integration within our specialty. *(Plast Reconstr Surg Glob Open 2024; 12:e6323; doi: 10.1097/GOX.0000000000006323; Published online 20 November 2024.)*

INTRODUCTION

The intersection of artificial intelligence (AI) and healthcare has tremendous potential across various medical specialties, with the potential to reshape the landscape of patient care and surgical precision in times to come. Particularly, the integration of AI in surgery has been a focal point of research, demonstrating significant potential in enhancing diagnostic accuracy, surgical planning, and patient outcomes.[1–3]

AI's influence in plastic and reconstructive surgery is multifaceted, with its utility ranging from big data analytics to facial recognition technologies, all aimed at refining surgical practices and patient outcomes.[4,5] Microsurgery, in particular, represents a critical and innovative segment of reconstructive surgery, embodying the intricate and delicate nature of the field. It is an area where precision is not just desired but required, and where AI's potential for enhancing surgical precision, planning, and patient-specific outcomes is being closely explored.

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The systematic integration of AI into microsurgery aligns with a broader trend of AI applications in surgical subspecialties, which remains predominantly in the preclinical phase. Although the potential of AI in plastic and reconstructive surgery has been alluded to in various studies, most research is still in the discovery, technical performance, and efficacy phases, with very few studies reaching the stage of clinical practice translation.[5] Nonetheless, the regulatory landscape has started to evolve to accommodate AI and machine learning-based medical devices, with approvals in the United States and Europe reflecting a growing recognition of these technologies' clinical value.[6] Such advancements point toward a growing field where AI not only assists in surgical procedures but also influences regulatory frameworks and healthcare policies.

The present systematic analysis seeks to harness this momentum by critically examining the role of AI in microsurgery. By systematically reviewing the existing literature and synthesizing the data from various studies, this article aims to provide a comprehensive overview of the capabilities and future directions of AI applications in microsurgery. A further aim is to classify subdomains of development where AI technologies have potential to augment the microsurgeon's skillset, enhance surgical outcomes, and pave the way for innovations in patient care.

Takeaways

Question: How could artificial intelligence (AI) impact microsurgery, and in which subdomains of reconstructive surgery will this play a role?

Findings: Detailed analysis led to the classification of 6 subdomains within AI applications in microsurgery, including information and knowledge delivery, microsurgical skills training, preoperative planning, intraoperative navigational aids and automated surgical tool control, and flap monitoring and postoperative predictive analytics for patient outcomes.

Meaning: The authors present a systematic review and six clear subdomains across which AI will likely play a role within microsurgery.

METHODS

Search Strategy

The methodology for this systematic analysis was designed to adhere to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. A comprehensive search of the literature was conducted between March 1 and March 15, 2024, across major electronic databases including PubMed, Medline, EMBASE (Excerpta Medica Database), and the Cochrane Library. In addition, platforms such as Web of Science, Scopus, and IEEE Xplore (Institute of Electrical and Electronics Engineers) were also searched. These platforms were selected due to their extensive coverage of biomedical research, ensuring a robust compilation of studies related to AI applications in microsurgery. A further manual search was also performed on Google Scholar.

The search was structured around a combination of keywords across all databases. (**See appendix, Supplemental Digital Content 1**, which displays the research strategy, **http://links.lww.com/PRSGO/D631**.) The search strategy was inclusive of all studies that addressed the application of AI in the context of microsurgery, without restrictions on study design, to encompass a wide spectrum of research from case studies to randomized controlled trials. The study was approved by the University Hospital Ethics Committee (reference number: 24094).

Study Selection

Inclusion criteria were defined to capture studies that specifically investigated the use of AI in microsurgical procedures within or related to reconstructive surgery. Exclusion criteria included non-English publications, articles not peer-reviewed, and studies outside the scope of microsurgery. Duplicate entries identified across databases were removed, and the remaining studies were screened based on titles and abstracts. A secondary, full-text review was conducted to finalize the selection, ensuring the studies conformed to the inclusion criteria (Fig. 1).

