Emerging Technology in Surgical Education: Combining Real-Time Augmented Reality and Wearable Computing Devices

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Abstract: The authors describe the first surgical case adopting the combination of real-time augmented reality and wearable computing devices such as Google Glass (Google Inc, Mountain View, California). A 66-year-old man presented to their institution for a total shoulder replacement after 5 years of progressive right shoulder pain and decreased range of motion. Throughout the surgical procedure, Google Glass was integrated with the Virtual Interactive Presence and Augmented Reality system (University of Alabama at Birmingham, Birmingham, Alabama), enabling the local surgeon to interact with the remote surgeon within the local surgical field. Surgery was well tolerated by the patient and early surgical results were encouraging, with an improvement of shoulder pain and greater range of motion. The combination of real-time augmented reality and wearable computing devices such as Google Glass holds much promise in the field of surgery. [Orthopedics. 2014; 37(11):751-757.]

Surgery is a highly methodological field constantly in need of technological advancements aimed at improving patient outcomes while facilitating cost-effective treatment strategies, knowledge transfer, and skill acquisition. For a technology to have application to surgery, it must offer utility in a portable, fiscally responsible package.

Wearable computing devices such as Google Glass (GG) (Google Inc, Mountain View, California) have recently aroused the interest of the medical community. In contrast to traditional videoconferencing platforms, GG is a device with an optical head-mounted display that possesses the ability to capture and display audio and video images in real time while interacting with the surrounding environment. Flexible mobile platforms such as GG could hold considerable potential in furthering the development of telemedicine (ie, the remote diagnosis and treatment of patients by means of telecommunications technology) as a tool to spread time-sensitive medical expertise to areas that are physically difficult to reach.

Google Glass has been tested in several academic medical centers worldwide to stream live point-of-view footage from surgeries to the medical community. Early adopters have praised the device’s portability and ease of use; however, real-time broadcasts of operative cases using traditional videoconferencing platforms over the Internet have been reported since the late 1990s. Currently, no peer-reviewed reports have described limitations or potential concerns with adoption of this tool by the surgical community. Of the more than 16,000 citations for “telemedicine” on PubMed (Medline), fewer than 250 pertain to surgery, suggesting that the rapid growth in telehealth has largely not affected the realm of surgery.

Augmented reality is a separate emerging technology that also has a promising future in medicine and especially in surgery.
Virtual reality replaces the real world with a simulated one, augmented reality can be defined as enhancing an individual’s visual experience with the real world through the integration of digital visual elements. The Virtual Interactive Presence and Augmented Reality (VIPAAR) system, an augmented reality platform conceptualized and developed at the University of Alabama at Birmingham, has effectively demonstrated the practicality and potential usefulness of virtual interactive guidance in the fields of neurosurgery, otolaryngology, and orthopedics. Although evaluation of GG suggests it has a valuable role in live point-of-view video recording, the application of GG as a mobile, augmented reality interface remains untested in a surgical setting. In this report, the authors describe the first surgical procedure combining the VIPAAR system and GG, which was performed on September 12, 2013, in Birmingham, Alabama. The integration of augmented reality platforms and applications with wearable devices such as GG opens all of surgery to the possibility of expert remote assistance, ultimately aiding in the development of surgical telementoring. The purpose of this study was to analyze the feasibility of augmented reality technology with a mobile videoconferencing platform in a surgical setting. The authors hypothesized that this pairing would result in a robust construct providing a portable mechanism for the implementation of VIP. The primary questions and challenges addressed in this article are related to the applicability and limitations of GG in the surgical environment, including its ability to host effective virtual interactive systems (eg, VIPAAR) for surgical assistance or education, ethical and confidentiality implications, and its role in the development of surgical telementoring.

**Methods**

**Case Description**

A 66-year-old man presented to the authors’ institution with 5 years of progressive right shoulder pain and decreased range of motion. Physical examination and radiographs were consistent with advanced osteoarthritis with an intact rotator cuff and adequate glenoid bone stock (Figures 2A-B). Secondary to persistent pain despite nonoperative treatment with nonsteroidal anti-inflammatory drugs and activity modification, the patient elected to undergo a total shoulder replacement. His preoperative American Shoulder and Elbow Surgeons (ASES) score was 40, and his preoperative Disabilities of the Arm, Shoulder and Hand (DASH) score was 53.5. The patient was aware of the intended study and provided signed consent to allow broadcasting and transmission of data through GG to a collaborating institution. The patient also consented to the details of the case being published.

