Augmented reality in dermatology: Are we ready for AR?

Priyank Sharma, MD, Ruth Ann Vleugels, MD, MPH, and Vinod E. Nambudiri, MD, MBA
Boston, Massachusetts

Augmented reality (AR) refers to a group of technologies that capture, analyze, and superimpose digital information onto the real world. This information gives health care providers unique and useful perspectives that can enhance patient care. AR has been utilized in selected scenarios in health care for several decades, notably laparoscopic surgery and vein finding. In recent years, improved wireless technologies, computing power, and analytics are leading to rapid growth in the AR industry. Novel health care–specific use cases are rapidly being introduced with the potential to widely affect clinical care, particularly in dermatology because of the visual nature of the field. In this article, we define AR, profile clinical and educational uses of AR in dermatology, and discuss key policy considerations for the safe and appropriate use of this emerging technology. (J Am Acad Dermatol 2019;81:1216-22.)

Key words: augmented reality; dermatology; digital imaging; health policy; innovation; lesion measurement; lesion tracking; patient education; technology; virtual reality.

Augmented reality (AR) represents an emerging technology that integrates digital information into real-world experiences, differing from virtual reality, where the real world is entirely replaced by a digital representation.[1] AR became widely discussed in mainstream media in 2016, when the global mobile game Pokémon Go gathered almost 45 million users within months of its release and continues to expand with uses in the fast-growing social media networks Snapchat and Instagram.[2-4]

In clinical medicine, AR is most frequently used to overlay digital information or representations onto existing visual platforms, such as headsets or Smartphone screens, although auditory, haptic, and other sensations can also be enhanced.[5] Dermatology is poised to be one of the first fields broadly affected by AR because of the visual nature of the field, the visual focus of AR, the myriad visual manifestations of skin disease, and the multitude of AR uses in procedural and cosmetic domains.

This article aims to provide an overview of AR technology, showcase current and near-term AR-enabled tools pertinent to dermatologists, and discuss key policy considerations to ensure safe and reliable use of this powerful advancement for our field.

A BRIEF HISTORY OF AR TECHNOLOGY

AR is broadly defined as "a live direct or indirect view of a real-world environment augmented by computer-generated sensory input."[6] The first AR system was created in 1968 as a head-mounted display and was only able to superimpose simple wireframe drawings onto real-time video images.[7] Since that time, the technology has rapidly evolved as a result of improved data processing, increased data transfer speeds, the ubiquity of camera-enabled Smartphones, and growing software developer interest.[7]

AR was first described clinically in 1995 by surgeons who visualized patient anatomy in real time during tumor resections by attaching trackers to surgical instruments and a headset worn during the procedure.[8] In 2013, the concept of AR in clinical care was popularized by Google Glass (Google Inc, Mountain View, CA), an optical head-mounted display designed in the shape of eyeglasses, giving

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Correspondence to: Vinod E. Nambudiri, MD, MBA, Department of Dermatology, Brigham and Women's Hospital, 221 Longwood Ave, Boston, MA 02115. E-mail: vnambudiri@bwh.harvard.edu.
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rise to multiple studies exploring clinical utility.[9-11] More recently, the AccuVein near-infrared vein finder was launched, showcasing a nonheadset use of AR, and clinical education uses are being discussed in medical literature.[9,12] Over time, the term AR has been increasingly referenced in the medical literature (Fig 1), signifying the increasing influence of—and interest in—AR in clinical medicine.

