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Google Glass in pediatric surgery: An exploratory study

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ABSTRACT

Introduction: Personal portable information technology is advancing at a breathtaking speed. Google has recently introduced Glass, a device that is worn like conventional glasses, but that combines a computerized central processing unit, touchpad, display screen, high-definition camera, microphone, bone-conduction transducer, and wireless connectivity. We have obtained a Glass device through Google's Explorer program and have tested its applicability in our daily pediatric surgical practice and in relevant experimental settings.
Methods: Glass was worn daily for 4 consecutive weeks in a University Children's Hospital. A daily log was kept, and activities with a potential applicability were identified. Performance of Glass was evaluated for such activities. In-vitro experiments were conducted where further testing was indicated.
Results: Wearing Glass throughout the day for the study interval was well tolerated. Colleagues, staff, families and patients overwhelmingly had a positive response to Glass. Useful applications for Glass were hands-free photo/videodocumentation, making hands-free telephone calls, looking up billing codes, and internet searches for unfamiliar medical terms or syndromes. Drawbacks encountered with the current equipment were low battery endurance, data protection issues, poor overall audio quality, as well as long transmission latency combined with interruptions and cut-offs during internet videoconferencing.
Conclusion: Glass has the some clear utility in the clinical setting. However, before it can be recommended universally for physicians and surgeons, substantial improvements to the hardware are required, issues of data protection must be solved, and specialized medical applications (apps) need to be developed.

1. Introduction

Portable information and telecommunication technology is advancing at a breathtaking speed. Mobile phones, first introduced in 1973 [1], have merged with personal digital assistants [2] to become what are currently termed smartphones. These offer computing power only available in desktop configurations several years ago, readily available software in the form of downloadable applications (apps), paired with constant connectivity to the internet. However, smartphones mostly still rely on manual input and control. Google Inc. (Mountain View, CA) has recently introduced Glass [3], a device that is worn like conventional glasses, but that includes a computerized central processing unit, integrated display screen, high-definition camera, microphone, bone-conduction sound transducer, and wireless connectivity (Fig. 1, Table 1).

Glass was first introduced in the framework of the Google Explorer Program in February 2013 in a limited edition of 8000 devices at a cost of US$ 1500. Prospective Explorer applicants were required to propose a project on google+ and were screened and selected.

We obtained a Glass device after proposing a pediatric surgery telementoring/teleproctoring project. Although physicians were conjectured to be "early adapters" in a recent letter to the editor [4], so far no reports or studies have been published on Glass in the peer-reviewed medical literature.

2. Research questions

The research questions to be answered by this study were:

- What are potential applications for Glass in the clinical setting? To be answered by brainstorming among participants of this

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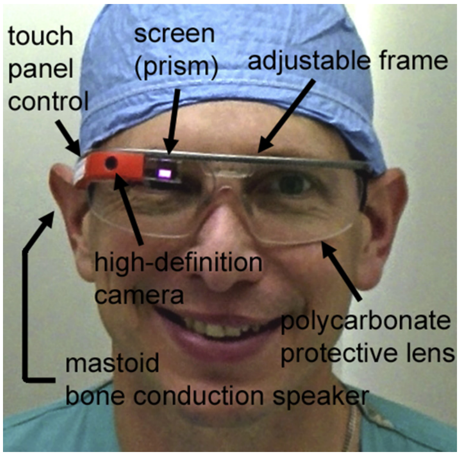

Fig. 1. Anatomy of Glass. The data processing unit of Glass is located on the wearer's right. It incorporates a prism that acts as a screen located just above the surgeon's right eye. The camera is located to the right of the screen, and both parts swivel to adjust to the wearer's individual facial shape. The touch control panel allows the wearer to swipe a finger back, front, and down to scroll through menus and tap to select items. The speaker is located behind the ear, in the battery portion of Glass. It utilizes bone conduction of the sound to the mastoid.

study and discussion with colleagues of other specialties while using Glass in the university hospital.

- What is the clinical utility of Glass in a typical academic pediatric surgical practice? Focusing mainly on photo/video-documentation, as well as online information queries.
- How does Glass perform in select controlled experiments, examining the quality of online information query, quality of videoconferencing, and resolution of imaging information transmitted via a transatlantic internet link?

3. Methods

The offices of risk management and ethics were consulted at both participating institutions and a framework for data handling and privacy was established.

The Glass used in this study was the Explorer version, with specifications listed in Table 1. In the course of the study interval, Glass was connected via Bluetooth to 2 different kinds of phones, a BlackBerry Bold 9650 (Research in Motion Ltd, Waterloo, Canada), and an Alcatel OneTouch Evolve Android 4.1 (Alcatel Lucent SA, Paris, France). The latter was also used for mobile internet tethering of Glass (connecting Glass to the internet via a 3G cellular network (t-Mobile US, Inc., Bellevue, WA)) to facilitate internet access where no local WiFi network was available.

