

D E B A T E

Artificial intelligence in plastic surgery: Current potential and future directions

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ABSTRACT

Artificial intelligence (AI) is set to reshape plastic and reconstructive surgery throughout all phases of patient care. By integrating computer vision, machine learning, natural language processing, and robotic systems, AI has the potential to enhance diagnostic accuracy, surgical planning, intraoperative decision-making, and post-operative monitoring. This article reviews the current state and anticipated future applications of AI in plastic surgery, discusses emerging technologies, and evaluates challenges related to safety, ethics, and regulatory adoption. We suggest that, when responsibly implemented, AI will ultimately become a core component of precision plastic surgery, offering individualized treatment, improved outcomes, and more efficient clinical workflows. (www.actabiomedica.it)

Key words: plastic surgery, artificial intelligence, reconstructive surgery, aesthetic surgery machine learning, computer vision



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Introduction

Plastic and reconstructive surgery is a specialty defined by both its visual nature and its reliance on rich data. Advances in imaging—including high-resolution photography, 3D scanning, ultrasound, CT, MRI, and near-infrared fluorescence—generate vast amounts of information that can be analyzed using AI techniques (1–4). At the same time, increasing computing power and the availability of large, annotated image datasets have driven breakthroughs in computer vision, generative modeling, and autonomous robotics (5). The primary goals of Artificial Intelligence (AI) integration in plastic surgery include improving patient selection, optimizing surgical planning, enhancing intraoperative safety, and enabling more objective assessment of outcomes. As patients increasingly seek minimally invasive, highly personalized procedures, AI offers powerful tools to support this evolution (1,6–8). Despite these advances, however, clear clinical guidelines for AI use in plastic surgery are still lacking. Implementation remains inconsistent, and careful evaluation is essential to ensure that AI tools are safe, effective, and ethically applied. We therefore considered it timely and valuable to provide a comprehensive perspective, summarizing current applications, highlighting the most promising developments, and offering a clinical reflection on future directions. We conducted a narrative review of the literature using PubMed to identify relevant studies. Articles published in English in the last 5 years were selected according to predefined criteria of relevance, scientific impact, and innovative contribution, to provide a comprehensive overview of the main applications of artificial intelligence in plastic surgery.

Current evidence and applications of AI in plastic surgery

Recent advances in artificial intelligence, particularly in machine learning (ML) and deep learning (DL), are reshaping both clinical practice and research in plastic surgery. Modern architectures such as deep convolutional neural networks (CNNs) and transformer-based models now lead progress in

image classification, anatomical segmentation, body-landmark detection, and the development of outcome-prediction tools (9,10). In parallel, computer vision systems are approaching, and in some domains exceeding, human-level performance in tasks including facial landmark analysis, soft-tissue volume estimation, skin lesion detection, and perioperative anatomical recognition (2,11). Generative AI, especially diffusion models and Generative Adversarial Networks (GANs), has introduced new possibilities to surgical planning and education (1). These models can generate realistic simulations of potential surgical outcomes, produce automated reconstructions of three-dimensional anatomical structures, and augment limited clinical datasets (12). Emerging developments are now moving toward physics-informed models capable of incorporating soft-tissue biomechanics for highly realistic predictive simulations (4). In addition, AI-enhanced robotic systems are evolving to include tremor reduction, precision micro-suturing, predictive movement guidance, and semi-autonomous tissue manipulation, positioning microsurgery as a primary field for future automation (13,14).

Preoperative applications

AI applications now extend across the entire surgical pathway, beginning with the preoperative phase. Automated morphometric analysis allows for precise assessment of facial and body symmetry, skeletal-to-soft-tissue relationships, breast and gluteal volumes, soft-tissue thickness, and contour ratios such as the waist-hip index. These tools optimize planning in rhinoplasty, liposuction, breast surgery, and body contouring (3,9,10). Predictive simulation models now generate personalized projections of aesthetic outcomes, estimate of postoperative symmetry, risk scores for contour irregularities, and even predictions of patient satisfaction. As biomechanical modeling becomes integrated, these simulations are expected to gain further realism and clinical value (3,7,15). Meanwhile, machine-learning systems also support patient selection and risk stratification by predicting wound complications, flap failure, venous thromboembolism, capsular contracture, fat necrosis, and unfavorable scarring (16,17).

