

Artificial intelligence in aesthetic and reconstructive surgery: Clinical applications, ethical challenges, and future trends

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Abstract

Artificial intelligence (AI) and machine learning (ML) are increasingly influencing aesthetic and reconstructive surgery. These technologies are transforming clinical workflows by enhancing precision, personalization, and operational efficiency across various stages of surgical care. **Aim:** To review the current applications, measurable benefits, and challenges of AI and ML in aesthetic and reconstructive surgery, and to explore their potential future impact on the field. **Material and methods.** This review synthesizes findings from recent studies, technological assessments, and clinical applications of AI and ML in surgical practice. Key areas examined include preoperative planning, imaging, robotic systems, intraoperative tools, and postoperative monitoring. **Results.** AI and ML have been shown to reduce surgical planning time by up to 35 % and improve breast symmetry assessment accuracy by over 90 %. Robotic systems and AI-powered automation enhance minimally invasive procedures and optimize intraoperative decisions. Furthermore, AI supports postoperative care through predictive modeling, complication monitoring, and real-time data interpretation. Despite these advances, challenges persist, including algorithmic bias, data privacy concerns, and the need for robust clinical validation. **Conclusions.** AI and ML are poised to significantly reshape aesthetic and reconstructive surgery. As these technologies continue to evolve, addressing ethical and regulatory challenges will be essential for their safe and effective integration into clinical practice.

Key words: artificial intelligence, machine learning, aesthetic surgery, reconstructive surgery, computer vision, algorithmic bias, robotic-assisted surgery.

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Искусственный интеллект и машинное обучение в эстетической и реконструктивной хирургии

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Резюме

Искусственный интеллект (ИИ) и машинное обучение (МО) все активнее влияют на эстетическую и реконструктивную хирургию. Эти технологии трансформируют клинические процессы, повышая точность, персонализацию и операционную эффективность на различных этапах хирургического лечения. Цель данного обзора – проанализировать текущие области применения, количественно измеримые преимущества и существующие вызовы ИИ и МО в эстетической и реконструктивной хирургии, а также исследовать их возможное влияние на будущее в этой области. **Материал и методы.** Обзор обобщает данные современных исследований, технологических оценок и клинического опыта использования ИИ и МО в хирургической практике. Рассматриваются ключевые направления, включая предоперационное планирование, визуализацию, роботизированные системы, интраоперационные инструменты и послеоперационный мониторинг. **Результаты.** Установлено, что ИИ и МО позволяют сократить время планирования операций до 35 % и повысить точность оценки симметрии груди бо-

лее чем на 90 %. Роботизированные системы и автоматизация на базе ИИ улучшают малоинвазивные процедуры и оптимизируют интраоперационные решения. Кроме того, ИИ способствует послеоперационному уходу благодаря прогностическому моделированию, контролю осложнений и интерпретации данных в реальном времени. Несмотря на достижения, сохраняются проблемы, включая алгоритмическую предвзятость, риски для конфиденциальности данных и необходимость клинической валидации. **Заключение.** ИИ и МО готовы существенно изменить эстетическую и реконструктивную хирургию. По мере развития этих технологий крайне важно решать этические и нормативные вопросы для их безопасной и эффективной интеграции в клиническую практику.

Ключевые слова: искусственный интеллект, машинное обучение, эстетическая хирургия, реконструктивная хирургия, компьютерное зрение, алгоритмическая предвзятость, роботизированная хирургия.

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Introduction

Artificial intelligence (AI) and machine learning (ML) have emerged as transformative forces in various medical disciplines, including aesthetic and reconstructive surgery. AI refers to the simulation of human intelligence processes by computer systems, encompassing learning, reasoning, and self-correction [1]. ML, a subset of AI, involves algorithms that enable systems to learn from data, identify patterns, and make decisions with minimal human intervention. In the context of surgery, these technologies are being harnessed to enhance diagnostic accuracy, optimize surgical planning, and improve postoperative evaluations [2].

In aesthetic and reconstructive surgery, AI and ML applications are particularly promising. For instance, computer vision – a field of AI that trains machines to interpret and process visual information – has been utilized to analyze facial features, assisting surgeons in planning procedures with greater precision [3]. Large language models, another AI advancement, are being explored for patient counseling, providing detailed explanations of surgical procedures and potential outcomes. These tools aim to address the subjective nature of aesthetic assessments by introducing objective measures, thereby standardizing evaluations and enhancing patient satisfaction [4].

