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Enhancing dermatology: the current landscape and future prospects of augmented and virtual reality technologies

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ABSTRACT

This article aims to provide a comprehensive assessment of the current status and future potential of augmented and virtual reality (AR/VR) technologies in the field of dermatology. We conducted an extensive review of the existing literature, encompassing studies and case reports related to the utilization of AR/VR in dermatology. This analysis encompassed diverse applications, including medical education, diagnostics, and dermatologic surgery, to offer a holistic view of their current implementations. Despite the significant interest generated within the dermatological community, the integration of AR/VR technologies in dermatology has not advanced at the same pace as in surgery. Our review underscores the current applications of AR/VR, which encompass improving medical education through interactive simulations, enhancing diagnostic precision, and facilitating complex dermatologic surgical procedures. Additionally, we address the challenges and constraints associated with their practical implementation in clinical settings. Augmented and virtual reality technologies possess immense potential to transform the landscape of dermatology. While their adoption has been gradual, these technologies have showcased their ability to enhance medical education, diagnostics, and surgical interventions. The future holds promising prospects for further developments in AR/VR applications, positioning them as valuable assets for dermatologists and aspiring dermatologists alike. However, it is imperative to address issues related to accessibility, cost-effectiveness, and patient acceptance to foster their widespread integration into clinical practice.

Keywords: Augmented reality, virtual reality, dermatology, digital dermatology, medical education, diagnostics

INTRODUCTION

Augmented reality (AR) and virtual reality (VR) are integral components of virtual environments (VE) that provide users with immersive experiences.[1] While VR fully immerses users in artificial settings, AR overlays virtual elements onto the real world, seamlessly merging the virtual and the physical. Over the past few decades, the utilization of AR/VR applications has surged significantly. These technologies have found substantial application in various medical fields, notably in plastic surgery.[2] Despite several compelling reasons, the adoption of AR/VR in the field of dermatology has remained relatively limited. First and foremost, the skin, as an easily accessible organ, offers an ideal canvas for AR applications. Secondly, dermatology heavily relies on visualization, making the potential impact of AR/VR profound. Lastly, the dermatological sector represents a multibillion-dollar industry in the United States alone, offering substantial economic opportunities.[3-5] The primary applications of AR/VR in dermatology can be broadly categorized into three main areas: education,[6-8] dermatologic surgery,[9,10] and diagnostics.[11] In a pioneering work published in the early 2000s, Gladstone and colleagues envisioned the twenty-first-century applications of VR in dermatology.[10] They envisioned a future where dermatologists could train using patient-specific skin and skeletal data just before performing complex Mohs surgery. Students would not only visualize lesions in 3D but also physically interact with them using haptic feedback systems. Such tools held the potential to revolutionize telemedicine. Moreover, VR technology would enable practitioners to explore lesions from various angles, thereby enhancing diagnostic accuracy.[5,8]

In this article, we review the current status of AR and VR in dermatology and provide insights into their potential future developments.

METHODS

All procedures were carried out in accordance with the ethical rules and the principles (of the Declaration of Helsinki).

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A rigorous literature review was undertaken, drawing from the Web of Science Core Collection and the MEDLINE® databases. Our research encompassed descriptors such as "virtual environments," "virtual reality," "augmented reality," "dermatology," and "dermatological science." To narrow our focus on the application of AR and VR in dermatology, the term "skin" was deliberately excluded. The parameters of our search were titles, abstracts, and author-specific keywords, without any date, document type, or other limitations. However, we concentrated only on English publications. This method resulted in a compilation of 64 papers, of which 35 were recent (within the past 5 years), and 51 were categorically aligned with "Dermatology." Each article was individually assessed, with selection based on relevance inferred from their titles and summaries.