Intraoperative applications

Intraoperatively, computer vision integrated with surgical cameras and ultrasound devices is increasingly capable of real-time recognition of perforator vessels, nerve pathways, vascular pedicles, dissection planes, and optimal incision markings. In the context of microsurgery, these tools may assist in identifying ideal anastomosis zones (18,19). AI-assisted navigation using augmented-reality overlays can guide safe dissection corridors, optimize perforator selection in flap surgery, (20) and support intraoperative symmetry adjustments in breast and gluteal procedures. Decision-support systems that analyze multimodal data—including real-time video, thermal imaging, and ICG angiography (13,20)—can predict flap viability, detect early perfusion deficits, recommend optimal fat-grafting volumes, and guide implant-pocket dissection (9,21).

Postoperative applications

Postoperatively, AI-based remote-monitoring tools often implemented through smartphone applications can detect signs of infection, hematoma, seroma, wound dehiscence, and early contour changes. By identifying these issues promptly, such systems facilitate earlier intervention and may reduce unnecessary clinic visits, improving both patient safety and convenience (22). Computer-vision systems also offer objective assessment of scar evolution, quantifying features such as hypertrophy, pigmentation, edema, graft resorption, and flap-volume changes, thereby standardizing postoperative follow-up and documentation (23).

Education and training

Artificial intelligence is also reshaping research methodologies, surgical training, and educational strategies within plastic surgery. Through large-scale data analysis, AI systems can examine millions of clinical images and patient variables, enabling the identification of subtle correlations that would be impossible to detect manually. These insights help the development of evidence-based recommendations for surgical techniques, refined complication-risk models,

and structured evaluation system aimed at objectively evaluating surgeon performance (1–4,6,24). In the educational domain, AI-driven tools are becoming increasingly integrated into surgical training. Virtual-reality environments now allow residents to rehearse case-specific scenarios, while automated systems can track technical skills using metrics such as instrument trajectory tracking, tremor quantification, and movement efficiency, and provide personalized feedback to accelerate skill acquisition (25–27).

Ethical issues

However, the advancement of AI also introduces significant ethical, legal, and regulatory considerations. Central concerns include dataset bias, the need for transparency in algorithmic decision-making, and the protection of patient privacy, particularly regarding informed consent for data use (28). Additionally, the emergence of semi-autonomous surgical systems raises questions about liability and safety standards, while hyper-realistic simulations risk generating unrealistic aesthetic expectations among patients (1,28). A comprehensive overview of AI applications in plastic surgery is presented in Table 1, which summarizes each domain with a brief description and illustrative examples.

Discussion

Artificial intelligence is rapidly reshaping plastic surgery influencing every stage of patient care while complementing, rather than replacing, the surgeon's clinical judgment. Its current applications range from enhancing preoperative planning, intraoperative precision, postoperative monitoring, and surgical education. At the same time, these advancements bring to light critical challenges, ethical considerations, and the need for multidisciplinary evaluation. Preoperative applications include predictive morphing, risk assessment, and realistic surgical simulations. Generative models, such as GANs and diffusion-based algorithms, allow patients to visualize potential outcomes, improving understanding of the procedure and fostering realistic expectations. Automated morphometric analysis of facial and body structures, volumetric assessment, and

Table 1. Summary of Application of AI in Plastic Surgery.

Application areas	Description	Examples
Preoperative Planning	Risk assessment, outcome prediction, 3D modelling, surgical simulation	Machine learning, deep learning, 3D imaging, simulation tools
Intraoperative guidance	Real-time anatomical recognition, robotic assistance, navigation, decision support	Computer vision, AI-assisted robotics, neural network
Post operative Monitoring	Complication detection, scar assessment, outcome evaluation	AI image analysis, predictive analytics, deep learning
Diagnostic support	Automated image analysis for lesion classification, facial analysis, and anomaly detection	Convolutional neural networks, support vector machines
Patient consultation	Simulation of surgical outcomes, facial recognition, personalized treatment planning	AI-powered simulation, image analysis
Administrative tasks	Scheduling, resource allocation, documentation, literature analysis	Natural language processing, automated systems
Education and training	Personalizes feedback, skill assessment, simulation-based learning	AI-driven simulators, feedback algorithms

