Mixed Reality with HoloLens: Where Virtual Reality Meets Augmented Reality in the Operating Room

Oren M. Tepper, M.D.
Hayeem L. Rudy, B.A.
Aaron Lefkowitz, B.A.
Katie A. Weimer, M.A.
Shelby M. Marks, M.A.
Carrie S. Stern, M.D.
Evan S. Garfein, M.D.

Bronx, N.Y.; and Rock Hill, S.C.

Summary: Virtual reality and augmented reality devices have recently been described in the surgical literature. The authors have previously explored various iterations of these devices, and although they show promise, it has become clear that virtual reality and/or augmented reality devices alone do not adequately meet the demands of surgeons. The solution may lie in a hybrid technology known as mixed reality, which merges many virtual reality and augmented realty features. Microsoft's HoloLens, the first commercially available mixed reality device, provides surgeons intraoperative hands-free access to complex data, the real environment, and bidirectional communication. This report describes the use of HoloLens in the operating room to improve decision-making and surgical workflow. The pace of mixed reality–related technological development will undoubtedly be rapid in the coming years, and plastic surgeons are ideally suited to both lead and benefit from this advance. (*Plast. Reconstr. Surg.* 140: 1066, 2017.)

Wearable computers have the potential to improve surgical care and education.[1,2] Traditionally, they belong in one of two categories: augmented reality or virtual reality. Augmented reality involves overlaying computer-generated images onto the actual environment. Google Glass (Google, Inc., Mountain View, Calif.) is one example of a wearable augmented reality device. Virtual reality, in comparison, involves complete immersion into a computer-generated environment. Oculus Rift (Oculus VR, Menlo Park, Calif.) is an example of a wearable virtual reality headset. Although both augmented reality and virtual reality devices show promise, there are significant limitations that have slowed their widespread adoption. These include the inability to interact with three-dimensional data packets in augmented reality, and exclusion of the real-world environment in virtual reality. Mixed reality merges many of the benefits of virtual reality and augmented reality and as a result may be more useful for surgeons. A comparison of various wearable devices is shown in Table 1.

From the Department of Surgery, Division of Plastic and Reconstructive Surgery, and the Department of Otorhinolaryngology–Head and Neck Surgery, Montefiore Medical Center/Albert Einstein College of Medicine; and 3D Systems Corp.
Received for publication October 2, 2016; accepted June 19, 2017.

DOI: 10.1097/PRS.0000000000003802

MATERIALS AND METHODS

In March of 2016, Microsoft Corp. (Redmond, Wash.) introduced the first commercially available mixed reality device called HoloLens. The wearable headset combines several types of sensors (infrared lasers, high-definition cameras, accelerometers, and microphones) and an integrated computer. Unlike other devices (such as Google Glass), the video display in HoloLens is created by the reflection of two high-definition 16:9 light engines onto each retina of the user and offers interpupillary calibration for each user, providing a true heads-up display functionality. Notably, this does not interfere with transmission of visual information from the surrounding environment.

Disclosure: *The authors have the following to disclose: Dr. Evan Garfein is a consultant for Stryker and the founder of Sigma Surgical. Dr. Oren Tepper is a consultant for Stryker CMF Dr. Carrie Stern is founder of MirrorMe3D. Katie Weimer and Shelby Marks are employed by 3D Systems Corporation.*

A "Hot Topic Video" by Editor-in-Chief Rod J. Rohrich, M.D., accompanies this article. Go to PRSJournal.com and click on "Plastic Surgery Hot Topics" in the "Digital Media" tab to watch. On the iPad, tap on the Hot Topics icon.