Table 1
Features of Google Glass, Explorer version.

Item	Feature
Processor (CPU)	OMAP 4420 Dual Core
Random access memory (RAM)	.682 Mbytes
Flash memory	16 Gbytes
Operating System	Android 4.0.4 Ice Cream Sandwich
Display	Prismatic head-mount color 640 × 360 pixel
Position sensing equipment	Accelerometer, gyroscope, magnetometer
Light sensing equipment	Ambient light sensor
WiFi connection	802.11b/g
Other connectivity	Bluetooth, micro-USB hub
Camera	5 Mpixels (2528 × 1956 matrix), 720p HD video
Battery	Lithium Polymer 2.1 Ah
Controller input	Capacitative touchpad on right temple frame
Weight	50 g

Glass was worn daily for 4 consecutive weeks in a University Children's Hospital by one of the authors (om). A diary was kept on all activities, uses, drawbacks, snags, and pitfalls. The criteria evaluated included ergonomics, battery life, audiovisual quality, functionality, connectivity, applications, acceptance, and data privacy issues, among others.

When taking pictures or video footage of patients, all subjects and their caregivers were consented for photodocumentation and the resulting files were shared with the patients/families at their request. File upload to a non-secure server was avoided by temporarily deactivating any internet connectivity when patient photographs or video were acquired.

Video recording of a pediatric mock trauma in our hospital was performed to evaluate the capability of following a simulation exercise from the instructor/examiner's perspective.

Opportunities of potential applicability in surgery were identified and collected. Performance of Glass was evaluated for such activities, and in select in-vitro experiments detailed below:

3.1. *Accuracy of coding for pediatric surgical diagnoses and procedures*

Using our Explorer edition Google Glass connected to the university nymc_public wifi connection, a list of 50 of the most common pediatric surgical diagnoses and 50 most common procedures from our billing sheet were entered into Glass via voice recognition input. The syntax used was "ok glass", "google", "cpt" or "ICD-9", and the particular diagnosis or procedure. The resulting search performed by Glass was analyzed for accuracy by comparing the code obtained by the Glass search to the codes on the billing sheet. Accuracy of Glass to produce the correct ICD-9 diagnosis and cpt procedure code were calculated.

3.2. *Lag time and latency of local and transatlantic videoconferencing*

A voice over internet protocol (VoIP) teleconference using the google+ hangout function was established between Glass and a desktop computer on the NYMC campus. Glass was connected to the nymc_public wifi connection; the desktop computer was connected via standard hardwired Ethernet connection in the same building. Lag times were calculated by synchronizing the watches of the participating individuals and measuring the lag between emitting and receiving a defined signal over the hangout connection. In a second experiment, Glass was connected using 3G cellular network internet tethering (as described in Methods above) and the test person was asked to explore the campus, with lag time tests made at 5 min intervals.

In a similar setup, a transatlantic connection between both participating centers (NYMC in Valhalla, NY, and the MHH in Hannover, Germany) was established. Glass was connected to the wifi link through a 6 Mbit/s bandwidth connection on the German side, and a 25 Mbit/s fiberoptic link on the NY side. Lag times were measured as described above.

3.3. *Vision testing through glass via transatlantic internet connection*

A VoIP teleconference using google+ hangout was established as described previously between NYMC and MHH. Standardized Snellen vision test charts were placed at a distance of 50 cm from Glass (in Hannover, Germany). The test person located in New York read the characters out loud for each line with increasingly smaller

Table 2
Voice-to-text inputs (enabled on glass).

say	Shown as	Examples
"Comma"	,	Require Maryland grasper *comma* hook cautery and 5 mm scope
"Period"	.	This concludes my dictation *period*
"Question mark"	?	What is the E T A for the trauma *question mark*
"Exclamation mark"	!	Work hour regulation require you to go home *exclamation mark*
"Smiley face"	:-)	Contextual, use as indicated
"Wink wink"	;-)	Contextual, use as indicated
"Sadface"	:-(	Contextual, use as indicated
"Kissy face"	:-*	Contextual, use as indicated
"Tongueface"	:-P	Contextual, use as indicated
"Grinface"	:-D	Contextual, use as indicated
"Colon"	:	What instruments *colon* 5 or 3 mm question mark
"Semicolon"	;	Allergic reactions colon hives *semicolon* laryngeal swelling period
"One half"	1/2	*One half* of the patients were randomized to the treatment group
"New line"	(Press return once)	Anesthesia colon general *new line* blood loss colon minimal new line
"New paragraph"	(Press return twice)	To whom it may concern comma *new paragraph* i am writing in regards…
"e g"	e.g.	The hernia *e.g.* the open processus
"Hashtag"	#	Metadata tag for social networking

(modified, from https://glass.google.com/myglass).

letters. Error rates were determined and correlated with the size of the characters.