Moreover, AI-driven predictive models are being developed to forecast surgical outcomes, allowing for personalized treatment plans. By analyzing vast datasets of patient information, these models can predict potential complications and suggest optimal surgical approaches tailored to individual patient profiles [5]. This personalized approach not only improves surgical precision but also enhances patient safety and satisfaction.

Despite these advancements, the integration of AI and ML into clinical practice faces challenges, including algorithmic bias, ethical considerations, and the need for rigorous validation. Addressing these issues is crucial to fully realize the potential of AI and ML in transforming aesthetic and reconstructive surgery [6].

Material and methods

This literature review follows a systematic approach in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The methodology is structured into four main phases: literature search strategy, study selection, data extraction, and quality assessment.

Literature search strategy

A comprehensive search was conducted across multiple electronic databases, including PubMed, Google Scholar, Scopus, and Web of Science. The search strategy employed Boolean operators (AND, OR) to combine relevant Medical Subject Headings (MeSH) terms and keywords, ensuring a broad yet targeted scope. The search covered literature published between January 2015 and April 2025. Primary search terms included: “artificial intelligence”, “machine learning”, “aesthetic surgery”, “reconstructive surgery”, “surgical innovation”, “AI-driven imaging”, “robotic-assisted surgery”, “predictive analytics in surgery”. Additionally, reference lists of selected articles were screened to identify further relevant studies.

Study selection

The selection process was conducted in two stages: screening phase – titles and abstracts of the retrieved articles were independently screened by two reviewers to exclude irrelevant or duplicate

studies, eligibility phase – the full texts of potentially eligible articles were reviewed based on predefined inclusion and exclusion criteria. Inclusion criteria: peer-reviewed journal articles published in English; studies specifically investigating AI and ML applications in aesthetic and reconstructive surgery; articles discussing AI-driven imaging, robotic-assisted surgery, predictive modeling, and postoperative monitoring; clinical studies, systematic reviews, meta-analyses, and relevant conference proceedings. Exclusion criteria: non-English articles; studies focusing on general surgery or unrelated medical specialties; editorials, opinion articles, or studies lacking quantitative outcome measures or methodological rigor; articles that did not meet the methodological quality threshold. Following this process, 171 articles were retrieved. Of these, 96 studies were selected based on relevance to aesthetic and reconstructive applications and methodological quality.

Data extraction and synthesis

Data from the selected studies were extracted using a structured data collection form. The following information was recorded for each study: study title, authors, and publication year; study design and methodology; AI/ML application in aesthetic or reconstructive surgery; key findings and contributions to the field; limitations and potential

biases. Findings were synthesized thematically to categorize AI applications into distinct domains such as preoperative planning, intraoperative guidance, postoperative monitoring, and ethical considerations.

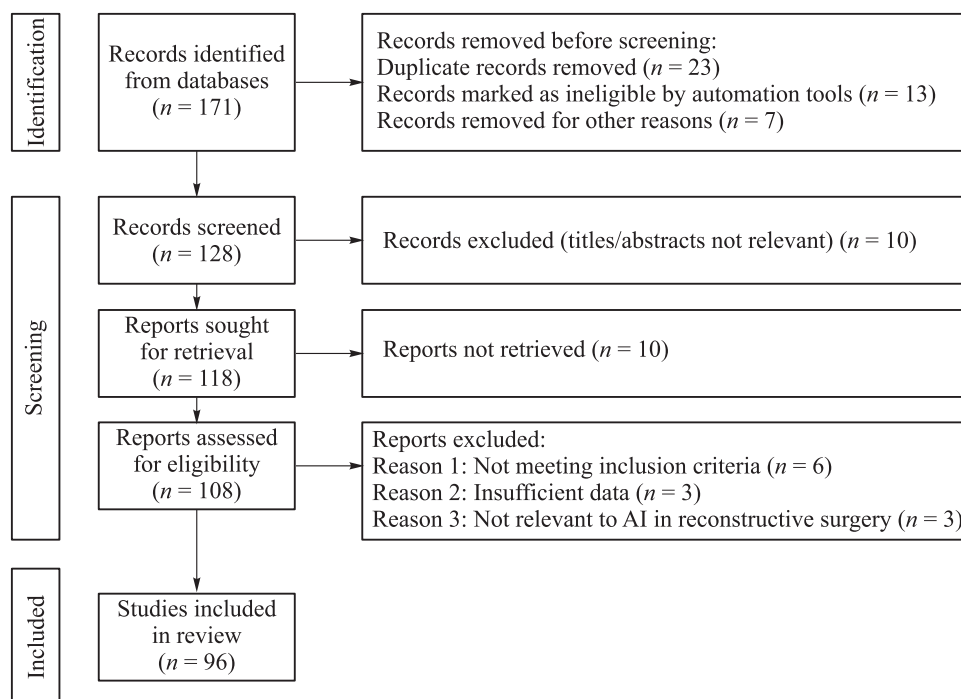
Quality assessment

The methodological quality of the included studies was assessed using the Mixed Methods Appraisal Tool (MMAT) for systematic reviews. Criteria included: research design appropriateness; data collection and analysis methods; sample size adequacy; reproducibility and generalizability of findings. Studies scoring low on methodological rigor were carefully evaluated for bias and their influence on the overall conclusions.