Data Extraction and Quality Assessment

Data extraction was performed by surgeons and a researcher with expertise in plastic surgery and AI. Extracted data included study design, AI application type, microsurgical procedure focus, and main findings related to the efficacy and safety of AI applications. The quality of each study was assessed using the Risk of Bias in Non-randomized Studies of Interventions tool, which evaluates bias in results due to confounding, selection of participants, classification of interventions, deviations from intended interventions, missing data, measurement of outcomes, and selection of the reported result, and the Quality Assessment Tool for Studies with Diverse Designs for appraising the quality of quantitative, qualitative, and mixed-methods research.

RESULTS

Study Selection

The search yielded 2377 articles, with 571 abstracts eligible for screening. After shortlisting and reviewing 86 full-text articles, 29 studies met the inclusion criteria for this systematic review (Fig. 1).

Quantitative Synthesis and Analysis

Given the diverse methodologies and applications across the studies, a meta-analytic pooling of results was not feasible. Instead, a qualitative synthesis was conducted, highlighting the innovative use of AI across various subdomains of microsurgical care. (**See appendix, Supplemental Digital Content 2**, which displays the studies summarized, **http://links.lww.com/PRSGO/D632**.)

Qualitative Thematic Analysis

Through the systematic review process, it became evident that AI applications in microsurgery can be grouped into 6 distinct subdomains (Figs. 2, 3). These subdomains

