The Use of Live Streaming Technologies in Surgery

A Review of the Literature

Muhammad Abu-Rmaileh, BS,[a] Tamara Osborn, MD,[b] Santiago R. Gonzalez, MD, MPH,[c] and James C. Yuen, MD[d]

Background: Live streaming surgery is a developing communication platform in medicine. To maximize the technological advances that allow for the live streaming of surgery, it is crucial to have an understanding of the various video-capturing devices that are available and their pros and cons of implementation. Possible barriers to the widespread use of live streaming surgery include cost, concerns about patient safety and privacy, and limited understanding of the current available resources. In this article, we present the results of our literature review of techniques for live streaming of surgery as a means to inform readers and promote their implementation.

Methods: We conducted a literature review of the literature to identify previous articles indexed in PubMed and Ovid. We used the following search terms: [Surgery AND Streaming], which generated 32 articles for initial review. References were reviewed within each document to find similar articles that were not captured by the initial search. The article selection criteria were peer-reviewed publications, case reports, and case series describing the use of live surgical streaming technologies.

Results: Literature review showed enhanced surgeon interaction with viewers and improved anatomy scores with the widespread use of live streaming. Surgeons reported positive feedback and wished to engage in more sessions in the future. The largest barriers to implementation of streaming technology are video quality through the Internet and patient information protection.

Conclusions: Live streaming of surgery for educational purposes has not been widely accepted in surgical training programs to date. Streaming accessibility has advanced over the past 2 decades with the availability of handheld mobile devices. However, little has been done to allow for live streaming of surgery to trainees in a manner compliant with the Health Portability Insurance and Accountability Act.

Key Words: distant learning, GoPro, live stream, live streaming, live surgery, livestream, livestreaming, medical education, remote learning, stream, streaming, surgical training, technology in medicine, teleconference, zoom

(*Ann Plast Surg* 2021;00: 00–00)

Streaming of live surgery is an evolving tool used in surgical education. Advances in technology and network speeds have allowed for live surgery to be an adjunct to modern training. Surgical live streaming promotes access to surgical expertise for trainees at all levels including medical students, residents, and fellows. Moreover, the COVID-19 pandemic has fostered the advancement of live streaming and teleconference systems such as Zoom, Cisco, and Google Meets, among others.[1] To maximize the utility of the technological advances that allow for the live streaming of surgery it is crucial to have an understanding of the various video-capturing devices that are available on the market. Our review showcases devices such as smart glasses, the Raspberry Pi, and the GoPro as some available video-capturing devices that may be used for live surgical streaming.

Although the benefits of surgical streaming are clear, live streaming has seen limited use by surgeons.[2] Limitations include cost, expertise, equipment challenges, and concerns for Heath Insurance Portability and Accountability (HIPAA) violations.[2] In this article, we present the results of our literature search reporting the evolving techniques for live streaming surgery as a literature review.

Received December 9, 2020, and accepted for publication, after revision March 26, 2021.

From the [a]College of Medicine, [b]Department of Surgery, University of Arkansas for Medical Sciences, Little Rock, AR; [c]Division of Plastic and Reconstructive Surgery, Department of Surgery, University of California San Francisco, San Francisco, CA; and [d]Division of Plastic Surgery, Department of Surgery, University of Arkansas for Medical Sciences, Little Rock, AR.

Conflicts of interest and sources of funding: none declared.

Reprints: James C. Yuen, MD, University of Arkansas for Medical Sciences, Slot 720, 4301 W. Markham St., Little Rock, AR 72205. E-mail: yuenjamesc@uams.edu.

ISSN: 0148-7043/21/0000–0000
DOI: 10.1097/SAP.0000000000002909

METHODS

For this literature review article, we conducted a comprehensive literature search to identify previous articles by indexing PubMed and Ovid. There were 3013 articles found using Pubmed and Ovid search using the search terms: Surgery AND (Stream OR Streaming). References were reviewed within each document to find similar articles that were not captured by the initial search.

Eligibility for Inclusion

Live streaming is defined as online streaming media simultaneously recorded and broadcast in real time.[3] The article selection criteria were peer-reviewed publications, case reports, or case series using technology and live surgical streaming, and articles reporting innovation and novel use of technology for live-surgical streaming. Articles were excluded if they were recorded but not broadcast in real-time, duplicate articles, and if they did not discuss use of novel streaming technique for the use of surgical education.