A single PRISMA flow diagram summarizes the selection process, including records identified, screened, excluded, and the rationale for inclusion in the final synthesis (Figure).

AI for preoperative planning and patient assessment

AI has become an integral component in the preoperative planning and patient assessment phases of aesthetic and reconstructive surgery. By leveraging advanced algorithms and machine learning models, AI enhances facial analysis, body contouring,



PRISMA flow diagram

Диаграмма процесса отбора исследований PRISMA

outcome prediction, and surgical planning, improving precision and patient satisfaction [7] (Table 1). In facial analysis, AI-powered tools have transformed how surgeons assess and plan procedures. Machine learning algorithms process high-resolution images to evaluate facial symmetry, skin texture, and anatomical structures, enabling simulation of postoperative outcomes [8]. For example, AI-driven 3D imaging systems generate visual predictions to help set realistic expectations and guide consultations [9, 10]. Similarly, in body contouring, AI models assess patient data and anatomical parameters to suggest customized procedures like liposuction or abdominoplasty [10]. These tools support data-driven decision-making and simulate expected results, helping patients understand outcomes and minimize risks [11].

Predictive algorithms also analyze patient demographics, surgical history, and procedural factors to estimate complication risks and optimize techniques [12]. In breast augmentation, for example, AI can predict capsular contracture likelihood based on implant type and surgical variables, aiding surgeons in tailoring safer approaches [13]. AI-based tools enhance personalized treatment planning by aligning procedures with individual anatomy and aesthetic goals. In rhinoplasty, AI evaluates nasal and facial proportions to suggest changes for natural symmetry [7]. In reconstructive surgery, it supports flap design by analyzing tissue availability and vascularity. Personalized planning improves precision and safety [14]. Moreover, AI-driven virtual assistants using natural language processing

now assist in consultations by accurately answering patient questions, improving efficiency and allowing surgeons to focus on complex care decisions [2, 15].

AI-driven imaging and simulation

AI has significantly advanced imaging and simulation techniques in aesthetic and reconstructive surgery, enhancing preoperative planning and customized visualization of outcomes (Table 2). The integration of AI with modalities such as three-dimensional (3D) modeling, augmented reality (AR), and virtual reality (VR) has increased procedural precision and personalization [16]. AI-driven 3D modeling processes patient-specific imaging data to generate detailed anatomical reconstructions, helping surgeons plan complex interventions with greater accuracy [17]. In cases like conjoined twin separation, VR simulations have enabled preoperative rehearsals, reducing intraoperative risks and improving coordination [18]. AI-powered AR/VR surgical simulations provide immersive, risk-free training environments. These tools help enhance surgical skills, build confidence, and offer real-time guidance. For example, the da Vinci Research Kit (dVRK) was used to develop a system combining AI and AR, improving surgical education and decision-making during robotic procedures [19, 20]. Simulation-assisted planning has been shown to reduce operative time by 18 % in facial reconstructive cases [20].

Outcome visualization tools use AI to predict postoperative appearances by analyzing individual patient data, particularly in procedures like

Table 1. Summary of key AI and ML applications in preoperative assessment and planning, highlighting the tools used, clinical benefits, and specific use cases

Таблица 1. Обзор основных применений ИИ и МО в предоперационной оценке и планировании с указанием используемых инструментов, клинических преимуществ и конкретных вариантов использования.