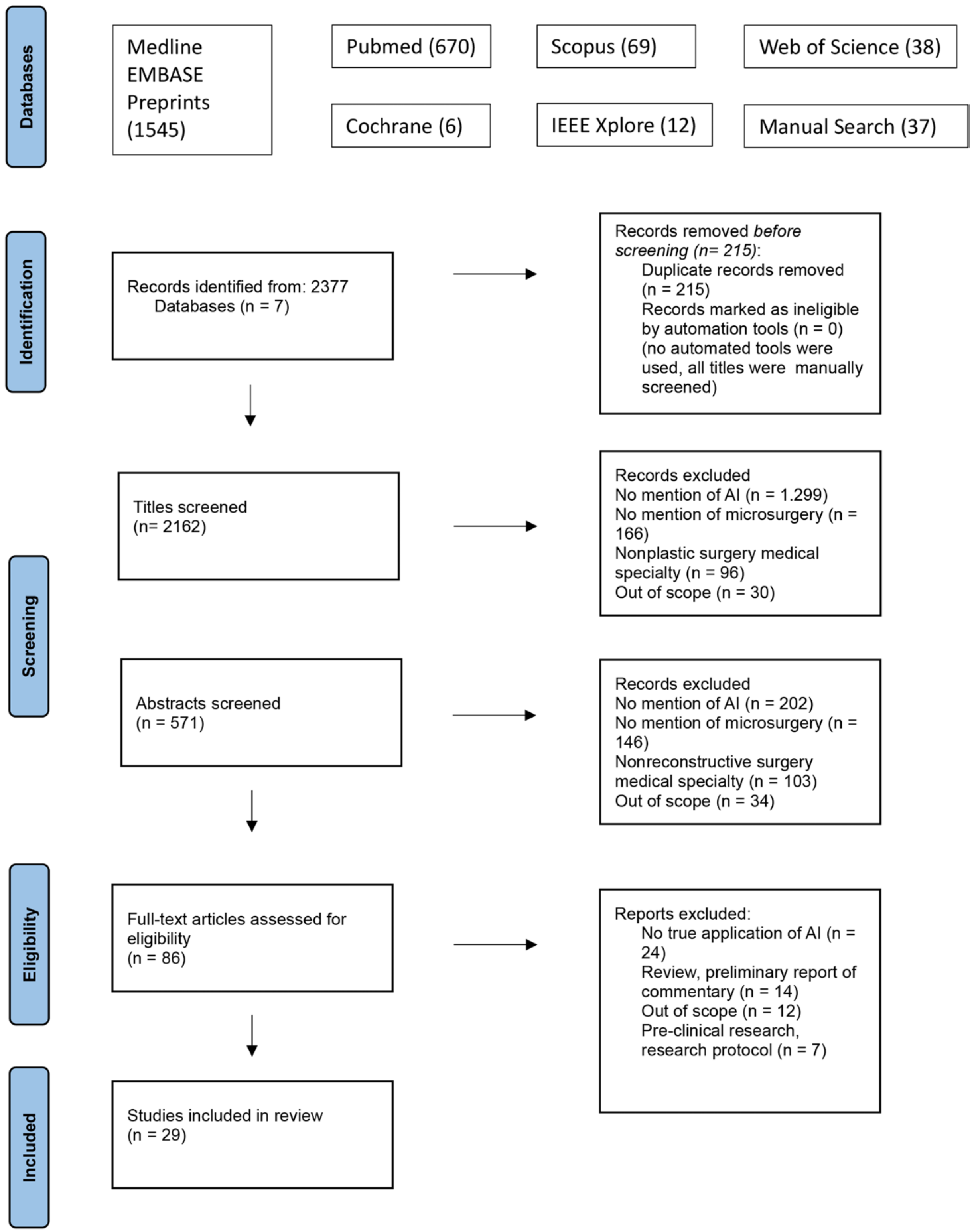

Fig. 1. PRISMA flowchart—systematic review of artificial intelligence in microsurgery.

were identified based on the primary objectives and outcomes of the studies, as well as the specific aspects of microsurgical practice they aimed to enhance. The following sections describe these subdomains and highlight key studies within each.

Information and Knowledge Delivery

One prominent subdomain identified is the use of AI to enhance the dissemination and quality of microsurgical knowledge. Studies in this area suggest that AI could significantly improve educational resources for

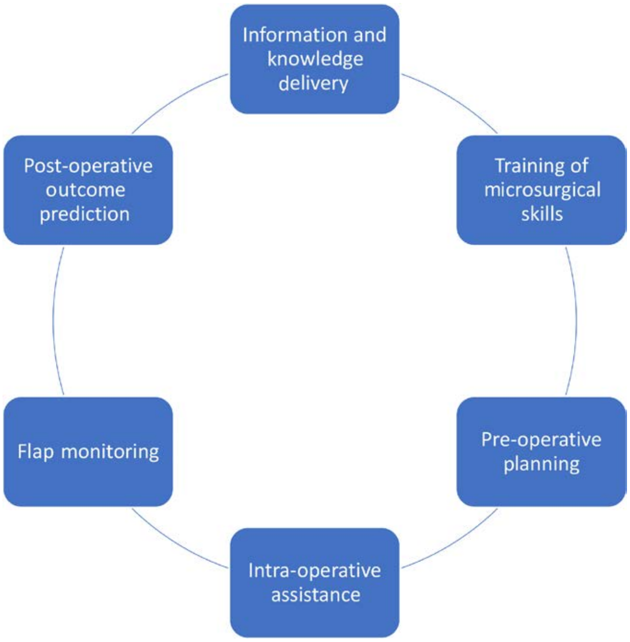

Fig. 2. The 6 subdomains identified from our systematic review within which AI seems to have potential in advancing the field of microsurgery.

both surgeons and patients. For instance, Berry et al[7] compared AI-generated information to that provided by the American Society of Reconstructive Microsurgery regarding microsurgery. They found that surgeons preferred AI-generated content from chat generative pretrained transformer (ChatGPT) 70.7% of the time for its comprehensiveness and clarity. Nonmedical participants also favored it 55.9% of the time. The readability analysis revealed that both ChatGPT and American Society of Reconstructive Microsurgery materials exceeded recommended patient proficiency levels across multiple readability formulas.[7] Similarly, Tian et al[8] reported ChatGPT's capability to produce patient-centered content with 95.6% accuracy. The authors noted that although ChatGPT showed promise in enhancing clinical workflow and patient education, its tendency to provide generalized responses necessitated surgeon oversight for procedure-specific nuances, emphasizing the need for surgeon oversight for procedure-specific nuances and reflection on ethical challenges.[8] Jeong et al[9] evaluated free flap surgery information from Google and ChatGPT, with ChatGPT's answers receiving higher Global Quality Score ratings. These studies indicate that AI could play a significant role in improving the accessibility and quality of microsurgical education.