**VIPAAR: Virtual Interactive Presence**

The VIPAAR system is software based and implements VIP by merging, in real
time, 2 video streams that capture separate and remote fields into a common task field, thus enabling real-time interaction between participants in that common task field (Figure 1). That is, participants can see each other’s actions in the common task field, as rendered by the VIPAAR system, as if they were physically present within the task field. In this case, the common task field was the surgery being performed in Birmingham. The system was used to merge a remote surgeon’s hands (a surgeon at Saint Joseph’s Hospital, Atlanta, Georgia) into the common surgical field (in Birmingham) using GG.

Logistical Set-up
Two experienced, fellowship-trained orthopedic surgeons (B.A.P., P.K.D.) participated in this case combining the use of GG and augmented reality. The officiating surgeon performing the surgery (Surgeon A: B.A.P.) was located in an operating room at the University of Alabama at Birmingham Highlands Hospital, Birmingham, Alabama, while the second surgeon (Surgeon B: P.K.D.) was remotely located in a conference room at Resurgens Orthopaedics, Emory Saint Joseph’s Hospital, Atlanta, Georgia. A VIP station with an Internet protocol-based connection was positioned in Atlanta. Surgeon A in Birmingham wore GG during the entire case, which enabled him to both interact with and stream live video to Surgeon B in Atlanta. The VIP station positioned in Atlanta received a streamed video input from the GG camera, thus allowing Surgeon B to virtually “reach into” the surgical field in real time and remotely assist Surgeon A from a different geographic location. Thus, the attending surgeon (Surgeon A) performing the total shoulder arthroplasty in Birmingham was able to see a hybrid image combining the image of the surgical field with the image of his colleague’s hands or tools through the GG head-mounted display. This set-up is shown in Figure 3.

The attending surgeon in Birmingham had 3 additional pieces of equipment beyond the arthroplasty suits used in joint replacement surgery. The first piece was GG, which was connected to an extended battery located in the surgeon’s back scrub pocket. The second was a headset for audio that was connected to a cell phone placed in the surgeon’s front scrub pocket; the audio headset allowed the surgeon to hear the remote surgeon, and the microphone in the cell phone allowed the remote surgeon to hear the operating surgeon through a Skype (Microsoft, Redmond, Washington) conference call. The third was the microphone of the television station recording the broadcast, which was attached to the lapel of the scrub shirt and connected to a transmitter on the surgeon’s waist. The surgeon was assisted by a resident and a nurse first assistant in addition to the scrub technician and other operating room personnel, including the circulating nurse and the anesthesiologist.

Results
Surgical Outcomes
The patient tolerated the surgery well and was discharged from the hospital the next day. Early surgical results were encouraging, with an improvement of shoulder pain and greater range of motion. In this case, the operative time was approximately 45 minutes longer than usual for this procedure when performed by Surgeon A. A postoperative radiograph demonstrated appropriate alignment with no evidence of failure (Figure 2C). At 1 year postoperatively, the patient continues to express satisfaction with the operation. His 1-year postoperative ASES score was 100 and his DASH score was .8.

Technology and Policy
Challenges Encountered Before Surgery
Prior to broadcasting the live surgery, GG and its hosting of the VIPAAR system was tested. Two key informa-
tion technology and policy concerns required solutions.

Secure Network Access. Google Glass does not allow for entry of user name and password for network authentication. Because hospital network security mandates the use of such authentication, for this pilot, the University of Alabama at Birmingham enabled explicit access for GG.

Health Insurance Portability and Accountability Act (HIPAA) and Confidentiality. Because GG requires that users communicate through a Google Hangout video session, which is not HIPAA compliant, provisions were made to protect patient privacy and confidentiality. These included patient consent for use of GG and VPPAAR, as well as assurance that no identifiable HIPAA information would be transmitted during the session.

Overall Performance of GG During the Surgical Trial

The GG form factor was convenient and relatively unobtrusive for Surgeon A. In general, the form factor was more convenient and less obtrusive than a camera mounted in the operating room for the purpose of capturing the surgical field.

Limitations Associated With the Use of GG

Recognizing that GG is a first-generation prototype, this singular experience enabled identification of several issues important to the eventual commonplace use of GG in the surgical environment.

GG Battery Life. During the surgery, GG continually sent and received real-time video, which required significant encoding/decoding and processing. The battery life was limited. To remain on beyond 20 to 30 minutes, GG had to be connected to a power source.