THE RELEVANCE OF AR TO DERMATOLOGY

The global health care AR market size is expected to quadruple from 2020 to 2025,[13] and given the visual focus of most health care–related AR uses, dermatologists are likely to see more AR use cases, posing both opportunities and challenges. While AR has the potential to enhance dermatologists' abilities to diagnose and manage cutaneous disease, incorrect use or overzealous early adoption could ultimately hinder clinical care. Furthermore, application of medical technologies that can distort reality might have the potential to exacerbate mental health conditions with cutaneous implications, such as body dysmorphic disorder and Munchausen syndrome.[14] Accordingly, as AR becomes more widespread in clinical and nonclinical settings, it will be important for dermatologists to be familiar with the technology's strengths and weaknesses to ensure its appropriate use and to manage patient questions and concerns. Additionally, it is broadly important for dermatologists to understand new technologies, to appreciate where they are appropriate to be used in clinical care, and to engage in the societal narrative around the implications of these advances on dermatology, as has recently been discussed in the use of artificial intelligence in dermatology.[15,16]

CURRENT AND NEAR-TERM USES OF AR IN DERMATOLOGY

AR is currently being deployed across a spectrum of clinical scenarios within dermatology. These uses can be broadly categorized into procedure planning and real-time assistance, lesion measurement and tracking, and clinical and patient education (Table I).[17-24] The following section discusses the current state of these use cases, where the technology might be applied in the near term, and future areas where AR could potentially benefit dermatology.

CAPSULE SUMMARY

- Augmented reality technologies integrate digital information into real world experiences. This article identifies applications of augmented reality technologies in dermatology.
- Augmented reality has multifaceted potential to effect dermatologists' abilities to deliver care by enhancing visual diagnosis and aiding in procedural planning. However, dermatologists should recognize that policy questions remain about new technology adoption.

Procedure planning and real-time assistance

In procedural planning, AR is typically used to create 3-dimensional (3D) reconstructions of anatomy from existing medical images, helping to optimize surgical approaches and to virtually explore target areas, particularly for complex procedures.[25,26] In 2017, the first total-face transplantation was successfully performed utilizing AR. Before the operation, the patient and donor computed tomography scans were transformed into 3D digital anatomic models to assist with surgical approach planning.[27] During the procedure, these digital models were superimposed into a headset used by the surgeons to provide real-time visualization of subsurface anatomy, thus delivering surgical guidance.[27]

In dermatology, AR's use for preprocedure planning has been described in the literature for Mohs surgery with the Google Glass technology.[28] Google Glass has not become widespread,[29] but other head-mounted AR devices, such as EchoPixel (EchoPixel, Santa Clara, CA), are emerging for the same uses.[19] Generally, augmented preprocedure planning in dermatology is useful for clinical scenarios requiring resections in cosmetically sensitive areas, such as the face. As AR technology advances and further incorporates haptic feedback, dermatologic surgeons and trainees could practice procedures before actual operations, exploring multiple resection and closure scenarios for an individual lesion and further enhancing the preprocedure planning process.[30]

There are 2 general methods by which AR enhances real-time procedures. The first is by digitally projecting useful data in the user's field of view, typically using a head-mounted device. One example of this is a surgeon wearing HoloLens goggles (Microsoft Corporation, Redmond, WA) during a procedure that enables him or her to see patient vital signs without turning away from the operating field.[20] The second method involves AR providing novel information to assist in procedures. A widely used example is laparoscopy, where a camera attached to a scope enables the surgeon to visualize and navigate a

> *Abbreviations used:*
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> 3D: 3-dimensional
> AR: augmented reality
> FDA: Food and Drug Administration

patient's internal structures. Recent advances in computational power and mobile technologies have resulted in other visualizations that were previously impossible. For example, during a face transplantation performed in 2017, surgeons used the Microsoft HoloLens device to create holographic 3D projections of the patient's anatomy, enabling visualization of blood vessels deep in the skull and guiding the next steps of the procedure.[27] In these cases, information that would otherwise be unavailable to the user is now readily accessible.

AR's greatest impact on dermatology may be on real-time bedside procedures, such as vein finding, ultrasound, and endoscopy, performed in settings more similar to a dermatologists' practice, where there are fewer resources than there are in formal operating rooms.[1,31] AR can also assist nonspecialist providers with procedures typically performed by dermatologists, thereby improving access to care and presenting an opportunity for additional dermatologist-led education.