Training of Microsurgical Skills

AI's potential to enhance microsurgical training by providing objective measures of skill emerged as another key subdomain. Oliveira et al[10] introduced Proficiency Index in Microsurgical Education, a computer vision system for evaluating microsurgical training that improved proficiency among experienced neurosurgeons. The system captured movements and showed an accuracy improvement from 0.2 to 0. 6. Franco-González et al[11] validated mitracks3D, which uses stereoscopic vision to assess trainees' skills quantitatively. Their study demonstrated significant differences in performance metrics between expert and trainee microsurgeons, affirming the system's capability to differentiate skill levels among participants.[11] McGoldrick et al[12] developed a video instrument motion analysis scoring system, correlating well with traditional rating scales and surgical experience. Sugiyama et al[13] created a deep learning algorithm using YOLOv2 (You Only Look Once version 2) to track instrument tips, showing high accuracy and correlation with experience levels. These advancements suggest that AI could provide a

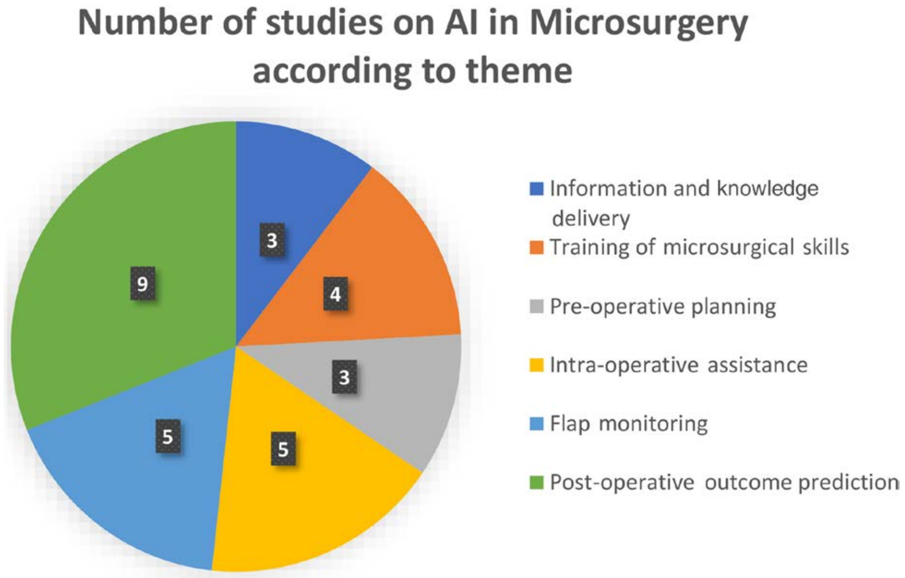

Fig. 3. The number of studies on AI in microsurgery subdivided by study theme.

standardized and personalized training approach, enhancing traditional methods.

Preoperative Planning

A third subdomain is AI's role in improving preoperative planning by enhancing efficiency and reducing subjectivity in perforator vessel identification. Mavioso et al[14] demonstrated that AI software could significantly reduce preoperative planning time by about 2 hours per case. The software identified perforators with varied accuracy, performing better for vessels larger than 1.5 mm.[14] Saxena[15] developed a deep learning algorithm for vessel segmentation, showing high sensitivity and specificity, addressing the lack of quantitative methods in current planning. Shen et al[16] introduced the deeply supervised attention enabled (DA)-UNet model, outperforming traditional methods in perforator localization for anterolateral thigh flap preparation. These studies highlight AI's potential to streamline surgical workflows and reduce operative risks through more accurate and objective data.