Application area	AI/ML tool or approach	Clinical outcome	Example or study context
Facial analysis and planning	ML-based 3D imaging, computer vision	Improved symmetry analysis and preoperative visualization	Rhinoplasty: AI assesses nasal structure for balanced reshaping [7]
Body contouring	Predictive analytics, personalized modeling	Tailored surgical plans, better aesthetic outcomes	Liposuction: AI predicts tissue response to different techniques [10]
Outcome prediction	Predictive algorithms	Risk stratification and complication forecasting	Breast augmentation: AI predicts capsular contracture risks [13]
Personalized planning	Patient-specific data modeling	Enhanced surgical precision and patient-specific customization	Reconstructive surgery: AI selects flap sites based on vascular analysis [14]
Preoperative consultation	NLP-driven virtual assistants	Streamlined consultations, accurate patient Q&A	AI chatbot answers FAQ with high accuracy, improving workflow [15]

Table 2. Summary of AI-driven imaging and simulation tools used in aesthetic and reconstructive surgery, detailing the functionality, clinical use cases, and measurable outcomes where available

Таблица 2. Обзор инструментов визуализации и моделирования на основе искусственного интеллекта, используемых в эстетической и реконструктивной хирургии, с подробным описанием функциональности, клинических случаев использования и измеримых результатов (где это возможно)

Tool / Technology	AI functionality	Application area	Clinical impact
3D modeling software	Anatomical reconstruction using patient imaging and ML algorithms	Facial reconstruction, flap design	Enhanced visualization and planning accuracy [17]
Virtual reality (VR)	Surgical rehearsal in patient-specific 3D environments	Complex surgeries (e.g., conjoined twins)	Reduced intraoperative risks through pre-surgical rehearsal [18]
Augmented reality (AR)	Real-time overlay of anatomical and procedural data	Robotic-assisted and intra-operative navigation	Improved surgical precision and feedback [19, 20]
Simulation-assisted planning	Interactive simulation with AI-generated feedback	Facial reconstructive surgery	Reduced operative time by 18% (insert correct reference)
Outcome visualization systems	Predictive modeling of postoperative appearance	Rhinoplasty, breast augmentation, body contouring	Improved patient understanding and satisfaction [21, 22]
AI-based performance assessment	Skill evaluation via ML-based analysis in simulations	Surgical training and education	Personalized feedback; improved training outcomes [24, 25]
Predictive analytics platforms	Data-driven planning based on prior patient outcomes	Plastic surgery, aesthetic design	Customized plans aligned to patient-specific features [3, 23]

rhinoplasty, where visualizing results is critical [21, 22]. This enables patients to form realistic expectations and participate more actively in decision-making. In addition to visual planning, AI contributes to personalized surgical design by analyzing large datasets to match patient-specific goals and features. For instance, in plastic surgery, algorithms generate visual representations of desired body changes based on individual measurements and inputs [3, 23]. Surgical simulation systems enhanced by AI also support performance evaluation and training. Machine learning models assess surgeon technique in virtual environments and deliver objective, personalized feedback [24, 25]. These tools elevate training standards and help ensure clinical proficiency, contributing to improved patient safety and outcomes.

Machine learning in reconstructive surgery

ML has emerged as a transformative tool in reconstructive surgery, offering innovative solutions to challenges in trauma, burn, and cancer reconstruction (Table 3). By analyzing vast datasets and identifying complex patterns, ML enhances clinical decision-making, improves surgical precision, and optimizes patient outcomes [26]. Its

integration into microsurgery, flap selection, and postoperative care has led to more personalized treatment plans and better monitoring protocols [27].

In trauma reconstruction, ML algorithms have been developed to predict complications by analyzing variables such as demographics, injury type, imaging data, and treatment protocols. These predictive models enable surgeons to stratify risk and tailor surgical strategies accordingly [28]. For example, in facial trauma, ML can process 3D CT scans to identify fractures and recommend interventions with greater accuracy, particularly in complex cases like comminuted fractures [29]. ML-based systems also support postoperative assessments by analyzing wound images and biometric data to detect early signs of complications such as infection or necrosis [30]. In one clinical study, ML-based wound monitoring reduced necrosis-related complications by 30 %, highlighting its potential to enhance outcomes.

Burn care has similarly benefited from ML innovations. Accurate classification of burn depth and extent is critical for treatment decisions, and ML models – particularly convolutional neural networks (CNNs) – have demonstrated diagnostic performance on par with expert clinicians [31]. These tools analyze thermal imaging and wound photos to differentiate

Table 3. Overview of ML applications in reconstructive surgery, organized by surgical context, tool type, clinical outcomes, and representative examples from the literature

Таблица 3. Обзор применения машинного обучения в реконструктивной хирургии, организованный по хирургическому контексту, типу инструмента, клиническим результатам и репрезентативным примерам из литературы

