

Review

ARTIFICIAL INTELLIGENCE IN PLASTIC AND HAND SURGERY –
POTENTIAL OR PROVOCATION?

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ABSTRACT

Introduction: Surgical specialities like plastic and hand surgery, which depend on precision, aesthetic, and functional outcomes, are integrating AI, creating potential and challenges. AI is rapidly transforming clinical procedures, requiring evaluation of its potential to improve clinical care and the challenges it faces. This narrative review critically evaluates the clinical applications, emerging innovations, and ethical challenges of AI in plastic and hand surgery, synthesising evidence on both its transformative potential and the challenges it presents.

Method: We conducted a narrative review of peer-reviewed literature using PubMed, Scopus, and Web of Science (2018-2025). Keywords included “artificial intelligence,” “machine learning,” “deep learning,” “plastic surgery,” “hand surgery,” “microsurgery,” and “convolutional neural networks.” We included studies on clinical applications, technological innovations, and ethical considerations. This review differs from existing syntheses by providing a balanced “Potential vs Provocation” framework that systematically addresses both benefits and challenges while proposing concrete implementation strategies for clinical practice.

Results: AI technologies such as convolutional neural networks and large language models classify skin lesions, evaluate aesthetics, and automate operative documentation.

Conclusion: Innovations such as generative AI, mixed reality, and predictive analytics in microsurgical procedures, patient-specific simulations, and smart rehabilitation have driven tremendous advances in this field. Despite this potential, significant challenges remain, including data bias, limited AI model interpretability, and concerns about liability and privacy. AI in plastic and hand surgery has significant potential to strengthen surgeons; however, integrating it requires acceptance, education, interdisciplinary collaboration, and ethical guidelines to address the challenges of this technological evolution.

Keywords: Artificial Intelligence; AI in Surgery; Plastic Surgery; Hand Surgery; Machine Learning; Deep Learning; Convolutional Neural Networks

Pendahuluan: Bidang spesialisasi bedah, seperti bedah plastik dan bedah tangan, yang sangat bergantung pada presisi serta luaran estetika dan fungsional, semakin mengintegrasikan kecerdasan buatan (*artificial intelligence*, AI) ke dalam praktik klinis. Integrasi ini membuka berbagai peluang sekaligus menghadirkan tantangan. AI dengan cepat mentransformasi prosedur klinis, sehingga diperlukan evaluasi terhadap potensinya dalam meningkatkan pelayanan klinis serta berbagai kendala yang dihadapi dalam penerapannya. Tinjauan naratif ini mengevaluasi secara kritis aplikasi klinis, inovasi yang berkembang, dan tantangan etis AI dalam bedah plastik dan bedah tangan, dengan menyintesis bukti ilmiah mengenai potensi transformatif sekaligus tantangan yang ditimbulkannya.

Metode: Kami melakukan tinjauan naratif terhadap literatur yang telah melalui proses telaah sejawat (*peer review*) pada basis data PubMed, Scopus, dan Web of Science untuk periode 2018 hingga 2025. Kata kunci yang digunakan meliputi *artificial intelligence*, *machine learning*, *deep learning*, *plastic surgery*, *hand surgery*, *microsurgery*, dan *convolutional neural networks*. Studi yang membahas aplikasi klinis, inovasi teknologi, dan pertimbangan etis dimasukkan dalam tinjauan ini. Berbeda dari sintesis literatur sebelumnya, tinjauan ini mengusulkan kerangka *Potential vs Provocation* yang berimbang untuk mengkaji manfaat dan tantangan AI secara sistematis sekaligus merumuskan strategi implementasi konkret dalam praktik klinis.

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Hasil: Teknologi AI, seperti *convolutional neural networks* dan *large language models*, telah dimanfaatkan untuk mengklasifikasikan lesi kulit, mengevaluasi aspek estetika, dan mengotomatiskan dokumentasi tindakan bedah.