Intraoperative Assistance

AI's application in providing real-time surgical assistance emerged as a promising subdomain, potentially improving precision and coordination during surgery. Nakazawa et al[17] implemented a real-time video-based needle detection algorithm with an average precision of 89.2%. Koskinen et al[18] developed a tool detection and gaze tracking system, accurately identifying microsurgical tools and providing insights into eye-hand coordination. Pietruski et al[19] explored augmented reality (AR) in microsurgery, enhancing the visual field and spatial awareness. Their AR system provided real-time overlays of critical anatomical structures and surgical plans, with surgeons reporting improved procedural confidence.[19] Chao et al[20] and Zhu et al[21] demonstrated preprogrammed robotic osteotomies' potential to improve accuracy in fibula free flap mandible reconstruction. These studies suggest that AI could revolutionize the intraoperative experience, enhancing precision and reducing operative times.

Flap Monitoring

Another subdomain is AI's ability to introduce automation and improve accuracy in flap monitoring postsurgery. Huang et al[22] developed a supervised machine learning model showing 98.4% accuracy in predicting postoperative flap circulation. Their deep learning model integrated into an iOS application demonstrated more than 95% accuracy in clinical use for predicting flap congestion.[22,23] Kiranantawat et al[24] created SilpaRamanitor, a smartphone application achieving high diagnostic accuracy for tissue perfusion monitoring. Provenzano et al[25] validated smartphone-based monitoring for detecting venous and arterial occlusion, showing consistent patterns in pixel change oscillations. Lee et al[26] developed an AI system for monitoring postoperative free flaps with high segmentation accuracy, reducing the workload on medical staff. These advancements indicate that AI could provide a reliable and cost-effective approach for continuous and autonomous flap monitoring.

Postoperative Outcome Prediction

Finally, AI can predict surgical outcomes and complications, aiding proactive patient care. O'Neill et al[27] developed a machine learning model with an area under the curve (also known as predictive power) of 0.95 in predicting flap failure, identifying obesity and smoking as significant risk factors. Myung et al[28] used an artificial neural network to predict donor site complications with a high area under the curve of 0.89. Kim et al[29] used unsupervised machine learning to identify diverse outcome patterns in autologous breast reconstruction. Kuo et al[30] and Formeister et al[31] demonstrated the superior predictive performance of artificial neural network models over logistic regression for surgical site infections and complications in head and neck flap reconstruction. Asaad et al[32] and Tighe et al[33] highlighted the utility of machine learning in identifying at-risk patients and enhancing audit quality outcomes. Puladi et al[34] and Shi et al[35] underscored the potential of AI in predicting blood transfusion needs and flap failure, respectively.

DISCUSSION

The integration of AI into microsurgery marks a pivotal evolution in the field of plastic and reconstructive surgery, heralding a new era of precision, personalization, and innovation. This systematic review has meticulously reviewed all available English-language literature on AI in microsurgery, unveiling the early explorations of and potential applications of AI across various stages of microsurgical care. The synthesis of findings across 29 studies has identified six key subdomains for future development within microsurgery. From preoperative planning to postoperative outcome prediction, each with its unique potential to augment microsurgical practice.

AI's potential ability to enhance information delivery and training in microsurgery can well be transformative in the future. Tools that generate comprehensive educational content and provide objective skill assessments promise to elevate the standard of training and patient education. These advancements could lead to more informed patients and better-prepared surgeons, ultimately improving surgical outcomes. In preoperative planning, AI's role in reducing subjectivity and time in planning processes can become increasingly noteworthy. By providing accurate and objective data, AI can streamline workflows, enhance surgical precision, and potentially reduce operative risks. This is particularly crucial in complex microsurgical procedures where precision is paramount. During surgery, AI's real-time assistance capabilities, such as tool detection and AR, may progressively offer substantial improvements in precision and coordination. These technologies not only enhance the surgeon's capabilities but may also reduce operative times, contributing to better patient outcomes. Postoperative care has already started to benefit significantly from AI, particularly in flap monitoring. Continuous, automated monitoring facilitated by AI can detect complications early, making postoperative care more effective and less dependent on specialist availability. This shift toward more autonomous patient-managed health reflects a broader trend in personalized medicine.

