Artificial Intelligence in plastic surgery: What is it? Where are we now? What is on the horizon?

DC Murphy^{1,2,5}, DB Saleh^{1,4}

¹Newcastle upon Tyne Hospitals NHS Foundation Trust, Newcastle upon Tyne, UK

²Institute of Genetic Medicine, Newcastle University, Newcastle Upon Tyne, UK

³Northumbria Healthcare NHS Foundation Trust, Tyne and Wear, UK

⁴PA Southside Clinical School, University of Queensland, Brisbane, Queensland, Australia

ABSTRACT

INTRODUCTION An increasing quantity of data is required to guide precision medicine and advance future healthcare practices, but current analytical methods often become overwhelmed. Artificial intelligence (AI) provides a promising solution. Plastic surgery is an innovative surgical specialty expected to implement AI into current and future practices. It is important for all plastic surgeons to understand how AI may affect current and future practice, and to recognise its potential limitations.

METHODS Peer-reviewed published literature and online content were comprehensively reviewed. We report current applications of AI in plastic surgery and possible future applications based on published literature and continuing scientific studies, and detail its potential limitations and ethical considerations.

FINDINGS Current machine learning models using convolutional neural networks can evaluate breast mammography and differentiate benign and malignant tumours as accurately as specialist doctors, and motion sensor surgical instruments can collate real-time data to advise intraoperative technical adjustments. Centralised big data portals are expected to collate large datasets to accelerate understanding of disease pathogenesis and best practices.

Information obtained using computer vision could guide intraoperative surgical decisions in unprecedented detail and semi-autonomous surgical systems guided by AI algorithms may enable improved surgical outcomes in low- and middle-income countries. Surgeons must collaborate with computer scientists to ensure that AI algorithms inform clinically relevant health objectives and are interpretable. Ethical concerns such as systematic biases causing non-representative conclusions for under-represented patient groups, patient confidentiality and the limitations of AI based on the quality of data input suggests that AI will accompany the plastic surgeon, rather than replace them.

KEYWORDS

Artificial intelligence – Plastic surgery – Big data – Machine learning – Technology

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CORRESPONDENCE TO

Declan Murphy, E: murphy.declan.1994@gmail.com

Introduction

Artificial intelligence (AI) – the development of computer systems which mimic human cognitive functions – is a powerful tool increasingly used across many industries. It has received investments of multiple £billions over recent decades, is predicted to add £630 billion to the UK's economy by 2035 and shows promise as the next frontier in healthcare.¹

The most encouraging application of AI in healthcare is machine learning. Machine learning allows a computer system to 'learn' without requiring specific programming.² This usually involves 'deep learning', where algorithms are based on biological neural networks operating at multiple levels which process raw data to derive output functions.

Progressively more information is used to guide healthcare decisions and implement precision medicine, but current

analytical methods are overwhelmed by the quantity of data. As the workload of UK primary and secondary care services increases, innovative ideas must be developed to match demand and enhance health outcomes. Moreover, it is expected that AI and machine learning will eventually have a high cost-benefit ratio, which is essential due to increasingly tight health economies worldwide.

Regarded as an innovative surgical specialty, plastic surgery is continually adapting. With the AI era upon us, it is important for plastic surgeons to understand how AI can advance the specialty, but also to recognise its limitations and potential ethical considerations.

Methods

Peer-reviewed published scientific literature and continuing scientific studies were searched using relevant terms in

the following databases: MEDLINE and EMBASE (Ovid), the Cochrane Central Register of Controlled Trials and the Cumulative Index of Nursing and Allied Health Literature. All levels of evidence were considered. Only articles published in the English language were reviewed. Online content published by journalistic media outlets and digital content were reviewed to determine current activities not published in peer-reviewed scientific journals.

We report current applications of AI in plastic surgery and possible future applications based on published literature and continuing scientific studies, and detail its potential limitations and ethical considerations.

Findings

Where are we now?

The partnership between AI and plastic surgery is in its infancy with most efforts at the 'proof of concept' stage, but developments are rapid and promising.

Medical imaging is leading the charge, with roughly 750 academic articles detailing AI and medical imaging published in 2016–2017.² Machine learning models using convolutional neural networks have been developed which analyse breast mammography as accurately as specialist radiologists.^{3,4} Current screening causes overdiagnosis, morbidity and time inefficiencies,⁵ suggesting that AI could improve the accuracy and efficiency of breast screening and mitigate human error.