Kesimpulan: Penerapan inovasi seperti AI generatif, realitas campuran (*mixed reality*), dan analitik prediktif dalam prosedur bedah mikro, simulasi yang disesuaikan dengan karakteristik pasien, serta rehabilitasi cerdas telah mendorong kemajuan yang signifikan dalam bidang ini. Meskipun memiliki potensi besar, sejumlah tantangan penting masih perlu diatasi, termasuk bias data, keterbatasan interpretabilitas model AI, serta permasalahan tanggung jawab hukum dan privasi. AI memiliki potensi besar untuk meningkatkan kemampuan serta mendukung pengambilan keputusan dokter bedah dalam bidang bedah plastik dan bedah tangan. Namun, integrasinya ke dalam praktik klinis memerlukan penerimaan dari tenaga profesional, pendidikan yang memadai, kolaborasi interdisipliner, serta pedoman etika untuk mengatasi berbagai tantangan dalam perkembangan teknologi ini.

Kata Kunci: Kecerdasan Buatan; Kecerdasan Buatan dalam Pembedahan; Bedah Plastik; Bedah Tangan; Pembelajaran Mesin; Pembelajaran Mendalam; Jaringan Saraf Konvolusional.

Conflicts of Interest Statement:

The author(s) listed in this manuscript declare the absence of any conflict of interest on the subject matter or materials discussed.

INTRODUCTION

The integration of Artificial intelligence (AI) into medicine is one of the most transformative developments of the 21st century. AI is the capability of machines, particularly computers, to perform tasks that mainly require human intelligence. John McCarthy first coined the term

“artificial intelligence” in 1955¹, and today AI systems are widely used across many medical fields to interpret complex datasets, detect patterns, and support clinical decision-making through algorithmic processes. Broadly, AI refers to machines that solve problems independently using computational models.

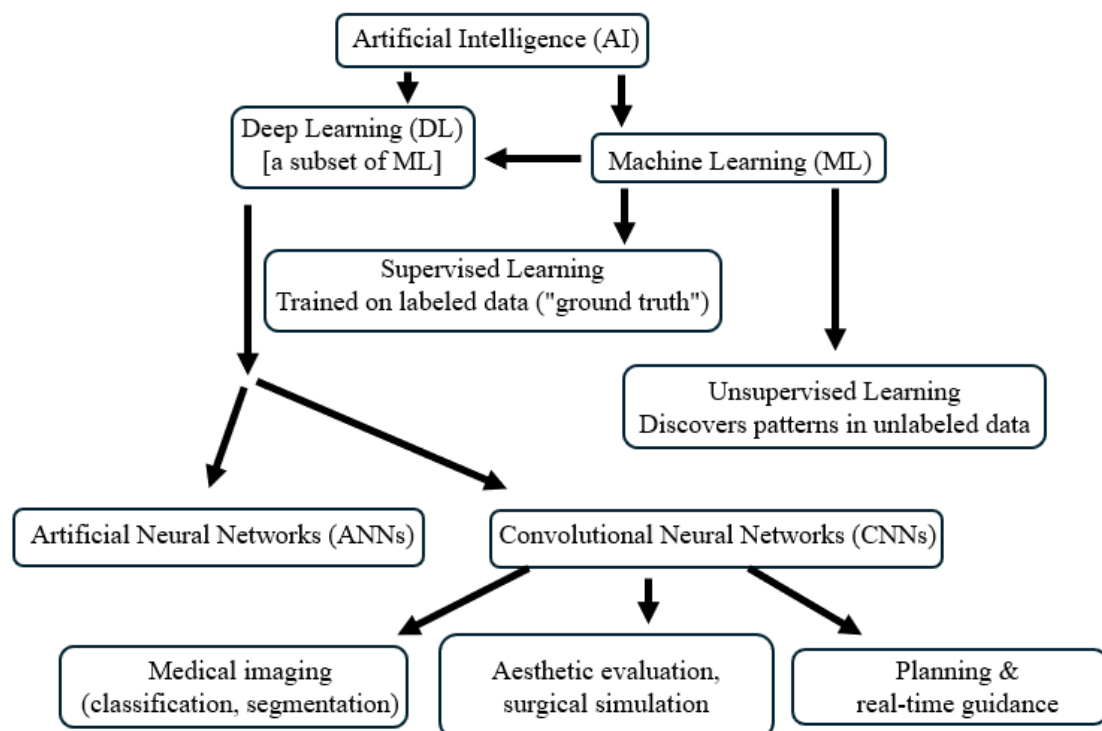


Figure 1. Flowchart of AI components focusing on ML and DL and their role in medical imaging and plastic surgery applications