RESULTS

Education

Improving dermatological education presents a significant challenge due to the difficulty of retaining visual memory without continuous exposure. Primary care physicians often exhibit suboptimal diagnostic accuracy for common skin conditions.[10,12] The integration of 3D silicon-made phantoms has shown substantial promise in enhancing diagnostic skills and knowledge retention compared to traditional 2D images.[13] Therefore, similar benefits are expected with the incorporation of AR.8 However, recent studies have produced unexpected results, with minor variations in knowledge acquisition and slightly improved knowledge retention among groups utilizing AR-based tools compared to textbooks.[7] This outcome could potentially be enhanced by integrating AR with haptic feedback, a common feature in surgical training tools.

A promising approach to training the next generation of medical professionals involves creating realistic 3D models that showcase skin diseases and abnormalities. These models would feature high-resolution clinical textures applied to newly generated 3D models with anatomically accurate proportions. They could be accessible on smartphones, tablets, or VR headsets, allowing for the adjustment of environmental conditions (e.g., lighting) to enhance realism. Additionally, synthetic clinical images could enhance these models by addressing the challenges of data scarcity and the lack of training on rare dermatological conditions and particular Fitzpatrick skin types. To illustrate, the incidence of melanoma is comparatively low among Black populations, which is significant because it contributes to their lower survival rates when contrasted with non-Hispanic White populations in the US. This gap underscores the necessity for diverse training data to improve diagnostic accuracy and treatment outcomes across all skin types.[14] Such disparities have garnered significant media attention.[15] The DermGAN project aims to enhance diversity in clinical skin images by generating images that exhibit the characteristics of specific skin conditions, locations, and underlying skin colors, which can then be transformed into 3D visualizations.[16]

In addition to healthcare professionals, some studies have explored AR/VR as educational tools for patients or the general public to raise awareness about skin disease prevention. For instance, Elke Hacker's group in Australia developed a virtual reality (VR) game that incorporates preventive skin cancer messages for youth and young adults.[17] This initiative was prompted by the persistence of high rates of sunburn among young populations despite successful public health campaigns in the 1980s. [15]

Another innovative application of VR in dermatology is the creation of the "Virtual Derm" VR app, which immerses students in a virtual dermatology practice.[18] This app is compatible with standard Android smartphones, ensuring accessibility for most students. It offers a unique learning experience, with students having the opportunity to solve 100 patient vignettes. [16]

Dermatologic Surgery

Dermatologic surgery, a specialized field within dermatology, focuses on surgical procedures aimed at repairing or enhancing the function and appearance of the skin.[19] While plastic surgery has significantly harnessed the potential of AR/VR technology,[20] its application in dermatologic surgery remains relatively limited. Apart from surgical training applications[21] (discussed in the preceding section on education), AR and VR have been employed in Mohs surgery to alleviate patient anxiety[22] and as surgical assistance tools.[23]

In the context of patient care, VR has been employed to mitigate pre- and intraoperative anxiety. Generic VR sequences, capable of reducing anxiety in various scenarios, have been used effectively in surgical contexts.[22] VR also holds promise as a patient education tool, offering patients a clearer understanding of surgical procedures, including complex interventions such as flap-based surgical defect reconstructions. However, detailed investigations into the impact of providing extensive surgical procedure information on patient anxiety are warranted.[22]

For medical professionals, VR serves as a valuable training tool across various surgical specialties, including dermatologic surgery. The realistic visual representation offered by VR, coupled with tactile sensations (haptic feedback), facilitates the training of dermatologic surgical procedures, mirroring the training methods employed in other surgical domains, notably plastic surgery. AR has demonstrated successful application in improving communication between surgeons and pathologists in Mohs surgery cases, especially when the surgeon did not directly interpret pathology slides.[23] Additionally, AR holds substantial potential in other facets of Mohs surgery and dermatologic surgery. After acquiring theoretical knowledge and training on artificial models, the most effective learning in surgical procedures occurs through hands-on experience with real patients.[21] However, due to limitations in staffing and scheduling, junior surgeons may occasionally find themselves performing procedures beyond their comfort level without the immediate supervision of senior faculty members. AR can bridge this gap by enabling senior faculty to remotely monitor operations and provide precise guidance to junior surgeons using superimposed AR images on the surgical site. In larger institutions, this could optimize the allocation of senior staff resources, allowing experienced surgeons to oversee multiple surgeries simultaneously.