Table 1. Comparison of Popular Wearable Computers*

	Google Glass	Oculus Rift	Microsoft HoloLens
			
Technology type	Augmented reality	Virtual reality	Mixed reality (augmented plus virtual)
Wearability	Eyeglasses-style	Adjustable headband	Adjustable headband
Battery life	1 hr of heavy use	Wired power consumption	2–3 hr of heavy use
HIPAA compliance	Yes; third-party applications	N/A	Not off the shelf
No-touch operation	Touchpad on right arm; can be voice-controlled	No	Controlled by gestures and voice command
True heads-up display	Yes	N/A	Yes; holograms can also be placed out of field of view

HIPAA, Health Insurance Portability and Accountability Act of 1996; N/A, not applicable.
*Oculus Rift, Google Glass, and Microsoft HoloLens.

Holographic images, three-dimensional objects, and two-dimensional windows may be placed anywhere in the user's visual field, enabling novel interactive experiences with complex data packets. The unit's weight is distributed through the head of the user through an adjustable headband and contains a 16,500-mWh rechargeable battery that can support active use for 2 to 3 hours (Table 1).

APPLICATIONS

Many valuable applications are immediately available to the surgeon using HoloLens. The most interesting, perhaps, is hands-free access and manipulation of complex and common data. Increasingly, plastic surgeons are using complex three-dimensional data as part of preoperative planning or intraoperative navigation. HoloLens can seamlessly and in sterile fashion integrate three-dimensional information such as holograms of virtual surgical plans, three-dimensional data used to produce stereolithographic or three-dimensional models, and digital implants into the surgeon's operative visual field. Figure 1 demonstrates intraoperative use of holograms to visualize holograms related to a virtual surgical plan for mandibular reconstruction, and to compare a hologram of preoperative skull morphology against a newly-formed calvaria in a child undergoing open cranial vault remodeling. Two-dimensional windows containing text, video, PDF files, or other standard data types may also

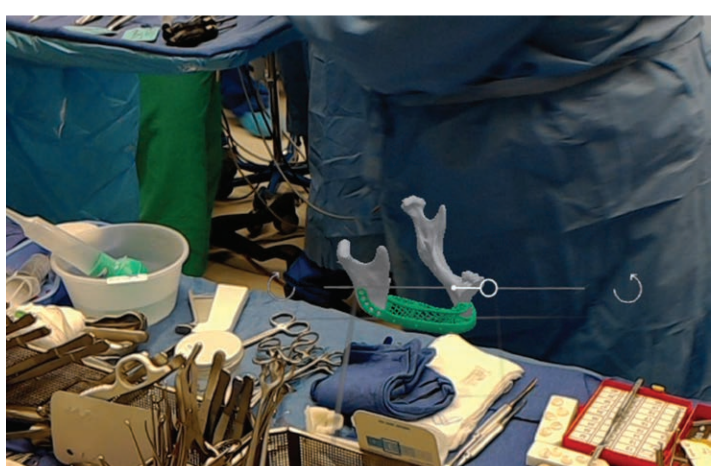

Fig. 1. A hologram of a mandibular implant affixed to the patient's mandible designed using virtual surgical planning for consultation during a mandibular reconstruction from the point of view of the surgeon in the operating room (virtual surgical planning designed by 3D Systems, Rock Hill, S.C.).

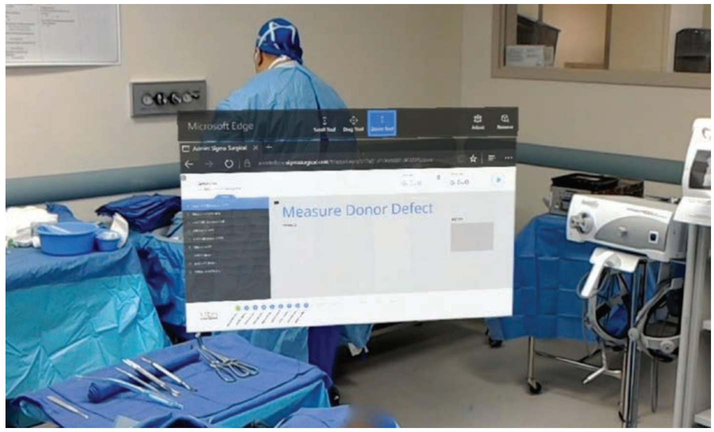

Fig. 2. Internet browser, Microsoft Edge, showing operative protocol from the point of view of the surgeon in the operating room. Various other two-dimensional windows can be simultaneously opened and placed throughout the environment of the HoloLens user.