RESULTS

There were 3013 articles found using Pubmed and Ovid search using the search terms: Surgery AND Stream OR Streaming. Of the 3013 articles, 2713 articles were not related to surgical streaming technology and were narrowed to 300 articles. We further reviewed the articles and found only 30 articles about surgical streaming and medical education. Further review of the references in these articles captured 2 more articles that were not found on initial search, and they were added to the literature review (Fig. 1). Table 1 documents the various live streaming platforms used by the different surgical specialties in chronological order.

Progression of Streaming Technologies

Live streaming surgery began with Isidor Schwaner Ravdin at the University of Pennsylvania when he broadcast the first surgery on television in 1952 with television cameras in the OR.[26] This initial operation showed the potential of live-streaming surgery and drew interest from the general public and medical practitioners alike. The first documented case of surgical streaming was performed in 1965 by Dr. DeBakey when he live streamed an aortic valve replacement via satellite approach with interactive telecommunication with surgeons in Europe.[27] The first clinical trial evaluating the efficacy of telecommunication of surgical education was published soon thereafter.[28] Teleconferencing systems of various kinds were set up all over the world including Norway,[29] Italy,[30] Brazil,[31] Singapore,[21] and many more.

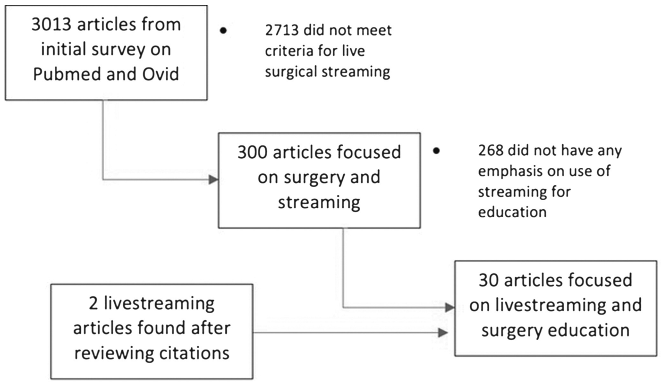

FIGURE 1. Inclusion criteria for literature review article.

Although these were the first steps in establishing clinical telementoring, they were clunky, expensive, and inaccessible to the average consumer.

Use of the World Wide Web and affordable consumer technology to stream surgery was first used in 2002 by Gandsas et al[4] at the University of Kentucky Medical Center. Initial technologies relied on a handheld computer and a video hub managed on a private local area network (LAN) linked together via Ethernet cables.[4,12] The streaming capabilities of this early system was limited by central processing units (CPUs) that could only render images up to 15 frames per second (fps) with an average Internet speed of 150 kbps.[32] There was substantial lag time and reduced image quality that halted using live streaming as an educational tool at this time, as well as the lack of wireless access. Further advances to these technologies occurred as hardware and connection speeds improved.

The first use of desktop computers for wireless live streaming was demonstrated in 2007 by Schneider et al.[6] The system was transmitted through a wireless LAN (WLAN) access points, which provided a connection speed of 11 Mb/s. The video streaming was used through Siemens and sent to a Pocket personal computer (brand: PocketLoox 600 of Fujitsu, Fig. 2).[6] This was an improvement on previous advances as it allowed clear definition of operative techniques and structures. Eighty-two percent of structures were able to be clearly identified via live streaming.[6] The primary limiting factor at this time was the inverse relationship between distance and connection speed.

In the more modern era, the market has primarily narrowed itself down to 2 main technologies: smart glasses, the most famous being Google Glass, and action point cameras, such as the GoPro. These 2 technologies are the most well-studied means of live streaming surgery.

Smart Glasses

Smart glasses are wearable glasses that contain small computers. They typically contain a video camera that can record and display what the viewer is seeing within the glasses themselves for an immersive experience. Their application for live streaming operative cases is apparent as surgery can be recorded in a first-person perspective. The first recording of plastic surgery via smart glasses (Google Glass) was performed on October 29, 2013, by Dr. Rosenfield for lower lid blepharoplasty.[9] The first live stream via Google Glass through Google Hangouts was done by Dr. Ponce at the University of Alabama for a shoulder replacement surgery on September 12, 2013.[9,33] Hiranaka et al[16] used Infolinker Smart-Glasses which transmitted the video stream through the web browser. Smart glasses have been used in a wide-variety of operations[8,11,14,17,20,22] and clinical applications (Fig. 3).