Audio. The audio was adequate only for the remote participant (consulting Surgeon B). That is, the receiving station in Atlanta was able to hear the operating surgeon (Surgeon A) at the University of Alabama at Birmingham, but the operating surgeon was unable to hear what was spoken by the consulting remote surgeon. This could be related to operating room noise, the battery pack used to power the head fan employed by the surgeon during arthroplasty procedures, or the surgeon wearing GG not being the one who was custom-fitted for the device by Google. For this particular case, Skype teleconferencing software coupled with a cell phone in the front scrub pocket and a headset worn by the surgeon allowed for adequate audio for communication.

Image Quality. The screen resolution of the GG display is 640×360 pixels. The remote surgeon (Surgeon B) felt that the image transmitted by GG, although not high-definition due to GG’s limited processing power, allowed him to effectively provide real-time guidance. The image viewed by Surgeon A through GG was of lower resolution and posed some problems with fine details of the surgical field. Additionally, Surgeon A, who wears glasses, had to wear contacts to clearly view the GG heads-up display. The screen held interactive or static information (eg, radiographs, magnetic resonance images, vital signs) (Figure 4). Although Surgeon A’s contacts were helpful, allowing him to view the GG heads-up display and interact with Surgeon B, the image quality for the GG transmission to the remote surgeon was better when GG was closer to the surgical field than what was generally comfortable for Surgeon A’s contact-corrected focal length. Both of these issues made the transmitting and receiving of information challenging.

Network Delay. There was a noticeable delay between the audio and video. The audio, which was provided by a teleconference call, was ahead of the video because the surgical image was sent back to Mountain View, California (Google Hangout), and sent...
back to Birmingham and Atlanta. Hence, when Surgeon B wanted to identify something in the surgical field, Surgeon A had to temporarily stop operating, look up to the heads-up display, and wait for the video to catch up with what was being spoken.

**Overall Performance of GG Combined With VIPAAR**

Google Glass supported integration with the VIPAAR system, enabling the local surgeon to interact with the remote surgeon within the local surgical field (Figure 5). Surgeon A reported that he was able to successfully view Surgeon B’s presence for the duration of the case. Surgeon B reported that the experience of inserting his hands into the simulated surgical field felt natural, allowing more precise instruction than through verbal interaction.

**DISCUSSION**

In a financially austere health care marketplace, emerging technology is a key factor in constraining costs while improving efficiency and the quality of care.20,22 However, for new technology to be adopted, health care providers and educators need to actively justify the cost of such technology and demonstrate measurable improvements to patient health care and medical education as a result. The combination of real-time augmented reality and wearable computing devices such as GG represents a novel breakthrough technology in the field of surgery, poised to irrevocably change health care and medical education. Nonetheless, the authors feel the need to highlight several aspects of GG’s functionality as it is used to host interactive augmented reality applications in the future. Although this may temper current enthusiasm regarding GG, a realistic understanding of the areas where improvements can unlock the potential value of this technology should be valuable to both technology developers and health care providers.

Surgery requires a high degree of technical skill acquired through an apprenticeship model of stepwise involvement in the operating room that has remained largely unchanged for generations.21 Given the accelerating complexity within the surgical field, coupled with fewer opportunities for residents to perform surgery, emphasis is currently shifting toward skill acquisition outside the operating room.22,23 This study demonstrated the application of a GG plus VIP construct between a local and a remote surgeon. For this operation, Surgeon A and Surgeon B were both fellowship-trained shoulder specialists; however, there is a paradigm for employing this construct with a resident and an attending physician.18 A recent study by Mattar et al25 revealed deficits in operative skills and autonomy among general surgery graduate trainees entering accredited surgical subspecialty fellowships in the United States. In the realm of orthopedic surgery, research conducted by Karam et al26 identified the importance of surgical skills laboratories and simulation technology as a required component of orthopedic residency training; however, only half of residency programs in the United States have a skills laboratory and program.26 The recent implementation of virtual reality simulation training has been successful in shortening the learning curve of surgical trainees by allowing them to achieve technical skill milestones more rapidly, with the additional benefit of not compromising patient care or extending the length of operations.27-29

Despite encouraging results, virtual reality simulators are imperfect models of the human body. Their interfaces, although sophisticated, do not allow trainees to view, feel, and manipulate the simulator in the way they would a native environment.30 The use of wearable, lightweight computing devices (eg, GG), with augmented reality technologies (eg, VIPAAR), may aid in propelling the further development of surgical telementoring by facilitating the transfer of complex skills from simulated environments to the operating room. In the real-time augmented reality environment generated by VIP, 2 physical realities are merged to provide a shared first-person environment for learning; hence, a remote surgeon can see what the operating surgeon sees and virtually identify relevant anatomy or help guide the surgical technique.7 The promising technology combination described here has the potential to bridge the gap between simulated environments and real surgical environments, provided its cost-effectiveness is demonstrated and several technical and ethical concerns outlined below are appropriately addressed.

