Review

Applications of Artificial Intelligence in Wound Care

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Abstract

Wound care is a large and growing industry in the United States. It is estimated that 2.5% of the U.S. population suffers from chronic wounds. While wound care is a multidisciplinary service, plastic surgeons are considered experts in wound care because they can provide definitive treatment. Artificial intelligence (AI) has potential to improve wound care efficiency and outcomes. AI-powered technologies can enhance wound care by aiding in: wound assessment, individualized treatment plans, remote patient monitoring, risk stratification and predictive analytics, and bioengineering. These applications will improve patient outcomes, reduce costs, and improve clinical workflows. While this potential has been demonstrated, these applications have not yet achieved clinical utility. It is important for plastic surgeons to collaborate with software engineers to guide development of AI-infused wound care applications.

Keywords: Ulcer, foundation model, computer vision, wound assessment, remote patient monitoring, bioengineering

INTRODUCTION

Wound healing is a well-studied process of inflammation, proliferation, and remodeling. There are several points at which this process can impair. Fortunately, there are ways to intervene conservatively and operatively to improve wound healing. Wound care is a foundational concept in plastic surgery. Our discipline has unique insight into wound care because of our expertise in tissue repair, experience in managing complex wounds, variety of reconstructive options, and attention to both functional and aesthetic outcomes.

Approximately 2.5% of the total U.S. population suffers from chronic wounds [1]. With a continuously aging population and increased chronic disease burden prevalence of diabetes, wound care is a key industry in the U.S. health care system. One estimate suggests that total Medicare spending for all types of wounds is between $28.1 to $96.8 billion annually [1].

Artificial Intelligence (AI) offers promise to enhance the accuracy, efficiency, and outcomes of wound care. The field has experienced a renaissance in recent years with the advent of foundation models and generative transformer networks [2]. AI has become multimodal, able to process text, visual, audio, and other types of information, which is analogous to how clinicians think. The promise of AI is that it can replicate aspects of clinical intelligence, but do so at greater scale, speed, replicability, and on-demand. This manuscript explores the various ways in which AI is impacting wound care, including wound assessment, individualized treatment plans, remote patient monitoring, risk stratification and predictive analytics, and bioengineered technologies.

WOUND ASSESSMENT

One of the most significant contributions of AI to wound care is its ability to facilitate wound assessment. Regular photos are a routine practice of wound care clinics. Important visual cues include wound site, area, depth, types of edges, tissue classification, type of exudate, and signs of infection [3]. Until now, insight into clinical photos has relied on plastic surgeons and other wound care specialists to assess the wounds. This process can be time and resource-consuming, and is subject to interpreter error.

Generative vision models will be able to analyze photos of wounds and 1) augment them for human interpretation or 2) interpret them independently. In the first case, these models will be able to process photos and improve their lighting, contrast, saturation, and focus to help clinicians assess a wound. They may also be able to highlight and overlay areas of interest in the wound bed. Goyal et al. have attempted a similar model for augmenting cutaneous lesions [4]. These models may also incorporate data from infrared thermography and spectroscopy and overlay parameters like temperature, oxygenation, and blood flow.

In the latter case, AI algorithms may be able to interpret the wounds themselves to measure progress of healing, triage for warning signs of ischemia/infection which require more intervention, and help identify which wounds may be amenable to definitive reconstruction [5]. There are commercial technologies, based on the previous generation of vision models, which purport to do some of this already. However, clinical studies have shown they poorly assess wounds, apart from calculating its two-dimensional size [6,7]. Newer generations models based on updated AI architectures should more accurately determine the extent of granulation tissue, eschar, ischemic tissue, necrotic tissue, and infection. Reifs et al. demonstrated this promise using the Resnet50 foundation vision model for wound assessment [8]. Further, Bansal and Vidyarthi created a deep neural network for diabetic foot ulcer assessment specifically, underscoring the potential of vision models for wound assessment [9]. Such tools would facilitate timely diagnosis and comprehensive monitoring of wounds, which is critical for preventing complications and ensuring effective treatment.

INDIVIDUALIZED TREATMENT

AI is also transforming wound care by enabling the development of personalized treatment plans. By analyzing patient data, including medical history, genetics, social factors, and wound characteristics, AI can predict who is going to heal a wound and who is going to respond to a treatment. AI can tailor treatment regimens, recommending specific types of dressings, medications, or interventions. In doing so, AI will replicate the tacit knowledge of experienced wound care clinicians and democratize this information to more patients. One interesting application is deciding between limb salvage and amputation for lower extremity wounds. It remains an open question whether limb salvage is more beneficial than amputation in many patients [10]. With the appropriate data and inputs, AI will have a role in predicting outcomes of either treatment, giving patients and clinicians more information to make a decision.

Moreover, AI can assist in optimizing the timing and sequence of treatments. For example, it can predict when a wound is likely to be ready for a particular intervention, such as debridement or grafting, thus improving the timing of these procedures and enhancing their effectiveness. Personalized treatment plans supported by AI can lead to faster healing, reduced complications, and better patient outcomes.