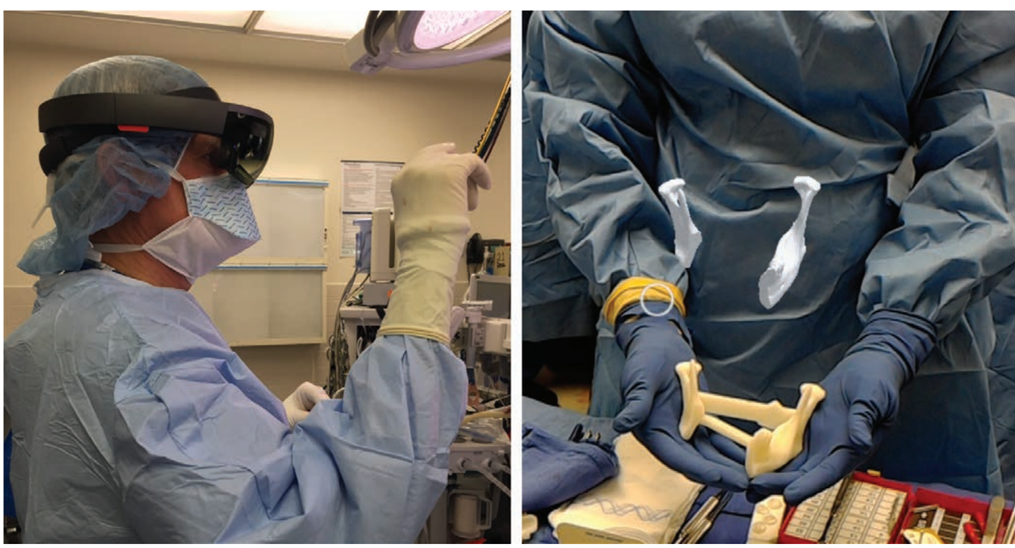

Fig. 3. Scrubbed surgeon using Microsoft HoloLens in the operating room (*left*) and image from HoloLens (*right*) showing comparison of holographic model of a resected mandible with a three-dimensional printed model (3D Systems).

be projected, enabling visualization of protocols and radiographs, for example. Figure 2 demonstrates how a Web-based protocol was consulted intraoperatively using Microsoft Edge. These windows can be opened, manipulated, and closed by the surgeon in a sterile environment using only hand movements in space. Figure 3 demonstrates a scrubbed and gowned surgeon operating HoloLens. The accompanying video to this article demonstrates intraoperative use of HoloLens from a point-of-view perspective. (**See Video, Supplemental Digital Content 1**, which demonstrates intraoperative use of HoloLens from a point-of-view perspective, available in the "Related Videos" section of the full-text article on PRSJournal.com or, for Ovid users, available at ***http://links.lww.com/PRS/C419***.)

HoloLens provides a robust platform for communication between the surgeon and others in a way previously not possible. Wearers are capable of broadcasting mixed reality scenes generated by the device to any smartphone or computer either by means of an on-board Skype application that allows for bidirectional communication between two parties or by means of the HoloLens Companion App by Microsoft, which sends a point-of-view livestream of the mixed reality composite to a paired computer.

Video. Supplemental Digital Content 1 demonstrates intraoperative use of HoloLens from a point-of-view perspective, available in the "Related Videos" section of the full-text article on PRSJournal.com or, for Ovid users, available at ***http://links.lww.com/PRS/C419***.