4. Results

4.1. Ergonomics

The test person found the view to be unobstructed by the head-mounted prism display, and the monitor itself was visualized by looking straight up without much effort. Glass is switched on either by manual control via the right temple touchpad or by the optional function of tilting the head back 20–30°. This feature proved useful in the operating room where manual input was impractical due to sterility issues. However, the head tilt function lead to Glass frequent turning on involuntary with everyday normal activity. On the other hand, it did not always react on the first attempt, and Glass automatically turned off after a short lag time of only a few seconds. A nurse watching this resulting repetitive backward head bobbing commented that this "can't be healthy".

In the current version of Glass, the camera is mounted straight ahead, and the camera mount can only be angled to the side to adjust for the wearer's anatomy. In order to record or document an open surgical case, the surgeon was required to perform an extreme downward cervical flexion, which was inconvenient, uncomfortable, and could not be sustained over longer periods of time.

In one instance, the test person wore Glass during a robotic surgery case (using a daVinci Si console, Intuitive Surgical, Sunnyvale, CA). Glass did not interfere with the 3D optical viewfinder or the controls.

Glass can be fitted with optional clear or tinted polycarbonate lenses. For use in the OR, the clear shields were attached and provided good splatter eye protection. Detachment and cleaning of the shields with 70% isopropanol and a microfiber cloth was unproblematic. The prism and chassis was also cleaned without difficulty or damage to the device using the microfiber cloth.

4.2. Input control

The manual input using the right temple touchpad is intuitive and easy. The wearer can easily scroll a "time axis" on previous functions or searches.

The voice recognition feature is pre-programmed by Google to understand some select terms and commands (Tables 2 and 3). It was valuable for the operator to familiarize himself with these terms before interacting with Glass. Text was usually recognized if spoken slowly and clearly.

4.3. Battery life

On a typical clinical day with typical use on rounds, clinics, and in the operating room (no teleconferencing or continuous video recording), one battery charge lasted from 07:00 in the morning to between 15:30 and 17:00 (between 8 1/2 and 10 h). Glass was recharged overnight for at least 6 h before resuming operation the following day. Recharging for longer periods of time (over the weekend) seemed to extend battery life on the subsequent day.

Table 3
Voice action commands (enabled in Glass).

say	Followed by	Examples
"Google"	Anything (questions, measurements, pictures of, etc)	"Google what is Hirschsprung disease"
"Take a picture"	Looking at what you want to take a picture of	
"Record a video"	Looking at what you want to record a video of	
"Get directions to"	Address, name, business name, type of business, or other destination	"Get directions to Westchester Medical Center"
"Send a message to"	One of your sharing contacts, then your message	"Send a message to Matthew Bronstein please come to signout rounds"
"Make a call to"	One of your sharing contacts	
"Make a video call"	One of your sharing contacts	
"Take a note"	Notes, blogs; any large body of voice-to-text input	"Take a note completely necrotic bowel comma decided to close abdomen"
"Post an update"	Text for their friends on the social network	Today period have cholecystectomy scheduled
"Show route overview"	Contextual; used in navigation mode to show entire route on screen	
"Hide route overview"	Contextual; used in navigation mode when showing entire route to go back to route navigation	
"Stop directions"	Contextual; used in navigation mode to stop route navigation	
"Share with"	Contextual; used after taking picture or video followed by one of your sharing contacts	"Share with Martin Lacher"
"Add caption"	Contextual; used after taking picture or video followed by voice-to-text input description or comment	"Add caption taking down Ladds bands"
"Reply"	Contextual; used in SMS or message mode when viewing a message	
"Read aloud"	Contextual; used in SMS or message mode when viewing a message	

(modified, from https://glass.google.com/myglass).

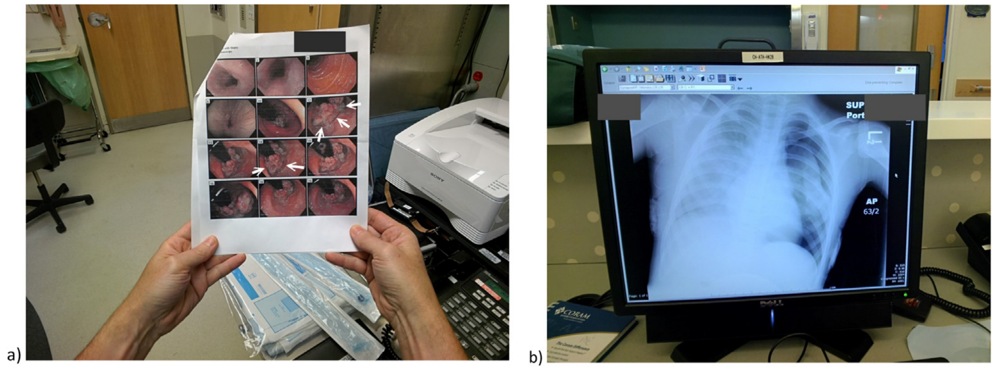

Fig. 2. Documenting pertinent findings during routine clinical activity. The printout of a referring pediatric gastroenterologist's colonoscopy report is held at comfortable arm's length (a), easily identifying a hamartomatous polyp in the low rectum (arrows, uncropped picture) to be excised. Glass adequately documents a left sided pneumothorax after trauma to the chest, displayed on a TFT monitor (b). In general, the 2528 × 1956 resolution matrix of the camera is adequate for high-quality images.