The beta version of GG, with its built-in computer and connectivity, is an effective form factor for transmitting

![Figure 5: Remote surgeon at the Virtual Interactive Presence and Augmented Reality (University of Alabama at Birmingham, Birmingham, Alabama) station inserting his hand, in real time, into the surgical field in Birmingham, Alabama.](image)
images of what the user sees and easily seeing text and images through the heads-up display. There have been favorable reports of surgeons’ using GG during surgery; however, these reports demonstrated using GG to capture and record surgery or to inject text, numeric, and image data into the display for viewing as needed.

There have also been reports of using GG for “asynchronous” consultation with remote experts who view the surgical field. Although there may be value in these implementations, no report has described using GG to host real-time interaction for assistance or guidance within the surgical field as captured by the glasses. The authors have described a novel use of GG—to host an interactive augmented reality application for surgical guidance. Their experience with GG to host such real-time interaction has allowed them to identify key issues that should be addressed for the most effective use in a surgical setting. Given its enormous potential value for surgical training and assistance, the authors hope that GG technology will evolve to longer battery life, increased processor power, providing higher-definition video image quality, an operating room-optimized matching of surgeon and camera view lines, and improved sound quality. Another improvement would be a binocular heads-up display, instead of the current monocular display.

Virtual interactive presence is a relatively new technology that has been implemented in surgery on a limited basis. Early implementations of this technology used existing visualization systems such as endoscopes, operating microscopes, and operating room cameras. Integration with endoscopy fit in well with existing workflow, since the surgeon operates in the same field within which the remote surgeon’s hands are merged. That is, the remote surgeon’s hands are seen on the arthroscopy tower monitor, allowing the operating surgeon to view the surgical field as normal while additionally seeing the remote surgeon’s hands point to anatomy in real time. Integration with microscopes and other visualization solutions (mounted cameras) required the surgeon to look at a separate monitor to see the merged image. Although useful, this was not the same as seeing the remote surgeon’s hands superimposed over the actual surgical field as the operating surgeon worked. Early VIPAAR systems required a cart in the operating room; recent mobile device-based solutions have reduced the need for an in-room presence, freeing operating room space. Currently, VIP is an audio-visual interactive solution, without tactile feedback. As the use of augmented reality software in surgical education grows, the addition of tactile feedback should enhance the learning and teaching experience.

Several shortcomings of this study should be kept in mind, the most significant being that this was a single surgeon’s experience involving a single surgical case. In addition, the authors did not seek to quantify benefits or estimate costs related to the adoption of this technological construct. Another limiting factor was that 2 experts in the field of shoulder surgery were involved in this study; therefore, knowledge transfer and skill acquisition were limited. Mainly owing to patient safety concerns and to minimize potential unexpected complications arising from the piloting of this technology combination, the authors did not feel comfortable having a resident perform the surgery while being guided by the remote consulting surgeon. Further research employing the aforementioned study design is warranted.

As surgeons increase their use of GG and related technologies, political, regulatory, and financial concerns will need to be addressed at a broad level. A few of these include medicolegal implications for the remote surgeon if untoward events occur, reimbursement for the assistance provided by the consulting surgeon, HIPAA and hospital network security concerns, informed patient consent, and financial support required for such emerging technologies.

**CONCLUSION**

This project demonstrated that GG can be mounted and worn in the operating room and that the system can host facilitative technology applications such as VIPAAR. However, its use as a real-time surgically optimized augmented reality interface is not yet practical. Improvements to GG such as longer battery life, increased processor power providing higher-definition video image quality, an operating room-optimized matching of surgeon and camera view lines, and better sound quality will enhance its performance in the operating room. Improvements in GG and communications infrastructure will make the integration of head-mounted, line-of-sight systems with real-time mentoring technology increasingly valuable for surgical interaction and mentoring.

**REFERENCES**

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