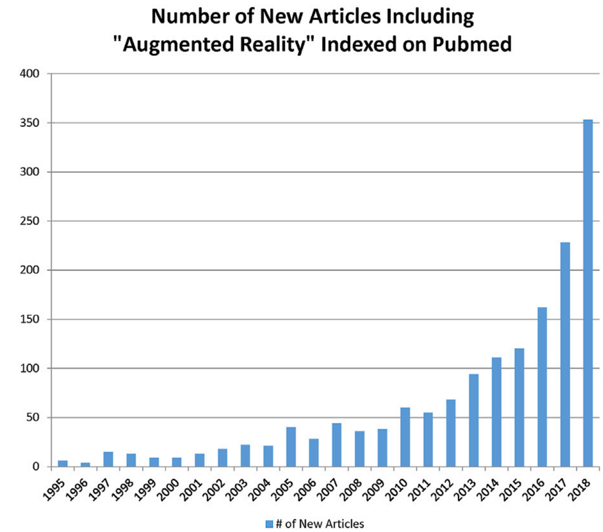

Fig 1. Number of new articles indexed on PubMed with "augmented reality" per year.

Lesion measurement and tracking

Measuring the size and progression of skin lesions has multiple implications within dermatology, including determining diagnoses, identifying treatments, counseling patients on prognosis, and accurately billing encounters.[32] Dermatologists report that they typically perform lesion measurements themselves rather than delegating this task to staff, suggesting the importance of accurately and precisely performing these measurements.[32]

Lesion measurement and tracking programs were among the first uses of AR in dermatology and can be intended for patient or clinician use. These programs range from freestanding mobile applications (eg, LesionMeter)[17] providing lesion measurement standardization in real time with a reference object, such as a credit card, to web-based platforms fully automating lesion identification and highlighting potentially suspicious areas for in-depth examination (eg, DermEngine).[18] Initially, such applications used AR to measure lesions after an image was recorded, but real-time digital measurements are now available as a result of enhanced data processing.

AR lesion tracking has the potential to substantially alter dermatology by standardizing how cutaneous lesions are measured. Standardization can improve clinical decision-making and outcomes by creating accurate, quantifiable records of lesion progression over time. These efforts could be further enhanced by using other emerging technologies, such as blockchain, which could make image sharing easier and more secure by creating a shared, interoperable database with computational algorithms to ensure permanent and chronologic record keeping with cryptographically secure access to images.[33]

AR can give dermatologists more confidence in measurements made by patients, other providers, and staff, providing more substance for discussion of diagnoses and treatments and enabling dermatologists to more confidently delegate this important task. A rich, standardized AR-driven data set would facilitate the performance of clinical research that was previously impossible, furthering dermatologists' knowledge of skin disease.

Near-term advances in lesion tracking could provide novel clinical information and enable new therapeutic possibilities. Studies using parents' mobile photos of infantile hemangiomas to identify the highest velocities of lesion progression demonstrate a sophisticated example of lesion tracking with therapeutic implications that could be greatly facilitated by the use of AR technologies.[34] Accurate 3D lesion measurement, compared with current 2-dimensional measurements, and incorporation of additional sensors, such as infrared or ultrasound, into measurements are currently in development and hold further clinical potential.[35] In plastic surgery, AR devices like the Vectra 3D system are being used for accurate 3D tissue volume assessment, tracking outcomes of lymphedema treatments, and facial reconstruction.[36,37]