Surgical indication	ML tool or application	Clinical impact	Example or study context
Trauma reconstruction	Risk stratification using patient data and imaging	Personalized surgical strategies; improved fracture analysis	3D CT scan processing for facial trauma [28, 29]
Post-trauma monitoring	Wound image and biometric analysis	Early detection of infection and necrosis	ML-based wound monitoring reduced necrosis complications by 30% [30]
Burn assessment	CNNs analyzing wound/thermal images	Accurate burn classification; faster decision-making	Deep vs. superficial burn prediction [31, 32]
Burn surgery planning	Donor-recipient site matching based on patient-specific factors	Optimized grafting, reduced complications	Burn graft optimization [33]
Cancer reconstruction (e.g., breast)	Predictive modeling for donor site morbidity	Preventive planning for complications such as hernia or infection	DIEP flap complication prediction [34, 35]
Aesthetic outcome simulation	AI-driven imaging and postoperative comparison	Improved aesthetic results and patient satisfaction	Breast symmetry simulation [36]
Flap selection	Preoperative imaging + ML for vascular mapping	Reduced flap failure; more efficient planning	Blood flow-based flap selection [37, 38]
Intraoperative monitoring	Real-time perfusion tracking via spectroscopy + ML	Timely intervention to prevent flap compromise	Near-infrared spectroscopy-guided decisions [39]
Postoperative flap surveillance	Wearable sensor data analysis with anomaly detection	Real-time alerts for vascular compromise; improved flap salvage rates	ML distinguishes normal vs. compromised flaps [40–42]
Microsurgical training	Video-based performance analysis and feedback	Enhanced technical skill assessment and training outcomes	Suture quality evaluation [43]
VR simulation in microsurgery	AI-powered VR with personalized feedback	Accelerated training, higher proficiency	VR microsurgery practice environments [44, 45]

between superficial and deep burns, facilitating timely debridement or grafting [32]. Moreover, ML aids in donor-recipient site matching by assessing wound characteristics and patient-specific variables, improving graft success rates and accelerating healing [33].

In cancer reconstruction, ML applications are particularly valuable in post-mastectomy breast reconstruction. Abdominally based free flaps, such as the deep inferior epigastric perforator (DIEP) flap, carry risks of donor site morbidity including hernia and infection. ML algorithms trained on large datasets can evaluate patient anatomy, comorbidities, and procedural factors to predict the likelihood of such complications, aiding in surgical planning [34, 35]. Furthermore, ML has been used to assess and predict aesthetic outcomes. AI-driven imaging tools simulate breast contour and symmetry, allowing

for alignment of surgical outcomes with patient expectations [36].

Flap selection and microsurgical planning have also improved with ML integration. Free flap surgeries require careful planning to ensure donor site viability and vascular integrity. ML algorithms analyze imaging data, tissue quality, and vascular anatomy to assist surgeons in selecting the optimal flap and predicting perfusion outcomes [37, 38]. Intraoperatively, real-time ML tools using near-infrared spectroscopy monitor perfusion dynamics, minimizing the risk of flap failure and enhancing intraoperative decision-making [39].

Postoperative monitoring of free flaps is another domain where ML is increasingly utilized. Traditional tools like Doppler ultrasound are resource-intensive and depend on clinical experience. Automated ML systems can process data from wearable sensors

to detect perfusion abnormalities or temperature fluctuations, generating real-time alerts that allow for timely interventions and flap salvage [40, 41]. Recent models have demonstrated high accuracy in distinguishing between normal and compromised flap circulation, reinforcing their clinical value [42].

Finally, ML has contributed to skill development and assessment in microsurgery. Procedures such as microvascular anastomosis require exceptional precision. ML-based systems analyze surgical videos to evaluate factors like suture placement and alignment, offering objective feedback for training and performance improvement [43]. Virtual reality (VR) simulators integrated with ML create realistic scenarios where trainees can practice microsurgical techniques and receive personalized feedback, accelerating proficiency development [44, 45].

AI in minimally invasive and non-invasive aesthetic procedures

AI and ML are increasingly transforming minimally invasive and non-invasive aesthetic procedures, enhancing precision, personalization, and outcomes. In treatments such as Botox injections, dermal fillers, and laser therapies, AI-driven optimization is becoming integral to clinical practice [46]. For instance, AI algorithms can analyze patient-specific data, including skin type, facial anatomy, and previous treatment responses, to recommend personalized injection plans. This not only minimizes human error but also improves consistency and symmetry – AI-optimized Botox injection maps have been shown to improve facial symmetry scores by 22 % [47].