DISCUSSION

There have been multiple reports describing the use of Google Glass and augmented reality in the operating room.[1–5] The senior authors (E.S.G., O.M.T., and C.S.S.) were Explorers of Google Glass and generally support its promise in surgical education, telecommunication, and workflow optimization. However, this technology is significantly limited by its inability to access critical data in a hands-free manner and other technical limitations of the device itself. Similarly, Oculus Rift has been previously investigated as a tool to improve surgical education and preoperative planning through simulation. Neurosurgeons at the University of California, Los Angeles, for instance, have used Oculus Rift preoperatively in combination with standard neuroimaging modalities to familiarize junior surgeons with the anatomy of the patient.[6] These simulation devices are handicapped by their exclusion of information from the actual environment, which has important implications for use in the operating room. Satisfying Health Insurance Portability and Accountability Act of 1996 regulations is an important issue and has been achieved on both Glass and HoloLens through simple modifications of information transfer protocols.

Adoption and use of any new technology depends on several critical features. HoloLens's design and functionality/hands-free operation to maintain sterility, robust battery life, and a comfortable form factor make it ideal for intraoperative use. HoloLens currently costs approximately $3000, compared with $1500 for the Google Glass Explorer package and $600 for Oculus Rift. The authors believe that the increased expense for HoloLens is justified through the ability to manipulate and visualize holograms in a "real" environment, which offers major potential advantages in surgery and which is not offered by Google Glass or Oculus Rift.

Limitations that may impede the adoptability of HoloLens include the current lack of available software for use in surgery, and the potential for nausea/vertigo with prolonged use. As with other wearable computers, there is some potential for nausea and vertigo based on predisposition of the user that can be dangerous in the operating room. This potential should be characterized through surveys if HoloLens is to be adopted on a large scale, and surgeons should determine whether they suffer these effects before using the device in the operating room. In addition, at the current early stage of development of this technology, there are few software programs that are of use to surgeons. As the popularity of the device grows, the authors expect that surgically useful software will be developed, as was seen with Google Glass.

CONCLUSIONS

Wearable computers such as HoloLens provide surgeons with access to real-time, multimodal information without interrupting workflow and surgical efficiency. The ability to interact intraoperatively with three-dimensional data packets gives surgeons far greater access to information and lays the groundwork for improved decision-making. It also facilitates the transition from preoperative virtual surgical planning to intraoperative mixed reality surgical performance. Microsoft HoloLens is the first mixed reality product that has widespread clinical potential. Given that many plastic surgery procedures are defined by complex three-dimensional anatomy with great demand for accuracy, our specialty should embrace such technology and remain at the forefront of its development.

Evan S. Garfein, M.D.
Department of Surgery
Division of Plastic and Reconstructive Surgery
Montefiore Medical Center/Albert Einstein College of Medicine
1250 Waters Place, 6th Floor
Bronx, N.Y. 10465

REFERENCES

1. Sinkin JC, Rahman OF, Nahabedian MY. Google Glass in the operating room: The plastic surgeon's perspective. *Plast Reconstr Surg.* 2016;138:298–302.
2. Davis CR, Rosenfield LK. Looking at plastic surgery through Google Glass: Part 1. Systematic review of Google Glass evidence and the first plastic surgical procedures. *Plast Reconstr Surg.* 2015;135:918–928.
3. Chang JY, Tsui LY, Yeung KS, Yip SW, Leung GK. Surgical vision: Google Glass and surgery. *Surg Innov.* 2016;23:422–426.
4. Brewer ZE, Fann HC, Ogden WD, Burdon TA, Sheikh AY. Inheriting the learner's view: A Google Glass-based wearable computing platform for improving surgical trainee performance. *J Surg Educ.* 2016;73:682–688.
5. Mitrasinovic S, Camacho E, Trivedi N, et al. Clinical and surgical applications of smart glasses. *Technol Health Care* 2015;23:381–401.
6. South P. Brain surgery with Oculus Rift. *VRExperience.* May 4, 2015.