AI is primarily divided into two main components: machine learning (ML) and deep learning (DL) (see Fig. 1). ML uses mathematical and statistical methods trained on data to help the computer improve its performance on given tasks. Training can be done using two methods.¹ Supervised learning, in which the computer learns from data where the correct answers (“ground truth”) are already known.² Unsupervised learning, where the system independently finds structures or patterns without being provided with the correct answers. DL, on the other hand, is a special type of ML which uses multilayered networks (artificial neural networks), inspired by the human brain². Among these, convolutional neural networks (CNNs) have gained particular importance in image analysis. They are highly effective for tasks requiring image classification and detail extraction. Currently, DL is state-of-the-art in medical imaging, with significant impact on plastic and hand surgery (PHS), including applications in aesthetic evaluation, lesion classification, surgical result simulation, and planning.^{3,4}

Conceptual Framework: The “Potential vs Provocation” Translational Pathway

To systematically evaluate the dual nature of AI in plastic and hand surgery, we propose a

structured analytical framework—the “Potential vs Provocation” Translational Pathway. This framework, adapted from established AI translation models, including the FDA’s 7-step credibility assessment framework for AI in healthcare (FDA, 2025), operationalises the evaluation of AI technologies across five critical stages:

1. AI Development → Algorithm design, model training on surgical datasets, and initial performance testing
2. Clinical Validation → Prospective multicenter trials, regulatory approval (FDA/EMA), and performance benchmarking against gold standards
3. Clinical Translation → Integration into surgical workflow, surgeon training, and patient-facing applications
4. Ethical & Regulatory Oversight → Data governance, bias mitigation, liability frameworks, and informed consent protocols
5. Outcome Monitoring & Feedback Loop → Continuous performance evaluation, adverse event reporting, and iterative model improvement

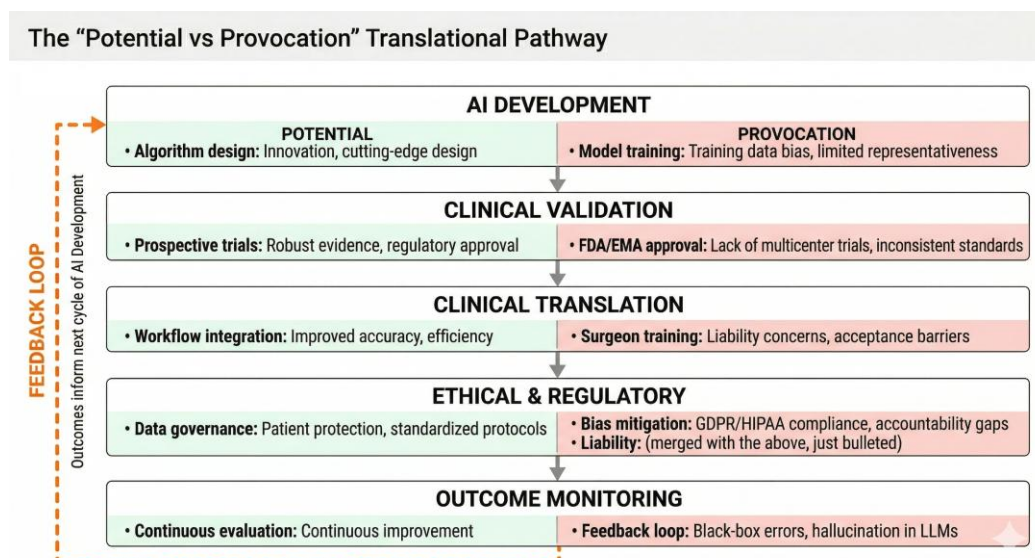


Figure 2. Conceptual Framework: The “Potential vs Provocation” Translational Pathway for AI in Plastic and Hand Surgery

This framework allows systematic assessment of both the Potential (benefits, improvements in accuracy, efficiency, patient outcomes) and Provocations (bias, liability, privacy concerns, algorithmic errors) at each stage. By mapping current applications and emerging innovations within this pathway, this review provides a structured approach to understanding where AI in PHS offers transformative promise and where significant challenges remain.