In laser treatments, ultrasound, and radiofrequency (RF) therapies, AI systems adjust energy parameters in real time based on tissue response, enhancing both safety and efficacy [48, 49]. ML algorithms can predict patient-specific responses, enabling personalized protocols for skin tightening and collagen remodeling. In ultrasound-based procedures, AI determines optimal energy depth; in RF therapy, it monitors impedance to ensure uniform heating [50, 51]. These innovations reduce overtreatment risks and lead to more predictable outcomes. Furthermore, AI-powered diagnostic tools are revolutionizing aesthetic assessments. Advanced imaging systems equipped with AI can evaluate skin conditions, simulate aging trajectories, and project post-treatment results, helping both clinicians and patients set realistic expectations [52]. These predictive capabilities facilitate shared decision-making and improve satisfaction. AI also tracks long-term treatment efficacy, helping refine and personalize future interventions [53].

The integration of AI also extends to robotic assistance in aesthetic treatments. Vision-guided robotic systems have been developed for skin therapies such as laser photo-rejuvenation, delivering energy uniformly across mapped surfaces using depth sensors and thermal cameras [54]. Such systems increase precision and reduce operator variability, marking a shift toward semi-autonomous aesthetic interventions [55, 56]. Moreover, AI supports personalized aesthetic planning. Recent approaches incorporate meta-learning to predict individual preferences in facial aesthetics [57]. By analyzing facial structure and personal preferences, AI assists in designing procedures – such as filler placement or Botox injection – aligned with each patient's perception of beauty. This enables bespoke outcomes that resonate more deeply with patient expectations [58].

Robotic-assisted surgery in aesthetics and reconstruction

The integration of AI into robotic-assisted surgery has significantly enhanced aesthetic and reconstructive procedures. Robotic systems equipped with AI offer improved dexterity, visualization, and control, enabling more accurate interventions [59]. In aesthetic surgery, these systems support minimally invasive techniques that reduce scarring and recovery time, especially in procedures like facelifts and body contouring. Rather than generalized benefits, studies highlight specific improvements – for example, robotic assistance ensures more precise tissue manipulation, enhancing symmetry and reducing revisions [21, 60]. In reconstructive surgery, especially post-mastectomy breast reconstruction or craniofacial repairs, AI-integrated robotic platforms assist in microsurgical tasks such as vascular anastomosis and flap dissection [61]. This precision improves surgical efficiency and outcomes. In one comparative study, robotic-assisted DIEP flap surgery reduced ischemia time by 15 minutes, significantly lowering the risk of flap failure [61]. Additionally, AI algorithms guide preoperative planning by analyzing patient data to predict anatomical challenges and personalize surgical approaches [62, 63].

These systems yield multiple benefits – shorter operative times, smaller incisions, reduced infection risk, and quicker recovery – all of which contribute to improved patient experiences [64]. Enhanced visualization allows for confident navigation of complex anatomy, especially when restoring both form and function in reconstructive contexts [65, 66]. Moreover, the combination of robotics and AI advances the field of personalized surgery. ML algorithms process patient-specific variables to optimize technique selection and predict outcomes,

leading to more precise, tailored interventions [67]. This data-informed customization reinforces the move toward safer, more efficient, and individualized surgical care [68].

Postoperative monitoring and complication management

AI has become increasingly integral in postoperative monitoring and complication management, offering innovative solutions to track healing, detect complications, and monitor implants. By leveraging predictive analytics, AI enhances postoperative care and outcomes, providing personalized and timely interventions [69]. In the realm of postoperative monitoring, AI systems analyze patient data to track healing processes and identify potential complications early. For instance, machine learning algorithms can process electronic health records (EHRs) to predict the likelihood of postoperative infections or other adverse events. A study by A. Callahan et al. demonstrated that deep learning methods could accurately extract implant details and reports of complications from clinical notes, achieving up to 96.3 % precision and 98.5 % recall [70]. This approach enables healthcare providers to monitor patient progress more effectively and intervene promptly when issues arise. However, despite high accuracy in some models, other studies have reported false-negative rates ranging from 11 % to 14 % for early infection detection – highlighting the importance of combining AI surveillance with clinical oversight [70, 71].

AI also plays a crucial role in monitoring surgical implants. By analyzing data from various sources, including patient records and sensor data, AI can predict the risk of implant-related complications. For example, in breast reconstruction surgeries, machine learning models have been developed to predict infection risks following implant-based procedures [71]. These models utilize algorithms such as random forests to identify predictive factors, with accuracy rates ranging from 67 % to 83 %. Key predictors include higher body mass index, older age, and postoperative radiation therapy [72]. By identifying patients at higher risk, clinicians can implement targeted preventive measures to mitigate potential complications.