The battery lasted only halfway through a 5 h case that started at 13:00, requiring us to recharge Glass in the middle of the case in order to photo document the latter part of the procedure and immediate operative results.

Continuous video recording or videoconferencing placed a particularly heavy drain on the battery. In both functions, the battery lasted only about 30–40 min until recharging was necessary.

4.4. Audio quality

It was difficult to hear audio through the mastoid bone conduction transducer in all but the quietest environments. Also, the party on the other end of telephone calls and teleconferences had difficulty understanding the wearer of Glass without the latter having to speak at high volume. This made conveying sensitive or private health information impossible in the hospital surrounding. The only way to maintain a conversation using Glass was being in a very quiet room, an office with the door closed for example.

In online discussion with the explorer community, the suggestion was made to cover the contralateral ear during a conversation to improve audio quality. The benefit was marginal, as was cutting the test person's hair short over the mastoid in an effort to improve bone transducer contact.

The test person dictated a total of 5 operative reports using Glass. In general, the transcriptionist had difficulties generating a reasonable record without excessive omissions and errors due to poor audio quality. Although one dictation came through with only one error, 3 of the 5 reports ultimately required re-dictation using a standard telephone line, and no further attempts of dictating through Glass were made.

4.5. Video quality

Glass was used on rounds, clinic and in the operating room to photo document a variety of conditions and media. Overall, the photo and video quality was high, and definitively sufficient to document all clinically relevant findings (Fig. 2).

Recording of the mock trauma from the examiner's perspective showed good audio and video quality, clearly documenting the participants' actions and verbalizations during the simulation exercise (video 1).

Supplementary video related to this article can be found at http://dx.doi.org/10.1016/j.ijsu.2014.02.003.

Difficult lighting circumstances (standard overhead operating lamps) had the potential to somewhat compromise image quality by overexposing the region of interest (Fig. 3). Also, the lack of a built-in flash lead to decreased image quality in low-lighting environments.

Another perceived deficiency was the lack of a zoom function, since the wide-angle lens of the camera captured a field of view too large for most typical medical applications. This led to decreased size of the surgical region of interest (operative field, monitor) on the obtained image (Fig. 4) unless the surgeon came unusually or impractically close to it with his head.

The head mount display screen was easily seen with the right eye and seemed to have adequate resolution to pick up pertinent details in most circumstances. Its contrast improved when looking at a dark background. When looking at very light backgrounds, it was hard to pick up subtle findings, particularly on projected radiographs.

The following is the supplementary video related to this article:

Video 1.

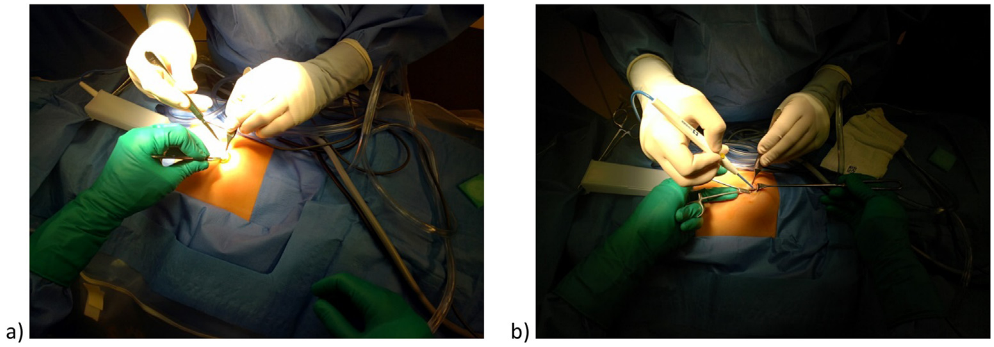

Fig. 3. Exposure and lighting control is important to obtain pictures of adequate quality with Glass. Overexposure (a) can be overcome by asking the nurse to dim the overhead surgical lights (b). Of note, Glass lacks a flash and therefore cannot compensate in low lighting condition (uncropped images).

4.6. Functionality

The factory-set default for video capturing is only 10 s, after which Glass requires manual input to extend the recording time for longer clips. While this interval may be adequate for social media, the automatic video timeout made hands-off recording of longer operating sequences impossible without modification of the software.

Complex medical terms such as “Ellis van Creveld Syndrome”, Microvillous Inclusion Disease”, “Cornelia de Lange Syndrome”, among others, were identified correctly by the voice recognition software about half the time. The information provided by the Google search engine was generally useful for clinical decision making. It was mostly based on entries to Wikipedia, pubmed, or other medical online repositories.