symmetry evaluation provide objective, data-driven insights that support precise surgical planning. With these tools, clinicians can better educate patients and help ensure that aesthetic goals are both achievable and safe. At the same time, care must still be taken, as AI-generated simulations, if misinterpreted, could unintentionally create unrealistic perceptions of post-operative results. Intraoperatively, AI-powered computer vision systems and augmented reality guidance improve precision and safety. By automatically recognizing anatomical landmarks, vascular pedicles, and dissection planes, these tools assist surgeons in complex reconstructions and microsurgical procedures. Robotics and semi-autonomous systems complement these capabilities by performing repetitive or highly delicate tasks with tremor reduction and consistent precision, allowing the surgeon to focus on critical clinical judgment. Looking ahead, next-generation robotic platforms may be capable of partially autonomous execution of microvascular suturing, standardized liposuction patterns, and precise dissection within anatomically constrained regions. In this context, explainable AI is essential to maintain trust and support the surgeon's autonomy rather than replace it. Post-operatively, AI facilitates early detection of complications, objective evaluation of healing, and assessment of functional and aesthetic outcomes. Automated analysis of scars, flap volumes, and tissue changes enables

standardized follow-up, while AI-assisted remote monitoring can detect signs of infection, hematoma, or contour irregularities, supporting timely interventions and improving patient safety and satisfaction. These tools offer a new level of objectivity and proactive care, but their effectiveness depends on careful integration with clinical judgment and standardized protocols. Over-reliance on automated assessments could risk misinterpretation, and validation in prospective studies is needed to ensure reliability across diverse patient populations and surgical settings. Ethical and practical challenges remain central to AI integration in plastic surgery. Data privacy and security must be rigorously safeguarded, especially when handling sensitive imaging datasets. Algorithmic bias, including issues related to demographic representation or beauty standards, must be identified and mitigated. Most AI tools still lack external validation and prospective clinical trials, and regulatory frameworks are continuing to evolve. Unresolved ethical and practical questions are: Who is accountable for predictive errors? How should image privacy be maintained? Where is the line between educational simulation and marketing-driven visualization? Addressing these issues through robust oversight and clear regulatory guidance is essential for the safe, equitable, and responsible adoption of AI in clinical practice. Education and training remain fundamental in the era of AI-enhanced plastic surgery. AI is

intended not to replace human judgement but to serve as an empowering tool that sharpens critical thinking and refining technical skills. Multidisciplinary teamwork among surgeons, engineers, and data scientists is needed to maximize the potential of such systems, to align a mutual understanding of their benefits and constraints. By providing adaptive learning programs that tailor content and difficulty to each trainee, AI has the potential to become a central component of resident education and skills certification, supporting a new generation of clinicians who are both technically proficient and AI-literate. Future directions point toward increasingly sophisticated and highly personalized applications of AI in plastic surgery. Specialty-specific, multimodal AI models are expected to enhance decision-making, outcome prediction, and patient-specific planning, supporting the advancement of personalized medicine. Among the most transformative anticipated developments are digital anatomical twins—virtual models replicating individual anatomy and physiology (29)—and AI-optimized surgical plans that incorporate soft-tissue biomechanics. Advances in robotics may enable autonomous or semi-autonomous microsurgical systems, while AI-assisted “surgical copilots” capable of analyzing multimodal intraoperative data could become part of routine practice (5). Concurrent innovations in regenerative medicine, including AI-guided scaffold design and tissue engineering, are also poised to expand reconstructive possibilities (30). Throughout this evolution, prioritizing ethical and inclusive innovation—through transparency, bias mitigation, and global collaboration—will be essential. Taking together, these advances promise a new era of hyper-personalized, minimally invasive plastic surgery with improved predictability, safety, and patient outcomes. In conclusion, AI in plastic surgery should be viewed as a collaborative and powerful extension of the surgeon’s expertise, capable of enhancing accuracy, efficiency, and patient outcomes while maintaining the central role of human judgment and the physician–patient relationship. When thoughtfully integrated into surgical planning, used to standardize aesthetic outcomes, and implemented under rigorous validation and ethical oversight, AI has the potential to transform the specialty toward more predictive, personalized, and minimally invasive surgical approaches.

Conclusions

AI is set to reshape plastic surgery. Current tools already enhance preoperative planning, intraoperative safety, and postoperative monitoring. Looking ahead, future systems are expected to integrate effortlessly into surgical workflows, allowing for levels of precision and personalization that were previously unattainable. Successful integration, however, depends on addressing ethical, technical, and regulatory challenges to ensure that AI augments—rather than replaces—human expertise and compassion. AI represents an extraordinary opportunity in plastic surgery, but without critical oversight, a powerful tool may risk introducing clinical inaccuracies. The future is not AI or the surgeon; it is AI with the surgeon—in a conscious, collaborative, and regulated partnership.

Conflict of Interest: Each author declares that he or she has no commercial associations (e.g. consultancies, stock ownership, equity interest, patent/licensing arrangement etc.) that might pose a conflict of interest in connection with the submitted article.

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