This systematic review, while comprehensive, is not without limitations. The inherent heterogeneity among the included studies in terms of AI technologies, surgical procedures, and outcome measures presents challenges in drawing generalized conclusions. Additionally, most of the studies are in the early stages of AI application in microsurgery, with limited large-scale clinical trials to validate the effectiveness and safety of these AI interventions. Furthermore, the rapid evolution of AI technologies may outpace the current evidence, necessitating continuous updating of the systematic review to incorporate the latest advancements.

Concurrently, as AI continues to permeate the fabric of healthcare, it is imperative to navigate the ethical landscape with diligence when looking at the future. The reliance on AI-generated content and predictive models necessitates a robust framework to ensure data privacy, patient consent, and the transparency of AI algorithms. A recent article explores the perceptions of plastic surgeons on the role of AI in plastic surgery through a survey of 153 professionals. It reveals limited AI experience among respondents, with mixed views on AI's potential to improve surgical planning and outcomes. Concerns were raised about overreliance on technology, patient privacy, and the need for informed consent and AI education in plastic surgery training. The study emphasizes the importance of balancing AI integration with preserving human expertise in the field.[36] Furthermore, the potential for AI to augment or even surpass human expertise raises important considerations regarding the surgeon's role, the patient–surgeon relationship, and the legal implications of AI-assisted surgical outcomes.[37] In essence, the integration of AI into microsurgery presents a frontier replete with opportunities and challenges. The findings from this systematic review not only highlight the current applications and benefits of AI in microsurgery but also underscore the need for ongoing research, ethical scrutiny, and interdisciplinary collaboration to fully realize AI's potential in transforming microsurgical practice and patient care. Concurrently, we must recognize the need to adapt curricula to include AI and robotic technologies.[38,39] As we stand at the cusp of this technological renaissance, it is incumbent upon the medical community to steward this integration with foresight, ensuring that AI serves as a complement to, rather than a replacement for, the art and science of microsurgery.

CONCLUSIONS

In conclusion, the integration of AI into microsurgery presents an exciting confluence of technology and surgical expertise, with the potential to redefine the paradigms of patient care, surgical training, and operative precision. However, the journey ahead requires a careful navigation of ethical considerations, continuous research, and collaborative efforts to ensure that the integration of AI in microsurgery enhances rather than supplants the art and science of surgery. We provide 6 clear subdomains for classifying future development of AI within microsurgery. The collective endeavor of the medical community will be pivotal in realizing the promise of AI in microsurgery, steering this technological evolution towards augmenting human expertise and improving patient outcomes.

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DISCLOSURE

The authors have no financial interest to declare in relation to the content of this article.