Diagnostics

Artificial intelligence (AI) has played a significant role in dermatology for several decades, particularly in the realm of skin cancer detection. Convolutional neural networks (CNNs) have demonstrated dermatologist-level classification proficiency for cutaneous lesions, encompassing both dermoscopic and non-dermoscopic images.[24] AI has proven particularly valuable when integrated with VR reconstruction of the body's surface. An exemplary instance is the Canfield® Vectra WB360 device, which amalgamates 2D photographs from 46 stereo-vision pods, resulting in a comprehensive VR reconstruction of the entire body that can be manipulated at will. The system further employs machine learning-based segmentation and classification to identify nevi and other cutaneous lesions, evaluating their probability of malignancy. Lesion information, along with its anatomical position, is cataloged, enabling the tracking of changes over time. This technology actively aids in the early detection of developing melanomas. A study (Melanoma Detection in Switzerland With VECTRA-MELVEC, ClinicalTrials.gov Identifier: NCT04605822) is currently underway to compare the diagnostic accuracy of dermatologists with and without the support of artificial intelligence. Patients receive their VR reconstructions and results, which they can review from the comfort of their homes. This innovative approach, thus far unique in dermatology, has garnered enthusiastic feedback from professionals in the field.

AI-driven smartphone applications, or "apps," have proven to be practical tools for enhancing diagnostics,25-28 despite some limitations regarding melanoma screening accuracy.[27] In a recent study,[25] a mobile augmented reality system was employed to provide real-time diagnostic support for melanoma lesions using deep learning. Parameters such as lesion diameter, color, and asymmetry are displayed in real-time within the camera view (**Figure 1**). Preliminary evaluations of the app have yielded encouraging results.[25]

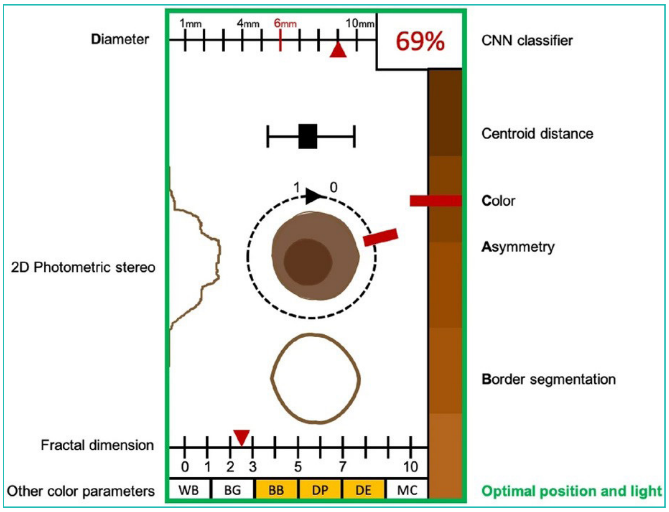

Figure 1. Proposed layout sketch of the augmented reality app for melanoma diagnostics[25]

These models are meticulously designed to incorporate high-definition clinical textures onto 3D models that accurately reflect anatomical proportions. Such models can be seamlessly accessed via a range of devices, including smartphones, tablets, and VR headsets. The dynamic nature of these models allows users to fine-tune environmental conditions, such as lighting, which further enhances the realism of the models. In addition, by incorporating synthetic clinical imagery, these models address crucial challenges like the dearth of data and insufficient training related to infrequent dermatological conditions and distinct Fitzpatrick skin categorizations. It's noteworthy that melanoma, for example, has a lower incidence among black demographics, which unfortunately leads to decreased survival rates when contrasted with non-Hispanic whites in the US.[14] The significant media spotlight has underscored such disparities.[15] A notable endeavor, the DermGAN project, is poised to bolster diversity in clinical skin imagery. It's designed to create images that vividly display specific skin conditions, localizations, and the intrinsic colors of the skin, which can subsequently be converted into 3D visualizations.[16]