For mock telementoring and teleproctoring sessions between a person sitting at a desktop computer and an individual wearing Glass, the google+ hangout application proved useful, although it was compromised by a variable lag time, freezing of the picture, and occasional cut-offs. It allowed multiple persons to join a conversation and participate in the teleproctoring. Also, the hangout application allowed participants to switch the video stream they broadcasted between the camera and their computer screens (“screenshare” function), which facilitated the transmission of medical images, diagrams, or alphanumeric information such as vital signs or laboratory values to the hangout, including the person wearing Glass.

4.7. Connectivity

Glass automatically connected to pre-programmed WiFi networks, and picked up the smartphones’ Bluetooth without any problems. Programming new WiFi networks was unproblematic via the website https://glass.google.com/myglass, through which the information including access codes was entered by scanning an individually generated on-screen quick response (QR) code with the Glass camera.

By design, data left on Glass was synchronized automatically to the Google cloud server through the WiFi connection anytime Glass was being charged and a stable WiFi connection was available.

However, hardwiring Glass to a computer through the micro-USB hub allowed the user to access the flash memory as an external drive, allowing data to be transferred, modified, and deleted without uploading it to a server.

4.8. Available software applications (apps)

Currently downloadable software applications that were executable without programming skills for Glass were found at https://glass.google.com/glassware. The available selection of apps was mainly focused on news and social media (Facebook™, Twitter™, Youtube™, cooking recipes, newspapers, magazines, shopping apps to name a few). There were no specific apps for the medical community on this site during the study interval.

4.9. Environmental acceptance

Overall, people had very favorable attitude towards Glass, including parents, patients, nurses, and colleagues. Many were interested, asked questions, and some spontaneously thought of applications that they felt would be worth exploring (Table 4). A few individuals were concerned that Glass could be filming or recording them clandestinely, and they were reassured that no recording of any sort was taking place without their knowledge and consent.

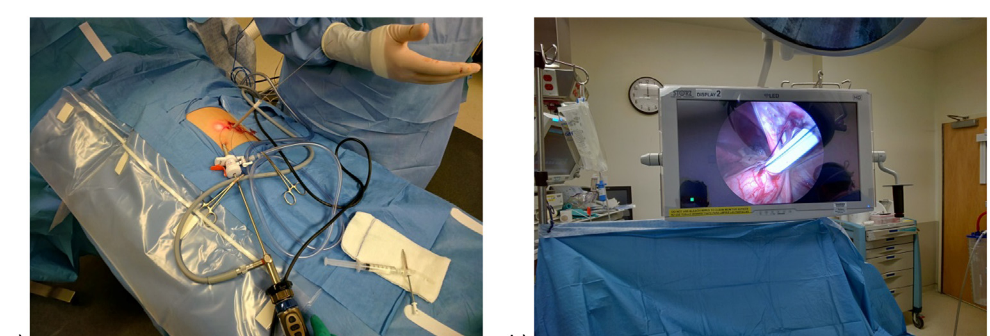

Fig. 4. Glass documentation of laparoscopic gastrostomy placement (uncropped images). Although details of the operating situs are well captured (a), the monitor only fills a small part of the entire field of view, and screen reflection on the monitor compromises clear identification of the intra-abdominal structures (b).

4.10. Data privacy issues

The main issue with regards to data privacy was the automatic synchronization of data to the Google server when Glass was being charged and connected to a stable WiFi network, since this would potentially allow protected health data to be transferred to an unprotected server outside of the hospital. We avoided such a breach by temporarily deactivating the internet connection as well as downloading and deleting all patient data from Glass before the automatic synchronization could take place.

The ethics board of our hospital was concerned that patient data was streamed through unsecured servers during a clinical VoIP hangout telementoring/teleproctoring session. Therefore, in this study, we exclusively performed hangout videoconferencing in an in-vitro or mock experimental setting without any true patient involvement.

4.11. Experiments

4.11.1. Coding accuracy

Glass provided the correct ICD 9 diagnosis codes in 82% of cases and the correct CPT procedure code in 74% of cases.

4.11.2. Lag time of videoconferencing

Lag times from the desktop computer to Glass were 1–5 s when connected via the university WiFi, 3–5 s when connected via 3G cellular phone network tethering, and up to 12 s for the transatlantic connection. There was occasional freezing of the image, and some cut-offs that either resolved spontaneously after a few seconds or required reconnection through the hangout (more frequent in the transatlantic transmission), although these occurrences were not quantified.

4.11.3. Transatlantic vision test

All characters 8 mm in size or larger were correctly identified in the transatlantic vision test. None of the characters 3 mm or smaller were legible in any of the trials (Fig. 5).