Current Applications in PHS

AI plays an important role in PHS, supporting key areas such as diagnostics, surgical planning, rehabilitation, and clinical process optimisation. In plastic surgery, AI applications are well established, particularly for image analysis and diagnosis. Specialised programs like CNNs can classify skin lesions, including melanoma and ulcer staging, with accuracy comparable to dermatologists, enabling faster, more accurate diagnosis and better records.^{5,6,7} Moreover, AI supports aesthetic evaluation using facial landmark detection tools that measure facial symmetry and proportion with high precision. This improves preoperative planning and patient consultation, but it also raises concerns about using AI in judging attractiveness.⁸ AI tools like generative adversarial networks (GANs) can help patients by showing realistic postoperative outcomes for procedures such as rhinoplasty and facial reshaping. In complex surgeries, AI helps with tasks like perforator flap planning, reducing intraoperative uncertainty and making surgeries safer and faster.⁹ Although AI integration in hand surgery is still growing, it shows promising features like image recognition algorithms which can help detect tendon and nerve injuries on ultrasound, X-ray, and MRI scans. AI-powered motion sensors and computer vision systems support rehabilitation after hand surgery by monitoring motor recovery and fine motor skills, enabling remote patient monitoring and feedback at home through mobile health applications. Finally, natural language processing (NLP) and large language models (LLMs) are being developed for surgical documentation and coding, helping reduce administrative work, although extensive testing and training are

needed to avoid errors, especially during live sessions.

Emerging Trends and Innovations in AI

The role of AI in PHS is quickly shifting from passive support to an active, collaborative partner in the operating room, forecasting a new era that includes not only diagnostic imaging but also basic surgical planning. This technology promises greater clinical precision, improved complexity management, and stronger patient engagement. As mentioned, GANs play an important role in aesthetic surgery because they can forecast surgical outcomes, improve the surgeon-patient relationship through shared decision-making, and enhance patient consultation. However, it can also raise medicolegal and ethical concerns when the actual surgical outcome does not match the AI-generated predictions.^{10,11} Moreover, AI is also used to predict postsurgical complications such as wound healing and infection risk. Using electronic medical records (EMR) data, imaging, and perioperative variables, the system can predict the likelihood of complications after breast or hand surgery, enabling precise risk counselling and helping surgeons plan their strategy more effectively.^{9,12} Robotic surgery platforms are rapidly developing through the integration of AI and are often used in clinical scenarios. These systems improve surgeons' accuracy in delicate tasks, such as free flap anastomosis and nerve coaptation, using features like tremor filtering and real-time feedback. As a result, they enhance the surgical team's potential by reducing fatigue and improving the precision of microsurgical procedures, especially in high-volume centres.^{13,14} Another emerging feature is the intraoperative mixed reality and augmented reality systems. These are integrated with AI-based imaging software, providing surgeons with overlays of vascular maps and critical anatomical structures during live procedures. Surgeons are even guided by resection margins shown directly within their surgical field. Recent peer-reviewed publications show that such technologies are already proving valuable in complex surgeries such as craniofacial reconstructions and composite tissue transplantation.^{10,15}

Risks, Limitations, and Ethical Challenges

Although AI holds high potential, it also poses significant limitations and ethical challenges that should be evaluated to mitigate the implications.¹⁶ One major concern is that these AI models have been trained on datasets predominantly reflecting Western facial features, specific demographic groups, or lighter skin tones. Henceforth, these models may perform poorly for patients coming from underrepresented backgrounds. These limitations may lead to diagnostic inaccuracy and impaired treatment outcomes. Because the training data may not cover the full range of patient anatomies or functional rehabilitation patterns, this may adversely affect hand surgery models.^{17,18} Few complex deep learning algorithms function as “black boxes”, making it difficult for clinicians to understand how decisions are made. This lack of transparency makes surgical decisions harder to interpret and, as a result, raises questions of responsibility when errors occur, including whether the developer, surgeon, or institution is ultimately responsible.^{11,18,19} Moreover, highly identifiable imaging data heightens privacy concerns. Many patients may not know their data could be used to train AI systems, complicating informed consent under strict protection laws such as GDPR and HIPAA.^{17,18}

Many AI models used in surgery still lack validation through prospective, multicenter clinical trials. Technical regulations from major authorities (FDA, EMA) are still in development, leaving surgeons to evaluate these tools' reliability and safety independently.^{15,20} AI-based evaluation of facial symmetry or attractiveness risks bringing biased beauty idols and creating unrealistic expectations. This highlights the need for surgeons to act as supportive counsellors and prioritise personalised, patient-centred care over algorithmic results.^{17,18}