The potential of AR/VR in dermatology is greatly amplified with the inclusion of haptic feedback. Often simply referred to as "haptics," this technology facilitates tangible interaction with the virtual environment, transmitting tactile nuances and force to the user.[29] Data related to skin attributes like temperature, texture, and rigidity can provide invaluable additional insights to bolster diagnostic evaluations.[30] In line with this, research by Kim and associates yielded a technique that can transform a singular image into a 3D tactile interface, supporting instantaneous rendering.[31,32]

DISCUSSION

VR has been proven valuable in patient care, particularly in alleviating preoperative and intraoperative anxieties. Standardized VR sequences, known to decrease anxiety across diverse settings, have found efficacy in surgical environments.[22] VR's potential extends to patient education, affording patients a lucid comprehension of surgeries, even intricate procedures like flap-based surgical defect reconstructions. For medical practitioners, VR stands as an indispensable training tool in numerous surgical specialties, inclusive of dermatologic surgery. Its capacity to combine lifelike visual depictions with haptic feedback enables robust training paradigms, reminiscent of the training techniques used in other surgical fields such as plastic surgery. The merit of AR is evident in enhancing dialogue between Mohs surgeons and pathologists, especially in cases where the surgeon might not directly interpret pathology findings.[23]

AR and VR, with their transformative capabilities, have ushered in a wave of advancements across various aspects of dermatology, spanning from education and patient engagement to surgical procedures. Their significant potential remains somewhat under-tapped, but the uptick in research over recent years offers a promising horizon. As these technologies mature, evolve, and become more accessible, they are poised to spark further innovations in the field.

Limitations

Addressing the constraints of AR and VR in dermatology requires a nuanced perspective, concentrating predominantly on applications while sidelining potential health repercussions from user interaction with these technologies. Challenges in leveraging AR/VR for dermatological learning mirror those in broader medical education. Recent extensive studies, possibly propelled by the challenges posed by the COVID-19 pandemic, have delved deep into these limitations.[33-35] For instance, Parsons and MacCallum conducted a deep dive into the potentials and constraints of augmented reality in medical academia, shedding light on the multifaceted utility of AR/VR in this sector while accentuating the necessity to prudently choose affordances during the development phase to amplify benefits.[33]

In dermatologic surgery and diagnostics, AR and VR technologies do face challenges that echo those in general surgical practices.[20] Current technological bottlenecks, like image fidelity, battery longevity, and ergonomics, can be impediments, but continuous technological progress is anticipated to alleviate these issues. Just like any other electronic medical data, the sanctity of patient confidentiality and legal compliance remains non-negotiable.

CONCLUSION

Virtual reality (VR) has demonstrated its substantial value in enhancing patient care, particularly in alleviating preoperative and intraoperative anxieties. The use of standardized VR sequences has consistently proven effective in reducing anxiety levels in diverse healthcare settings, including surgical environments. VR's potential extends beyond anxiety reduction, encompassing patient education, where it provides patients with a clear understanding of complex surgical procedures, such as flap-based surgical defect reconstructions. Additionally, VR serves as an indispensable training tool for medical practitioners in various surgical specialties, revolutionizing training paradigms with its lifelike visual depictions and haptic feedback, akin to those employed in fields like plastic surgery. Augmented reality (AR) has also demonstrated its merit in dermatology, particularly in enhancing communication between Mohs surgeons and pathologists. This is especially valuable in cases where the interpretation of pathology findings may require collaborative input. The transformative capabilities of AR and VR have ushered in a wave of advancements in dermatology, impacting education, patient engagement, and even surgical procedures. While their full potential is yet to be fully realized, the increasing volume of research in recent years points towards a promising future. As these technologies continue to mature, evolve, and become more accessible, they are poised to ignite further innovations in the field of dermatology, ultimately leading to improved patient care and outcomes.

ETHICAL DECLARATIONS

Referee Evaluation Process

Externally peer reviewed.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

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Author Contributions

All the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

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