5. Discussion

To our knowledge, this is the first time a systematic evaluation of Google Glass in the healthcare environment has been performed. Several reports of the potential utility of Glass for medical doctors are available in the popular press and online [5–7], but most of these are limited to anecdotal "proof of concept" applications, lack in-depth analysis of advantages versus drawbacks, and so far no studies on Glass have been published in the peer-reviewed medical literature. Interestingly, the operating room is identified as a potential setting where Glass could become most beneficial, and indeed several reports document the live two-way broadcast of actual patient surgeries [8,9]. It is surprising that practically none of these accounts include a discussion on data privacy and security, taking into account that the data streaming in these activities takes place via a potentially unsecured Google server by default. One surgeon used Glass in the operating room to view pertinent imaging data during the actual procedure [10]. In this case, the data was loaded onto the flash memory prior to surgery, and was accessed as needed. A problem was being able to scroll through images without using manual control, as there is no verbal scrolling command pre-programmed into the current version of Glass.

In one recent article [11], the authors used Glass to follow procedures in Oral and Maxillofacial Surgery to assess if the recording would add anything to conventional documentation through existing wall-mounted/OR light cameras. They postulated some utility for students watching from a surgeon's perspective, but also recognized the problem of the camera's inopportune frontviewing angle to record the operative field, as well as "choppy" footage due to movement of the surgeon's head. Having a hinge that can point the camera downwards at a 40–50° angle would be useful, not just

Table 4
Some potential applications for Google Glass in the surgical setting.

Application	Examples	Anticipated challenges
Telementoring during surgery	An experienced surgeon could give advice in real-time during an operation.	- Camera angle and field of view. - Quality of 2-way transmission, lag time. - Legal aspects, responsibility, privileges, licensing, malpractice, data security.
Recording consent discussion	Surgeon wears Glass during informed consent discussion. Record is later shared with patient family.	- Battery life - Downloading and sharing cumbersome
Telepresence in the trauma bay, on patient transports, emergency room, or intensive care unit.	Junior practitioners can be supervised by and can interact with faculty and experts, particularly in unusual or unanticipated circumstances.	- Camera angle and field of view. - Quality of 2-way transmission, lag time. - Legal aspects, responsibility, privileges, licensing, malpractice, data security.
Photodocumentation in the operating room	Surgeon can take pictures and video clips during an operation using voice commands and without breaking scrub	- Camera angle and field of view - Lighting conditions (see Fig. 3) - Data security if uploaded to server
Interaction with parents/caregivers during an operation	Surgeons could "call" the parents/caregivers during long procedures for an update and reassurance	- Potential to interrupt surgical workflow
Answering calls and text messages	Glass can be used to answer telephone calls and text messages without breaking scrub	- Distraction from operation - Poor audio quality (with Glass version 1.0)
Coding	ICD 9/10 and CPT codes can be looked up	- Glass recognizes only about 70–80% of all procedures/diagnoses using voice input
Online medical encyclopedia	Unusual syndromes and conditions can be looked up on the go	- Glass may not recognize voice input -Asking Glass to look up condition verbally may be disruptive to surrounding - List of results requires manual scrolling
Viewing real-time fluoroscopy or ultrasound images when performing percutaneous access	During percutaneous central venous access, or during percutaneous orthopedic procedures, the realtime ultrasound or fluoroscopy images could be visible for the surgeon in the head-mounted display of Glass, allowing the surgeon to have a simultaneous view of the surgical field and the imaging information.	- the resolution of the screen may be insufficient to project discreet findings. - Lag time of the acquired versus the displayed image must be minimal.

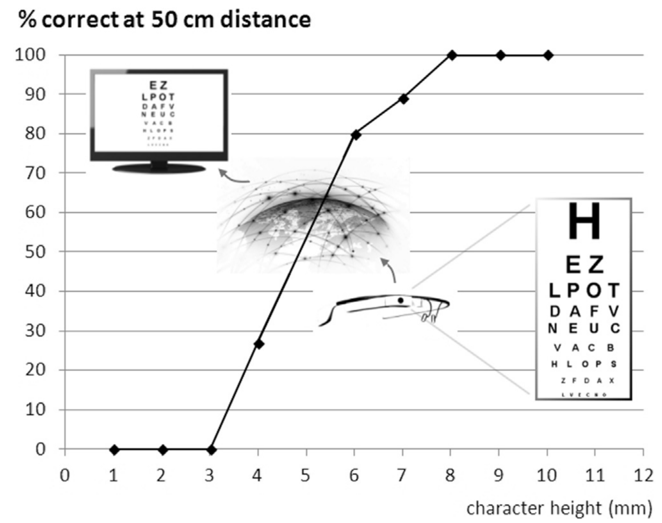

Fig. 5. Transatlantic vision acuity test using standard Snellen chart. The charts were scanned with Glass in Germany in 50 cm distance, and the receiving test person was reading the transmitted image on a standard 19 inch TFT monitor using a google+ hangout connection. The graph represents the percentage of correctly identified characters in relationship to the actual character height (in mm).

in surgery, but also in other professional fields with a typical optical benchtop working configuration [12].