REFERENCES

1. Morozov A, Taratkin M, Bazarkin A, et al; Young Academic Urologists (YAU) Working Group in Uro-technology of the European Association of Urology. A systematic review and meta-analysis of artificial intelligence diagnostic accuracy in prostate cancer histology identification and grading. *Prostate Cancer Prostatic Dis.* 2023;26:681–692.
2. Li B, Feridooni T, Cuen-Ojeda C, et al. Machine learning in vascular surgery: a systematic review and critical appraisal. *NPJ Digit Med.* 2022;5:7.
3. Lex JR, Di Michele J, Koucheki R, et al. Artificial intelligence for hip fracture detection and outcome prediction: a systematic review and meta-analysis. *JAMA Netw Open.* 2023;6:e233391.
4. Jarvis T, Thornburg D, Rebecca AM, et al. Artificial intelligence in plastic surgery: current applications, future directions, and ethical implications. *Plast Reconstr Surg Glob Open.* 2020;8:e3200.
5. Spoer DL, Kiene JM, Dekker PK, et al. A systematic review of artificial intelligence applications in plastic surgery: looking to the future. *Plast Reconstr Surg Glob Open.* 2022;10:e4608.
6. Chadebecq F, Lovat LB, Stoyanov D. Artificial intelligence and automation in endoscopy and surgery. *Nat Rev Gastroenterol Hepatol.* 2023;20:171–182.
7. Berry C, Fazilat AZ, Lavin CV, et al. Both patients and plastic surgeons prefer AI-generated microsurgical information. *J Reconstr Microsurg.* 2024;40:657–664.
8. Tian WM, Sergesketter AR, Hollenbeck ST. The role of ChatGPT in microsurgery: assessing content quality and potential applications. *J Reconstr Microsurg.* 2024;40:e1–e2.
9. Jeong T, Liu H, Alessandri-Bonetti M, et al. Revolutionizing patient education: ChatGPT outperforms Google in answering patient queries on free flap reconstruction. *Microsurgery.* 2023;43:752–761.
10. Oliveira MM, Quittes L, Costa PHV, et al. Computer vision coaching microsurgical laboratory training: PRIME (Proficiency Index in Microsurgical Education) proof of concept. *Neurosurg Rev.* 2022;45:1601–1606.
11. Franco-González IT, Pérez-Escamirosa F, Minor-Martínez A, et al. Development of a 3D motion tracking system for the analysis of skills in microsurgery. *J Med Syst.* 2021;45:106.
12. McGoldrick RB, Davis CR, Paro J, et al. Motion analysis for microsurgical training: objective measures of dexterity, economy of movement, and ability. *Plast Reconstr Surg.* 2015;136:231e–240e.
13. Sugiyama T, Sugimori H, Tang M, et al. Deep learning-based video-analysis of instrument motion in microvascular anastomosis training. *Acta Neurochir (Wien).* 2024;166:6.