Table I. Categories and examples of AR

AR use category	Category description	Software example and target user	Reference
Lesion measurement	Programs digitally measure the size and other qualities of lesions and may include clinical decision support.	Lesion Meter, a Smartphone application to measure skin lesions over time. Target users: patients	Lesion Meter[17]
Lesion tracking	Programs measure the size and other qualities of lesions and may include clinical decision support.	DermEngine's full body imaging feature, a mobile or web-based image recognition program for identifying and tracking clinically relevant lesions. Target users: dermatologists	DermEngine[18]
Procedure planning	Programs enhance surgical planning by creating rich 3D representations of patient anatomy.	EchoPixel, a medical visualization software company undergoing clinical trials for procedural planning software use. Target users: physicians	EchoPixel[19]
Real-time procedure assistance	Programs 1) superimpose digital information onto a patient through a headset or other devices or 2) create digital information displays with more robust information than standard monitors.	Microsoft HoloLens, a headset display that superimposes digital information onto the users field of view, has been demonstrated to accomplish both real-time procedure assistance tasks. Target users: physicians performing procedures	Microsoft Hololens[20]
Clinical education	Programs create rich, interactive clinical education experiences through 3D visualizations of disease, often superimposed on healthy individuals in unexpected ways, simulating real-life disease identification and management similar to medical standardized patients.	mARble, for medical student education, a dermatology-specific application with digital skin lesions superimposed on healthy individuals. A wound care simulation for nursing students found enhanced performance on wound diagnostic parameters in the group that utilized AR. Target users: health care trainees	Noll C, Häussermann B, von Jan U, Raap U, Albrecht UV. mobile Augmented Reality in Dermatology. Biomed Tech. 2014;59(S1): 1216-1220. https://doi:10.1515/bmt-2014-4552; Jorge NR et al[21]
Patient education	Programs in this category can enhance patient education across a range of topics, including disease screening, self-care, disease management, explaining imaging or other procedures, possible treatment outcomes, and any other existing patient education efforts.	Clinical medicine application: SpellboundAR, a platform for creating AR patient education experiences that can be viewed through mobile devices, tailored to different clinical needs (eg, a simulation of sites and sounds of being in an MRI). Dermatology applications: Currently focus primarily on skincare and cosmetics, such as HiMirror and Samsung's Lumini. Target users: patients	SpellboundAR,[22] HiMirror,[23] and Samsung's Lumini device[24]

3D, 3-Dimensional; *AR*, augmented reality; *mARble*, mobile Augmented Reality blended learning environment; *MRI*, magnetic resonance imager.

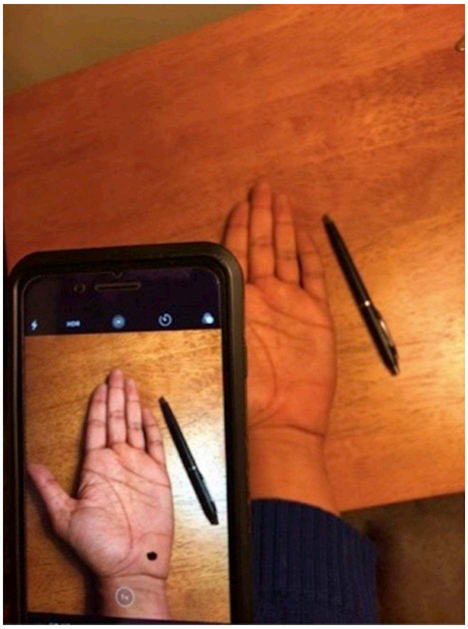

Fig 2. Example of use of augmented reality. Augmented reality can create digital lesions, such as a simulated skin lesion appearing on an individual's hand, for clinician and patient education purposes.

Clinical and patient education

In clinical education, AR can provide rich, dynamic learning experiences to help dermatology trainees understand medical complexity. AR is ideal for dermatology education because visual information is highly relevant to the diagnosis and management of cutaneous conditions. Educational applications could be particularly helpful for expanding the breadth of basic dermatology training to physicians in other fields given the high variation in the quality and quantity of dermatology educational offerings across residency programs.[38] Specific potential applications of AR in dermatologic education include simulations for lesion identification and management (Fig 2), excisions, cosmetic procedures, and Mohs micrographic surgery.