Predictive analytics further enhance postoperative care by forecasting potential complications and facilitating proactive management. AI-driven models can assess a multitude of variables to predict outcomes such as surgical site infections, venous thromboembolism, or cardiac events. For instance, the MySurgeryRisk AI system utilizes EHR data to predict postoperative complications successfully,

enabling healthcare providers to tailor postoperative care plans to individual patient needs [5].

In orthopedic surgery, AI has been employed to predict patient risk of postoperative complications after procedures involving the liver, pancreas, and colorectal regions. By analyzing large datasets, machine learning algorithms can identify patterns and risk factors that may not be evident through traditional analysis, thereby informing clinical decision-making and improving patient outcomes [73]. The application of AI in postoperative monitoring extends to remote patient management. AI-powered platforms can analyze data from wearable devices and mobile applications to monitor patients' recovery in real-time [74]. This continuous monitoring allows for the early detection of deviations from expected recovery patterns, enabling timely interventions without the need for frequent in-person visits. Such approaches have been particularly beneficial in plastic surgery, where remote monitoring can enhance patient engagement and satisfaction [75].

Moreover, AI contributes to the development of explainable and transparent predictive models, which are essential for clinical adoption. Recent advancements have focused on creating interfaces that provide clear explanations for AI-driven predictions, addressing concerns about the “black box” nature of some AI systems [76]. For example, Y. Ren et al. proposed an explainable AI framework designed to answer critical questions regarding postoperative complication predictions, enhancing the transparency and trustworthiness of AI applications in clinical settings [77].

Ethics and challenges of AI in aesthetic surgery

The integration of AI into aesthetic surgery introduces significant ethical considerations, particularly concerning biases in AI algorithms and the safeguarding of patient privacy and data security. Addressing these challenges is crucial to ensure equitable, safe, and effective applications of AI in this medical field [78]. AI algorithms in aesthetic surgery are susceptible to biases that can influence clinical decisions and perpetuate narrow aesthetic standards. These biases often stem from non-representative training datasets that fail to capture the diversity of patient populations [79]. For instance, if an AI system is trained predominantly on images of individuals from a specific ethnic background, it may not perform accurately for patients from other backgrounds, leading to suboptimal or inappropriate recommendations [80]. This issue is particularly pertinent in aesthetic surgery, where concepts of beauty are deeply subjective and culturally varied.

Studies have emphasized that algorithmic bias and fairness are significant ethical issues in AI models used in plastic surgery, highlighting the need for diverse and representative training datasets to mitigate these biases [78].

To address these biases, it is essential to develop AI models that are trained on diverse datasets encompassing various ethnicities, ages, and body types. Additionally, implementing fairness-aware algorithms that actively detect and correct for biases during the training process can enhance the equity of AI applications in aesthetic surgery. Algorithmic failure rates and misclassification – such as false-positive symmetry corrections or erroneous detection of facial asymmetries – can lead to inappropriate treatment plans. These failures often go unnoticed when models are trained on limited or homogeneous datasets. Ongoing monitoring and evaluation of AI systems are also necessary to identify and rectify any emergent biases, ensuring that the technology serves all patient groups effectively [81].

Patient privacy and data security are other critical ethical concerns in the use of AI for aesthetic surgery. The reliance on large datasets, often including sensitive patient information, raises questions about how this data is stored, shared, and utilized. Breaches of patient data can have severe consequences, including the potential misuse of personal information or reputational harm [82]. For instance, AI systems used for facial recognition or aesthetic analysis may require detailed images of patients, which are inherently sensitive. Ensuring that this data is protected against unauthorized access is paramount [83]. To protect patient information, stringent measures such as secure encryption, data anonymization, and regular cybersecurity audits must be implemented. Compliance with international frameworks like the General Data Protection Regulation (GDPR) is critical to ensure ethical and legal use of data in AI systems. Transparent communication with patients about how their data will be used, stored, and shared is also essential to foster trust and ensure ethical compliance [84].

Another ethical challenge is the potential for misuse of AI in aesthetic surgery, including its application for non-medical purposes. For instance, AI tools designed for facial analysis or enhancement could be misused to perpetuate unrealistic beauty ideals or support harmful social trends. This raises broader ethical questions about the societal impact of AI technologies and the responsibility of developers and clinicians to use these tools in a manner that prioritizes patient well-being and avoids reinforcing negative stereotypes [85]. Moreover, the integration of AI in aesthetic surgery requires clinicians to maintain an active role in decision-making processes.