14. Mavioso C, Araújo RJ, Oliveira HP, et al. Automatic detection of perforators for microsurgical reconstruction. *Breast (Edinburgh, Scotland)*. 2020;50:19–24.
15. Saxena E. Deep learning for personalized preoperative planning of microsurgical free tissue transfers. *Proc AAAI Conf Artif Intell*. 2022;36:13140–13141.
16. Shen D, Huang X, Huang Y, et al. Computed tomography angiography and b-mode ultrasonography under artificial intelligence plaque segmentation algorithm in the perforator localization for preparation of free anterolateral femoral flap. *Contrast Media Mol Imaging*. 2022;2022.
17. Nakazawa A, Harada K, Mitsuishi M, et al. Real-time surgical needle detection using region-based convolutional neural networks. *Int J Comput Assist Radiol Surg*. 2020;15:41–47.
18. Koskinen J, Torkamani-Azar M, Hussein A, et al. Automated tool detection with deep learning for monitoring kinematics and eye-hand coordination in microsurgery. *Comput Biol Med*. 2022;141:105121.
19. Pietruski P, Majak M, Świątek-Najwer E, et al. Supporting fibula free flap harvest with augmented reality: a proof-of-concept study. *Laryngoscope*. 2020;130:1173–1179.
20. Chao AH, Weimer K, Raczkowsky J, et al. Pre-programmed robotic osteotomies for fibula free flap mandible reconstruction: a preclinical investigation. *Microsurgery*. 2016;36:246–249.
21. Zhu J-H, Deng J, Liu X-J, et al. Prospects of robot-assisted mandibular reconstruction with fibula flap: comparison with a computer-assisted navigation system and freehand technique. *J Reconstr Microsurg*. 2016;32:661–669.
22. Huang R-W, Tsai T-Y, Hsieh Y-H, et al. Reliability of postoperative free flap monitoring with a novel prediction model based on supervised machine learning. *Plast Reconstr Surg*. 2023;152:943e.
23. Hsu S-Y, Chen L-W, Huang R-W, et al. Quantization of extraoral free flap monitoring for venous congestion with deep learning integrated iOS applications on smartphones: a diagnostic study. *Int J Surg*. 2023;109:1584–1593.
24. Kiranantawat K, Sitpahul N, Taeprasartsit P, et al. The first smartphone application for microsurgery monitoring: SilpaRamanitor. *Plast Reconstr Surg*. 2014;134:130–139.
25. Provenzano D, Chandawarkar A, Caterson E. Abstract QS14: novel smartphone-based free flap monitoring tool using machine learning. *Plast Reconstr Surg Glob Open*. 2019;7:111–112.
26. Lee SM, Chung MJ, Kim Z, Lee KT, Kim JS. Automatic segmentation and evaluation techniques for free flap in reconstruction surgery using deep learning. 2023 IEEE Conference on Artificial Intelligence (CAI), June 5–6, 2023, Santa Clara, CA. IEEE; 2023:138.
27. O'Neill AC, Yang D, Roy M, et al. Development and evaluation of a machine learning prediction model for flap failure in microvascular breast reconstruction. *Ann Surg Oncol*. 2020;27:3466–3475.
28. Myung Y, Jeon S, Heo C, et al. Validating machine learning approaches for prediction of donor related complication in microsurgical breast reconstruction: a retrospective cohort study. *Sci Rep*. 2021;11:5615.
29. Kim DK, Corpuz GS, Ta CN, et al. Applying unsupervised machine learning approaches to characterize autologous breast reconstruction patient subgroups: an NSQIP analysis of 14,274 patients. *J Plast Reconstr Aesthet Surg*. 2024;88:330–339.
30. Kuo P-J, Wu S-C, Chien P-C, et al. Artificial neural network approach to predict surgical site infection after free-flap reconstruction in patients receiving surgery for head and neck cancer. *Oncotarget*. 2018;9:13768–13782.
31. Formeister EJ, Baum R, Knott PD, et al. Machine learning for predicting complications in head and neck microvascular free tissue transfer. *Laryngoscope*. 2020;130:E843–E849.
32. Asaad M, Lu S-C, Hassan AM, et al. The use of machine learning for predicting complications of free-flap head and neck reconstruction. *Ann Surg Oncol*. 2023;30:2343–2352.
33. Tighe D, McMahon J, Schilling C, et al. Machine learning methods applied to risk adjustment of cumulative sum chart methodology to audit free flap outcomes after head and neck surgery. *Br J Oral Maxillofac Surg*. 2022;60:1353–1361.
34. Puladi B, Ooms M, Rieg A, et al. Development of machine learning and multivariable models for predicting blood transfusion in head and neck microvascular reconstruction for risk-stratified patient blood management. *Head Neck*. 2023;45:1389–1405.
35. Shi Y-C, Li J, Li S-J, et al. Flap failure prediction in microvascular tissue reconstruction using machine learning algorithms. *World J Clin Cases*. 2022;10:3729–3738.
36. Farid Y, Gutierrez LFB, Ortiz S, et al. Artificial intelligence in plastic surgery: insights from plastic surgeons, education integration, ChatGPT's survey predictions, and the path forward. *Plast Reconstr Surg Glob Open*. 2024;12:e5515.
37. Morris MX, Song EY, Rajesh A, et al. Ethical, legal, and financial considerations of artificial intelligence in surgery. *Am Surg*. 2023;89:55–60.
38. Kapila A, Wittesaele W, Kapila V, et al. Should we train robotic surgery skills during plastic surgery residency? Presented at Plastic Surgery the Meeting, October 27–30, Boston, United States of America. *Am Soc Plast Surg*. 2022.
39. Kapila AK, Hamdi M. Time to evolve plastic surgery education? Integrating robotic techniques and artificial intelligence into training curricula. *Plast Reconstr Surg Glob Open*. 2024;12:e5778.