In a recent study of AR in dermatology education, medical students who utilized a mobile AR platform to simulate lesions on healthy skin were found to have better long-term knowledge retention.[39] AR has also demonstrated efficacy in teaching nonphysician trainees; in a 2019 study, nursing student performance in wound diagnostic parameters was improved by training with a virtual simulator that included AR compared with a simulator that did not.[21] Near-term advances might allow AR to simulate lesion growth and show digital responses to treatments, where incorrect choices show lesion growth, possibly providing a richer learning experience, and long-term advances can incorporate tactile experiences enabling trainees to palpate digitally simulated raised or bumpy surfaces.

Many AR tools currently exist to improve existing patient education efforts, including tools explaining disease screening, self-care, disease management, and what upcoming imaging or procedures entail, such as SpellboundAR (SpellBound, Ann Arbor, MI), a platform for health professionals to create mobile AR experiences for any patient education endeavor.[22] In dermatology, AR patient education has largely been driven by cosmetic-focused products, often with AR-enabled skincare devices to help patients identify the potential impact of elective treatments and nonmedical skincare. Examples include HiMirror (Hi Mirror Enterprise, Taipei, Taiwan),[23] a small mirror that identifies skin areas with potential for cosmetic enhancement, and Samsung's Lumini device (Ridgefield Park, NJ)[24] with similar features linked to a Smartphone application, demonstrating the ability of AR to enter the patient-as-consumer dermatology landscape.

Ultimately, AR could help patients triage straightforward skin conditions and identify areas of cosmetic improvement in relatively simple cases, while leaving complex management to dermatologists. However, caution should be taken with direct-to-patient AR programs claiming to educate patients on skin health, given their potential to offer diagnostic recommendations on the basis of data that is not yet validated, which could potentially result in patient harm. Likewise, a company's motivation for profit or desire to promote specific products could be reflected in the cosmetic recommendations AR devices are programmed to generate, potentially leading to overutilization and creating a new domain of technology-driven dermatoethical challenges.[40] AR has the potential to improve patient outcomes and quality of life, but it will be important for dermatologists to utilize their expertise to evaluate these tools and ensure their validity as safeguards of the specialty for both our peers and our patients and to ensure these products do not give patients unrealistic outcome expectations.

KEY POLICY CONSIDERATIONS FOR AR

AR is likely to further permeate into dermatology as a clinical and educational tool, as widespread adoption of the technology grows, driven by the greater availability of data, advanced data analysis techniques, and growing Smartphone usage.[41] As with any emerging technology, important policy considerations should be addressed before widespread use to ensure patient safety and avoid negative impacts on the field.

Dermatologists should be cautious when using or interpreting data from devices and software not yet approved by the US Food and Drug Administration (FDA). AR tools have only recently started gaining FDA approval, typically for presurgical planning (eg, Novarad's OpenSight preoperative planning software's approval in October 2018).[42] Legally, companies promoting AR tools not yet approved by the FDA must be judicious in their clinical claims; dermatologists should exercise caution when exploring such tools outside of investigational settings and in counseling patients on new or potential devices and technologies as they are made available.[40]

To safely use AR tools in clinical practice, evidence ensuring their accuracy and precision should be required before FDA approval. Dermatologists seeking to use AR tools should familiarize themselves with the technology and underlying algorithms in order to enhance their understanding and appropriate use of the tools and to be better equipped to communicate their potential value to patients. Familiarity with AR tools would also help decrease the potential liability of introducing such technologies into clinical practice and help limit regulatory barriers to FDA approval.[43]

One area in need of particular guidance is the medicolegal context supporting AR utilization. Understanding state and federal licensure requirements for utilizing AR tools for skin conditions would improve integration into clinical practice. Guidance on any changes in liability when AR is integrated with other technologies (such as teledermatology) could further enable adoption. Last, understanding and outlining reimbursement implications when utilizing AR tools would be critical to underscoring the enhanced value provided by using AR to further dermatologic care.

Beyond shaping policy, dermatologists should also consider whether and how AR should be incorporated into or alongside their current treatments. As patients increasingly utilize this new technology for self-management and diagnosis, it will be important for dermatologists to be familiar with the technology's strengths, limitations, and potential future evolutions.

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