Another group discussed the use of Google Glass in interventional radiology [13], and concluded that Glass could play a big role in training, and that head-worn action cameras may be alternatives. While action cameras are already worn by many athletes to obtain spectacular images, they generally do not possess the integrated processing power or 2-way audiovisual capabilities of Glass. Also, action cameras generally are much heavier and cumbersome compared to Glass.

Bluetooth earpieces that link to a mobile phone allow hands-free audio communication but lack the videoconferencing capabilities of Glass. They also have a very limited set of voice commands and by themselves do not link to the internet. Although frequently used by professionals, including surgeons, their impact in clinical practice has not been systematically evaluated.

However, hands-free communication has been studied in driving, with some concern that communicating during traffic negatively impacts on the alertness and attention, particularly in individuals of advanced age [14]. This could be particularly relevant if a surgeon is distracted by accepting a call during a complex or critical portion of a procedure.

We agree that Glass has some promising utility in the medical setting. However, our study has shown that before a universal recommendation, substantial improvements should be made to both the hardware and software, and specialized medical applications (apps) need to be developed.

For example, a significant drawback is the limited battery power of the current version of Glass. Most surgeons work more than 10–12 h per day, and a device that could hold its charge and function for at least a full 24 h before recharging would be necessary and practical in our field. Also, the battery capacity needs to be much more powerful if continuous video recording or videoconferencing (necessary for telepresence/telementoring/teleproctoring applications such as proposed by the above referenced sources) are planned. While waiting for a Glass version with a more powerful battery, an external battery pack can be connected to the USB-hub as an interim solution. These battery packs are readily available in electronic stores, usually add between 2 and 6 Ah, but require the surgeon to carry a separate pack connected to Glass by cable. Another option would be to hardwire the surgeon during the procedure via the USB port.

While the image quality of the Glass camera was overall quite good, we propose some modifications that would enhance the applicability in medicine. An LED (light emitting diode) flash or supplemental light source would be helpful to obtain optimal photos and video in low-lighting conditions. LED flashes are standard on most smartphones today, and should be integrated on future Glass versions. In addition, a zoom function with voice control would allow the surgeon to focus in on the region of interest, such as the monitor during laparoscopic procedures, or the surgical field.

Considering the prototype nature of the voice recognition software on Glass, and its design for a wide variety of activities, it was surprising to find that it recognized many complex medical terms. For reliable medical application, however, the error rate must be decreased substantially. Integrating dictionary and syntax modules available for different specialties, such as medicine, engineering, aerospace, biochemistry etc. for example, would enhance voice recognition and make Glass more suitable for professionals.

It also would be advantageous to expand the spectrum of the built-in audiovisual voice commands of Glass functions, for example to extend video recording beyond the 10 s default. Short clips may be sufficient for social media, but they are mostly inadequate for documentation and education in the clinical surrounding.

The less than optimal transmission quality encountered in our experiments may be due to extrinsic factors other than Glass. However, considering the lag time, the cut-outs, and the occasional dropped connection encountered with current equipment, we doubt that meaningful telementoring/teleproctoring in the operating room is feasible in this phase of development. Our vision test showed that fine print was not recognizable during teleconferencing. A more stable connection, higher video resolution, and quicker response time is needed.

At this time, there are no special programs available for the medical community, which means that such apps so far must be created by the end-user. Surgeons usually lack the time and skills to program apps, and programmers may not understand the functionality sought by physicians and surgeons. We propose that Google as well as other software companies join in on an interdisciplinary discussion between developers, programmers, and medical users to develop software applications for the medical and surgical field. One very interesting application would be to integrate documentation of a procedure (dictating the operative report, including key images during surgery for medico legal purposes) with coding, billing, and logging the case. Also, the patient's name and wrist-worn barcode could be scanned before the procedure, and Glass could aid in the timeout process by verifying the correct patient, procedure, and laterality of the intervention. Besides our limited compilation of potential uses in Table 4, there are countless other applications for surgery and medicine that are worth exploring. Applications can be grouped into those helping with information gathering (online queries of medical dictionaries, coding), virtual presence (videoconferencing, telementoring, teleproctoring), hands-free video or photodocumentation (including physical findings, procedures, and processes such as consenting), and heads-up display of clinical or imaging information (displaying vital signs or laboratory values during a trauma, real-time ultrasound imaging during percutaneous access procedures). Concerning medical and surgical education, it may be useful to allow an instructor to visualize a particular situation "from the student's perspective" be having the latter wear Glass and the instructor follow the action on screen. This way, the instructor can better understand the student's point of view, describe what the student is looking at, and proctor the trainee in a way previously not feasible.