While AI can provide valuable insights and recommendations, over-reliance on these systems could undermine the importance of clinical judgment and the individualized nature of patient care [86]. Ensuring that AI serves as a supportive tool rather than a replacement for human expertise is essential for maintaining the ethical integrity of aesthetic practices.

The ethical considerations of using AI in aesthetic surgery also extend to issues of accessibility and equity. The development and implementation of advanced AI technologies often require significant financial investment, which can lead to disparities in access [87]. Patients from underprivileged backgrounds or in regions with limited healthcare resources may not benefit from these innovations, exacerbating existing inequities in healthcare. Addressing these disparities requires policymakers and stakeholders to prioritize equitable access and consider affordability when deploying AI solutions in aesthetic surgery [88].

Future directions and innovations

The integration of AI into aesthetic and reconstructive surgery is ushering in a new era of personalized medicine and innovative educational methodologies. Emerging trends, such as generative AI for surgical education, real-time intraoperative analytics, and wearable sensor-driven patient feedback, are poised to revolutionize the field [89].

Generative AI, which involves the use of algorithms and neural networks to create new content, is making significant inroads into surgical education. By analyzing vast datasets, these AI systems can generate realistic surgical scenarios, providing trainees with immersive and diverse learning experiences. This approach enhances the acquisition of surgical skills by allowing for repeated practice in a controlled, virtual environment, thereby reducing the reliance on cadaveric specimens and live patients [90]. A review exploring the integration of generative AI into surgical training assessed its potential to enhance learning and teaching methodologies, noting that while promising, technical challenges such as data quality issues and model interpretability remain barriers to widespread adoption [91].

In addition to simulation, AI-powered platforms are being developed to provide real-time feedback during surgical procedures. These systems analyze intraoperative data to offer immediate insights, enabling trainees to refine their techniques on the spot. In one system currently being tested, AI provides real-time alerts during flap harvesting and microsurgical anastomosis, significantly reducing intraoperative decision fatigue and errors [92].

Table 4. Future AI technologies in aesthetic and reconstructive surgery**Таблица 4.** Будущие технологии искусственного интеллекта в эстетической и реконструктивной хирургии

Technology	Application	Stage	Expected impact
Generative AI	Simulation, documentation, patient education	Pre/Intra/Post-op	Improved planning, documentation, education
Real-time intraoperative AI	Live monitoring, perfusion tracking	Intraoperative	Enhanced surgical safety, reduced complications
Wearable sensor integration	Remote postoperative monitoring	Postoperative	Early complication detection, reduced follow-ups
Personalized AI platforms	Treatment selection, predictive outcomes	Pre/Postoperative	Patient-specific care, optimized aesthetic outcomes
Meta-learning for preferences	Predicting aesthetic goals	Preoperative	Tailored cosmetic planning, increased satisfaction

Beyond education, AI is transforming personalized medicine in aesthetic and reconstructive surgery (Table 4). By analyzing large datasets and patient profiles, AI can provide personalized treatment recommendations based on individual characteristics, medical history, and desired outcomes. This assists surgeons in tailoring procedures to each patient's unique needs, optimizing results, and minimizing risks [93]. Moreover, AI-powered tools are being utilized to predict postoperative outcomes and potential complications. By analyzing preoperative data, these systems can forecast healing trajectories and identify patients at higher risk for adverse events, allowing for proactive management strategies. This predictive capability enhances patient safety and improves overall surgical outcomes [94].

The integration of AI into surgical practice also extends to intraoperative decision-making. Generative AI can be used before surgery for planning and decision support by extracting patient information and providing patients with information and simulation regarding the procedure [95]. During surgery, AI systems now assist in tracking real-time perfusion, flagging deviations from expected parameters, and logging intraoperative adverse events – data that traditionally went undocumented. Postoperatively, generative AI can assist with discharge planning, follow-up scheduling, and complication surveillance. Furthermore, AI is facilitating advancements in non-invasive aesthetic procedures. By analyzing patient data, AI systems can recommend personalized, non-surgical treatments that align with the patient's aesthetic goals and medical history. This approach not only enhances patient satisfaction but also broadens the scope of aesthetic treatments available to individuals who may not be candidates for surgery [96].

Conclusions

AI and ML are transforming aesthetic and reconstructive surgery through enhanced planning, precision, and predictive care. These technologies offer measurable improvements, such as up to 35 % reductions in surgical planning time and over 90 % accuracy in outcome prediction. Addressing algorithmic bias, validation standards, and data privacy concerns is essential for their safe and equitable integration. With innovations like generative AI, intraoperative analytics, and personalized predictive models, AI is poised to redefine patient care and education in the surgical landscape.

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