Clinical Integration and Future Outlook

AI in PHS is advancing rapidly as more institutions and surgeons adopt it; its benefit depends on responsible, careful clinical integration, not just technological advancement. The future of AI lies in being an optimised assistant to surgeons, not a replacement, helping clinicians improve accuracy, safety, and personalised surgical care.^{18,21} To achieve this,

clinicians will need to learn, understand and apply this technology as an important professional skill. Clinicians must understand AI's limitations and biases and how to interpret its recommendations, and this should become part of surgical training. Recent studies show a growing call for workshops, updated curricula, new educational structures, and guidelines to prepare surgeons for AI use.^{10,22}

Concrete Implementation Strategies

To move from theoretical promises to practical implementation, this review proposes three concrete strategies:

1. **Federated Learning Protocols:** Establishing multicenter collaborative networks where AI models are trained locally on institutional datasets without sharing sensitive patient data. This approach addresses data governance concerns while enabling diverse, representative training across different populations and demographics.
2. **Prospective Multicenter Clinical Trials:** Moving beyond retrospective validation to prospective, multicenter trials with standardised protocols. Such trials would provide robust evidence for clinical efficacy, safety, and generalizability – currently a major gap in AI adoption.
3. **AI Competency Certification in Surgical Training:** Developing formal certification programs within surgical residency curricula that assess AI literacy, interpretability skills, and responsible deployment. This would ensure surgeons can critically evaluate AI outputs and integrate them appropriately into clinical decision-making.

Successfully integrating AI will require multidisciplinary collaboration, bringing together not only clinicians and ethicists but also computer scientists and regulators. For safe use, setting standards and ethically adopting AI in PHS requires partnership between the public and private sectors, academic-industry projects, and collaboration across surgical specialities (10). Professional societies such as the American Society of Plastic Surgeons (ASPS) and the International Federation of Societies for Surgery of the Hand (IFSSH) are already calling for comprehensive guidelines. These include minimum requirements for clinical validation,

reliable patient consent processes, and standards for data quality and model transparency.²³ As shown in Figure 3, integrating AI into PHS is complex and involves many decision points and technical bottlenecks. Success will depend on

actively managing both ethical and technical challenges, continuously assessing real-world impact, and taking a flexible, evidence-based approach to implementation.

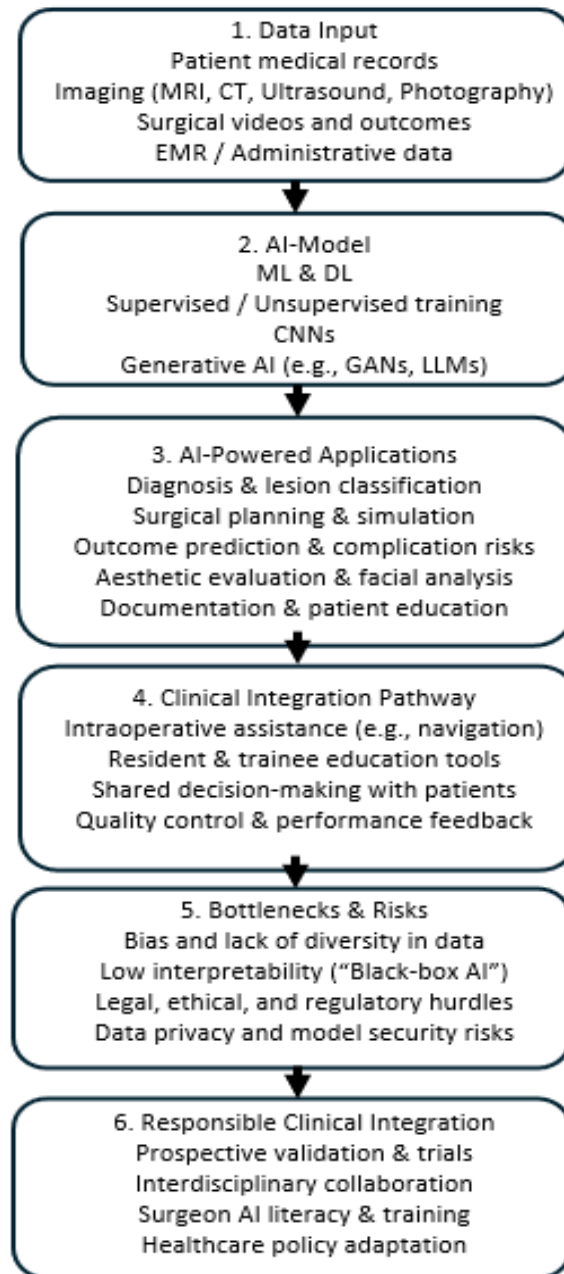


Figure 3. Overview of AI integration in PHS, illustrating the process from data collection to algorithm development and clinical application.