The data privacy issues raised by our experiments with Google Glass need to be part of timely, much broader discussion. Recent political events have revealed that government agencies use mass surveillance tactics and have the capability to break into even the most heavily secured networks, including the mobile phones of allied heads of state [15]. Thus, even advanced data encryption does not necessarily guarantee privacy in our times. Healthcare providers are required to protect all private and sensitive patient information. At the same time, practitioners are generally described as "early adapters" of new technology [4], and items such as smartphones are in ubiquitous use among medical doctors around the world. In a survey among faculty of North American postgraduate medical training programs, over 85% of respondents used a smartphone, and most used smartphone apps in clinical practice, including apps where sensitive patient information was entered and stored [16]. Although widely prevalent, there is practically no regulation of this technology to date. Some hospitals may ban or restrict the use of smartphones entirely, effectively depriving their staff of the clear benefits of handheld personal information technology. Others simply ignore the problem by transferring the responsibility and legal risk to their staff in the hope that the governments or some other regulatory body will provide a universal framework for practice. Neither course of action is appropriate nor desirable and should be replaced by a proactive initiative that embraces new technologies, and at the same time protects patients as well as healthcare professionals along with sensitive information.

A pivotal problem is that many of the data processed via smartphones are automatically uploaded to a potentially unprotected server. On Android phones, for example, the default setting automatically uploads any taken pictures to the photo application in google+ (and thereby, the Google server). Conversely, pictures taken on an iPhone are automatically synchronized to Apple's Fotostream function on its iCloud server if the user does not specifically disable it. While less critical for social media information, it is particularly important in the healthcare workplace to allow the user to determine which data are synchronized to what kind of server at what time point, and to avoid automatic uploads or synchronizations without user control. As a rule, smartphones and portable devices should not synchronize sensitive patient data to a commercial server, and physicians using any kind of smartphone should carefully turn any "auto-sync" function off.

In our trial phase, we noticed that Glass automatically synchronizes when it is plugged in for charging and has a stable WiFi connection. Since we had no control over the synchronization, we disabled the internet connection during the acquisition of patient information, and only turned the connection back on after the data were downloaded to an encrypted laptop and erased from Glass. Consequently in future versions, the Google Glass software should be modified to allow the user more control over synchronization events. It should also allow the user to avoid uploading of any information to an unsecured server. In the long run, information companies such as Google or Apple may exhibit an interest in working with the medical community to design a secure network and server strategy that could be certified by hospitals for use by their staff. From an entrepreneurial perspective, such a service could even take the form of a fee-based subscription, offering high-level encryption for data transfer and storage. Besides physicians and surgeons, other interested entities such as patients, therapy groups, as well as direct-observed medication administration projects, may be interested in such a service.

Another concrete important issue is hygiene of Glass in the hospital. We tested Glass for the possibility of cleaning with 70% isopropanol. The shields, the frame, the touchpad and the prism tolerated repetitive wiping with alcohol, and no adverse effects were noted on the equipment. Stronger more aggressive solvents were not used, nor were they considered essential in this context. Of note, the current design of Glass is not compatible with prescription eye glasses. This is another important improvement in a future version.

Admittedly, our report has several limitations. Foremost, it falls short of representing a true controlled scientific study. As such, it should rather be taken as a report on our cumulative experience of an innovative device in a novel setting, taking into considerations ethical, legal, and practical constraints. The internet connections were not standardized or quantified for speed and reliability, we simply used what was practical in our general setting. All statistics mentioned are purely descriptive. Furthermore, things such as voice recognition may depend on the clarity of the individual speaking and may vary with different persons.

In essence, the current version of Glass changed our everyday work routine mostly in three particular aspects:

- Hands-free photodocumentation and video recording, particularly useful in the sterile environment of the operating room, since it allows recording from the surgeon's perspective without changing gloves or compromising sterility.
- Realtime online search of complex medical condition and rare syndromes, as well as diagnosis and procedure codes for billing.
- Hands-free 2-way communication by telephone or videoconferencing (audio currently limited by poor quality as described above).

6. Conclusion

Google Glass has some clear utility in the clinical setting, and foreseeably a great potential to favorably impact medical and surgical practitioners in their daily activities. However, there are significant drawbacks in the current design and performance of the device in the healthcare environment. Google is about to exchange the Explorer version of Glass with the next edition 2.0. We are looking forward to evaluate the next generation device and provide feedback to help with the future development of a specialized Glass for tomorrow's medical and surgical community.

Ethical approval

Hospital risk management was consulted both at the Westchester Medical Center and at the Medizinische Hochschule Hannover.

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Author contribution

Oliver J. Muensterer: Grant aquisition, study design, study subject, data collection, data analysis, writing of the manuscript.

Martin Lacher: Study design, data collection, data analysis, editing the manuscript.

Christoph Zoeller: Study design, data collection, computer and network setup, editing of the manuscript.

Matthew Bronstein: Data collection, computer program setup, editing of the manuscript.

Joachim Kübler: Study design, experimental design, data collection, data analysis, editing of the manuscript.

Conflicts of interest

The authors have no conflict of interest.

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