AI can also aid the diagnosis of dermatological disease. A convolutional neural network system trained using pattern recognition from 129,450 images can differentiate benign and malignant skin cancers to equivalent or greater success than certified dermatologists.^{6,7} A similar network detected breast cancer metastases from sentinel lymph node biopsy specimens which when combined with human pathologists' opinions, reduced human error by 85%.⁸ By improving our ability to detect specific pathologies we can employ limited resources to treat patients with confirmed disease.

Cosmetic plastic surgery has also begun to use AI. A semi-supervised machine learning model was trained using 165 images of females which had been graded by human referees. The authors report that the model was successful in objectively classifying attractiveness.⁹ Similarly, AI can successfully predict an individual's age based on their facial features by identifying characteristics that contribute to their aged appearance.¹⁰ This may then inform the most appropriate cosmetic procedures to successfully portray of reduction in age. A cosmetic surgery group in South Korea has taken this one step further and begun using motion sensor surgical instruments to collect data in real-time and, using an AI programme, can advise the operating surgeon on adjustments required to achieve an optimal outcome.¹¹

AI has also been successful at integrating cross-sectional imaging during complex facial tumour resections and head and neck reconstructions. The surgeon wears a headset which allows them to overlay three-dimensional radiological

images onto the patient so the pathology can be viewed from all angles. The surgeon can then decide which surgical approach is most appropriate to achieve maximal tumour resection and minimise complications.¹²

What is on the horizon?

The application of AI to facilitate the interpretation of radiological imaging will likely be its first route into everyday healthcare because current practice is time consuming and depends on the clinicians' competency.¹³ Several studies suggest that AI algorithms can analyse plain radiographs of the wrist to identify fractures as effectively as specialists.^{14,15} Similar methods could be used to improve the accuracy and efficiency of detecting closed fractures of the hands and digits, which form a significant proportion of a plastic surgeon's workload and if missed can have profound implications for affected patients. Automated image analysis will allow AI models to simultaneously interpret multiple images with increasing accuracy and reduced interrater variability.

Similarly, computer vision – developing machines that understand visual media – has rapidly advanced so machines now have capabilities in object and scene recognition equivalent to humans.¹⁶ One minute of high-definition surgical video contains 25 times more data than high-resolution computed tomography. Such rich data interpreted using AI-based image analysis could provide unprecedented detail to inform surgical decisions and techniques.¹⁷

Big data are analysed and organised to reveal patterns and associations using deep learning algorithms. Centralised big data portals could collate information submitted by plastic surgeons across the world to create large databases for interpretation using AI algorithms. These portals could accelerate our understanding of disease pathogenesis and genotypic risks,¹⁸ and could deduce best-practice protocols for aspects of plastic surgery that currently lack robust evidence, such as defining optimal margins for skin cancer excisions and predicting failures following oncological reconstructions.

The individualisation of evidence-based medicine – precision medicine – is imminent. AI and the capture of big data will accelerate the evolution of precision medicine. Given the variability in data acquisition across healthcare platforms, machine learning is key to assimilate historical data and project a benefit to both patients and healthcare providers. Output functions may complement the plastic surgeon's cognition to influence clinical decisions, predict the success of interventions and calculate the risk of postoperative complications.¹⁹

Current scientific evidence for the development of AI systems that can perform or complement surgery is limited and interventions remain in their infancy. However, interest in this field continues to grow. An AI robotic surgical system acting as a navigational aid for surgeons while operating has been shown to aid intraoperative decisions.²⁰ A camera records the operation, anatomical structures are identified, the stage of the procedure is determined using an AI system, and the surgical team are advised on how best to proceed.²⁰ An autonomous robotic surgical system which

uses supervised AI to perform basic surgical procedures without requiring direct involvement of a surgeon has also been developed.²¹ When performing a number of very basic surgical skills on porcine tissues, outcomes were better than expert surgeons and robot assisted surgery, showing the dexterity and cognition required for basic surgical skills can be programmed into an AI model.²¹

Three-dimensional planning, anatomical localisation and surgical navigation could be married to assist the surgeon in real-time decision making perioperatively. Current systems are very basic and far from being able to perform complex surgical procedures. However, in the future, they may be able to perform more complex tasks. There is potential for advances to improve the efficiency and effectiveness of surgery, reduce the length of surgery and time a patient spends anaesthetised, and decrease the time required for a patient to recover from an operation. This technology also provides exciting opportunities to improve surgical outcomes in low-and-middle income countries where the number of surgeons and their expertise can be suboptimal and resources are scarce.²⁰ The armed forces may also adopt autonomous AI surgical machines to manage injuries occurring far from a medical centre. Like other specialties, the cost-benefit analysis of robot assisted surgery in plastic surgery is unclear. It should be determined before widely adopted in a national healthcare setting.