REMOTE PATIENT MONITORING

Remote Patient Monitoring (RPM) is one of the tantalizing promises of AI. RPM is when healthcare providers monitor patients outside of traditional care settings using digital medical devices. This is particularly impactful in wound care, as it empowers patients with chronic wounds, which need regular care, or those living in remote areas. Indeed, studies have shown that these populations can achieve good care with RPM technologies [11]. AI-powered mobile applications and devices can capture and assess wound images, as previously discussed, and alert healthcare providers to any signs of complications. These tools allow patients to receive continuous, on-demand care without frequent in-person visits, reducing the burden on both patients and healthcare systems.

RPM also empowers patients to take a more active role in their own care. Patients can use AI-driven apps to monitor their wounds, receive personalized care instructions, and even engage in virtual consultations with healthcare providers. This approach not only enhances patient engagement and adherence to treatment but also enables early detection and intervention, which is crucial for preventing complications.

PREDICTIVE ANALYTICS AND RISK STRATIFICATION

Another application of AI in wound care is its ability to perform predictive analytics and risk stratification. By analyzing large datasets from electronic health records (EHRs), AI can identify patterns and correlations that may not be immediately apparent to clinicians. For example, AI can predict which patients are at higher risk of developing chronic wounds or experiencing delayed healing. A study from Denmark used machine learning on their national registry to identify diabetics patient who are most at-risk for diabetic foot ulcers, thereby facilitating earlier detection [12]. Their work emphasizes the value of advanced computing methods as well as of large databases that include clinical and social factors.

AI-powered predictive models can also assist in identifying patients who are at risk of wound complications, such as infections or amputations, allowing for early intervention and more proactive care. This is also valuable in managing diabetic foot ulcers, where timely detection and intervention are critical to preventing severe outcomes. Risk stratification supported by AI can help healthcare providers prioritize resources and tailor interventions to the needs of individual patients, ultimately improving the quality of care and reducing healthcare costs.

BIOENGINEERED TECHNOLOGIES

AI is also playing a role in the development of advanced wound care technologies, such as smart dressings and bioengineered tissues. Smart dressings, which are equipped with sensors and AI algorithms, can monitor wound conditions in real time, such as moisture levels, pH, and bacterial presence. Kalasin et al. developed the FLEX-AI sensor integrated into a bandage which measured a wound's pH-dependent voltage, which was correlated with stages of healing [13]. These dressings can provide continuous feedback to healthcare providers while preventing the need for visual wound assessment, enabling timely interventions and reducing the risk of infection or other complications.

Furthermore, AI is being used in the design and optimization of "bioprinted" tissues, which are increasingly being used in wound care, particularly for chronic or non-healing wounds [14]. By analyzing data from clinical trials and patient outcomes, AI can help optimize the composition and structure of these tissues to improve their effectiveness and integration with the patient's body.

CHALLENGES AND ETHICAL CONSIDERATIONS

Despite the many benefits of AI in wound care, there are also challenges and ethical considerations that must be addressed.

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Perhaps the largest obstacle is ensuring AI technologies are geared for clinical applications. Software engineers and technologists need clinical context to answer the right questions and create patient-centered applications. That is why it is critical for wound care clinicians and plastic surgeons, specifically, to be involved in AI development.

The next major challenge is finding the appropriate data, in terms of both quality and availability. AI algorithms rely on large datasets to train and validate their models, but in wound care, data can be scarce, inconsistent, or biased. Fortunately many wound care clinics are technologically-enabled and high-touch, ensuring a large repository of data for analysis. The authors propose wound care clinics adopt data quality management guidelines if they are to be involved in this work. Further, using the data must be in compliance with existing patient privacy regulations.

Another challenge is the approaching to AI model building. New large foundation models are created every week, each having their own unique features. Selecting the appropriate model that complements your data and training method is crucial. This is why it is important for clinicians to collaborate with computer scientists. Scientifically, it is also important to rigorously develop, test, and validate AI technologies to ensure clinical utility.

There are also ethical considerations when using patient data. Issues such as patient privacy, data security, and informed consent must be carefully managed to ensure that AI tools are used responsibly and transparently. Additionally, the potential for AI to exacerbate existing health disparities must be addressed. For instance, if AI algorithms are trained on datasets that are not representative of diverse populations, they may perform poorly in certain patient groups, leading to unequal care.

FUTURE DIRECTIONS

The future of AI in wound care is promising. The key will be aligning technological development with clinical applications and the right data. The above applications need further development to achieve clinical utility, and the authors believe plastic surgeons should be involved in this development.

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Other future directions include the integration of AI with other emerging technologies, such as robotics and 3D printing, to create more sophisticated wound care solutions. For example, Wang et al. mention several 3D printed wound dressings and the potential for AI to augment that process [14].

Another exciting direction is the use of AI in wound care research and education. AI can analyze vast amounts of clinical data to identify new insights and best practices, which can then be used to inform guidelines and training programs for healthcare providers. By continuously learning from real-world data, AI has the potential to accelerate the advancement of wound care knowledge and improve the quality of care delivered to patients.

CONCLUSION

AI is making a profound impact on wound care, offering innovative solutions that enhance the accuracy, efficiency, and outcomes of wound management. These include wound assessment, individualized treatment plans, remote patient monitoring, risk stratification and predictive analytics, and bioengineering. While challenges and ethical considerations remain, the potential benefits of AI in wound care are immense. As wound care experts, plastic surgeons must guide development of AI to achieve clinical utility in wound care.

DECLARATIONS

Authors' contributions

Made substantial contributions to conception and design of the review: Talwar A, Shen C, Shin JH

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