POTENTIAL OR PROVOCATION –
WHAT’S THE VERDICT?

AI has already demonstrated significant benefits in PHS. It supports accurate diagnosis, enables personalised and efficient surgical planning, and improves patient communication. However, as illustrated in Table 1, there are still challenges that remain and need to be addressed (see Table 1).

How This Review Differs from Existing
Syntheses

While several narrative and systematic reviews have explored AI in plastic surgery, this

review offers several distinct contributions: (1) We adopt the structured “Potential vs Provocation” analytical framework that explicitly maps both benefits and challenges across the translational pathway; (2) We focus specifically on plastic and hand surgery combined, whereas many existing reviews focus primarily on plastic/reconstructive surgery alone; (3) We propose concrete implementation strategies (federated learning, prospective trials, competency certification) that bridge the gap between current evidence and clinical practice; and (4) We integrate emerging technologies including generative AI, mixed reality, and LLMs within a unified translational model.

Table 1. Opportunities and Challenges of AI in Plastic and Hand Surgery

Potential	Provocations	References
Image-based diagnosis and classification of skin lesions, burns, facial asymmetry, and aesthetic indicators using CNNs with dermatologist-level accuracy	Data bias and underrepresentation of racial, gender, and age groups may lead to inaccurate assessments or aesthetic inappropriateness	Esteva et al., 2017; Singh et al., 2024
Automated preoperative planning and 3D surgical simulation, including flap viability prediction and craniofacial morphometry, improving accuracy and reducing operative time	Lack of interpretability (black-box issue) in AI decision-making limits trust and clinical adoption, especially in high-stakes, high-precision procedures	Novotny et al., 2024; Kapila et al., 2025
Predictive models for surgical complications, operative risk, and personalized outcomes; support informed consent and individualized patient management	Accountability and liability in case of AI-influenced adverse events remain unresolved across jurisdictions	Kooi et al., 2024; Mansoor & Ibrahim, 2025
Standardized aesthetic evaluation tools using symmetry scoring, facial analysis, and attractiveness indices; helpful in aesthetic consultations	Subjectivity of aesthetic standards and sociocultural variation pose risks of algorithmic overgeneralization	Dhawan et al., 2024; Singh et al., 2024
Generative AI and LLMs assist in documentation,	Hallucinations and content accuracy of AI-generated text may lead to	Rao et al., 2024; Hogue et al., 2025

Potential	Provocations	References
surgical reporting, and patient education through natural language generation	misuse or misinformation if not properly supervised	
Enhanced resident and student education through interactive simulations, AI-based curriculum personalization, and virtual case scenarios	Digital divide and training disparities among institutions may lead to unequal access and AI literacy among surgeons	Hogue et al., 2025; Singh et al., 2024
Federated learning and cross-institutional model training allow for multicenter development of robust, privacy-preserving AI tools	Data governance issues including consent, anonymization, and cross-border model sharing require strong legal frameworks	Yin et al., 2021; Mansoor & Ibrahim, 2025

Current evidence suggests that AI should be considered a partner in patient care. Its potential is undeniable, but to move from a source of provocation to a trusted partner, it still requires responsible development. The goal is to improve patient outcomes while preserving the human aspects of surgical practice.

CONCLUSION

AI is no longer a concept in PHS but a present reality. The future lies in collaboration between humans and machines, innovation and ethics, and surgeons and software, for the best patient-centred care. Whether AI turns into a source of transformation or conflict depends on how it is developed and integrated. Finally, AI should be seen as a powerful extension, not a replacement.

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Not applicable

DECLARATION OF GENERATIVE AI USE

The authors declare that no generative artificial intelligence (AI) tools were used in the preparation, writing, or revision of this manuscript.

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