AI may allow patients to be managed at home more readily, which would provide financial savings for the healthcare system and limit unnecessary nuisance for patients. Although current evidence is sparse and some applications remain controversial, telecommunication and AI may assist plastic surgeons in monitoring skin wound homeostasis, wound healing progress and physiological parameters in the future. For example, AI may predict the healing time of burns when assessed using reflectance spectrophotometry,²² and may help to inform surgeons of the most appropriate management for patients. Similarly, following an injury, patient photographs could be processed to determine wound's size, colour and tissue oximetry, which then would inform patients on how best to self-manage their wound in the community using machine learning led technology in an interface such as a smartphone.¹⁸

Limitations and ethical considerations

To ensure that AI is widely accessible and appropriately applied in the healthcare setting, it must be clinicians who decide which future healthcare objectives are important. They must then collaborate closely with computer scientists to guarantee that AI algorithms are clinically relevant and interpretable by healthcare professionals.²⁵ Data must be collected using robust methods and increasingly digitalised, and must be preprocessed into a clean, consistent and usable format for AI machines. Frameworks detailing its cost effectiveness, safety and security must be extensive. Data provided for companies to train algorithms must be secure and ensure confidentiality.²⁵ If industries use data from healthcare systems to develop algorithms, it is

important that high ethical standards are maintained and that healthcare systems can reap their long-term benefits. Algorithms must be validated and evidence supporting AI's safety and effectiveness must be comprehensive and accessible. With patient data being modelled to provide a superior healthcare experience, the standard expected from automated systems must be at least equivalent to those held of clinicians.

It is important to recognise the limitations of AI. The outputs gained using AI depend on accurate and unbiased data input. If biased, the patterns and predictions are potentially unreliable. For example, racial minorities and females are underrepresented in clinical studies and trials. Systematic biases will therefore cause nonrepresentative predictions for these patient groups.²⁴ If they are solely reliant on AI making clinician decisions using unsuitable data, patients may undergo procedures without providing fully informed consent, which risks compromising patient autonomy.²⁵

Although there is some concern that the growth of AI may result in job losses for a number of healthcare professionals, AI does not seem to be able to replicate doctors' decisions made by their 'gut feelings', which are developed from clinical experience. Similarly, it is argued that the 'human element' of healthcare is essential and cannot be removed.²⁶ Even though robotic systems have been shown to perform basic surgical skills to a high standard,^{20,21} thousands of stages must be completed for a single operation. For autonomous robotic surgery to achieve such complexity, much more work is required.²⁶ Hence, AI is likely to perform as a useful tool to assist, but not replace, doctors.²⁷

The introduction of AI into a plastic surgeon's clinical practice raises multiple ethical concerns. AI systems claiming to provide an objective classification of attractiveness raises many ethical dilemmas.^{9,28} There is the possibility for discrimination based upon ethnicity and gender. The 2013 Miss Korea pageant reached international news because of the similarity in their contestants' facial features following cosmetic surgery.²⁹ If used in isolation to inform cosmetic surgical interventions, AI may be perceived to propagate racial divide and de-diversify the human image.^{30,31}

Software apps which use AI such as Snapchat have created a new perception of beauty by making photo-editing technology readily available to the public.³² Users can alter their appearance into an unattainable aesthetic. Increasingly people request cosmetic surgery to emulate the filtered versions of themselves,³³ which has been linked to deteriorating mental health and body dysmorphic disorder.³⁴ It is essential for cosmetic surgeons to consider the mental health of their patients when deciding whether cosmetic surgery is appropriate.³⁵

Conclusion

The partnership between AI and plastic surgery is in its infancy but developments are rapid and promising. Medical imaging is leading the charge and shows potential

in improving the accuracy and efficiency of screening programmes and mitigating human error. In the future, AI shows potential in informing reconstructive and aesthetic surgical practices. It is important for surgeons to collaborate with computer scientists so outcomes are directed towards improving patient care and to understand important limitations and ethical concerns relating to implementing AI into everyday surgical practices.

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