One of the major advantages of Smart glasses is the ability to see the point of view of the surgeon. Learners can see a first-person point of view from an expert surgeon. Students can have improved visibility of difficult to view areas of the operation. An additional benefit is augmented reality, where a surgeon can allow another surgeon to virtually superimpose their hands within the surgical field to provide intraoperative guidance.[34] Intraoperatively, surgeons can verify recording and interact with viewers. Quality is improved compared with other methods. These devices are hand free and allow the surgeon to work without disrupting aseptic technique. They are additionally user-friendly. All the surgeon has to do is place the glasses on, and no further adjustments are needed.

There are a few disadvantages to these devices. The biggest hindrance is image quality, which is dependent on network speed. Hiranka conducted 3 trials with the video quality ranging from 320×240 with a frame rate of 5 fps to 640×480 with a frame rate of 15 fps.[16] Image quality has been described as inferior to digital single-lens reflex.[35] Battery life has been shown to be limited to 8.5–10 hours throughout the day and 2.5 hours in the OR. As of this writing there have been a few battery packs that extend the life of these glasses. Lighting and audio quality are generally limited and require an attached light-emitting headset and audio-canceling headphones, respectively. These issues—especially privacy—were some of the reasons Google stopped production for mainstream consumption[36]; however, Google has since been reintroduced for manufacturing and healthcare sectors looking to streamline workflow.[37]

Raspberry Pi

Chaves et al[38] developed a system that wirelessly streams surgery using a Raspberry Pi device. A Raspberry Pi is a mini single board computer that can be used for a variety of purposes, depending on their programming. Chaves' hardware included a Logitech C270 webcam, a Raspberry Pi 2 model B using Linux operating system (Fig. 4), a wireless adaptor, and a battery. The videos were streamed using Mjpeg-streamer, which is a streaming application designed for devices with limited CPU and random access memory space. Because of the small CPU and memory of the Raspberry Pi, the images are transferred through hypertext transfer protocol to web browsers using motion JPEG (MJPEG) streaming.[38]

The primary advantage of this set up is that it is cost-effective and the entire setup costs around $100. This provides an affordable, yet effective means of transmitting live streamed surgical procedures. They were able to achieve high video quality using a HD 720p capture with a transmission speed of 150 Mpbs with addition of a 4-dBi antenna. The stream was able to connect to multiple computers to live stream the surgery.

The primary disadvantage to this setup is a lack of audio. At the time of this writing, no means of transmitting audio or interacting with students has been incorporated. The Mjpeg-streamer lacked a way to stream audio concurrently with video; however, incorporation of audio is in development.[38] The authors noted stream quality can use improvement as well.[38]

Go-Pro

Go-Pro HERO system is one of the leading commercially available action cameras. Bizzotto et al[7] were the first group to do a point of view test of the Go-Pro in orthopedic and general study. Since that study, Go-Pros have been used extensively in surgical recording and education, as the device has a base unit cost of $400 and is easy to use. Go-Pros have been used to record and transmit various specialties, such as orthopedic,[7,15] neurosurgery,[20] otolaryngology,[23] opthalmology,[18] and many others.

One of the advantages is the image quality as GoPro can record using 4K SuperView and has a built-in microphone for audio recording.[18] The device is portable and easy to use and does not have a steep learning curve. A companion application allows the surgeon to calibrate the camera's focus to the surgeon's working distance. Battery life ranges with high-quality video recording has ranged from 1.5 to 14.5 hours.[23] GoPro recorded surgery with subsequent review from attending surgeons lead to a 90% satisfaction rate among residents in addition to 80% finding areas to improve upon in surgery.[24] In a feasibility studying comparing GoPro Hero 4 silver, Google Glass, and Panasonic Hx-A100, the GoPro had the highest quality of video.[20]

Go-Pro does have limitations. Operating room lights can overexpose the video and requires extensive adjustment before proceeding

TABLE 1. Surgical Specialties and Live Streaming: Documents the Various Live Streaming Platforms Used in Various Surgical Specialties

Authors	Year	Procedure	Technology	Processing	Speed	Image Quality	Length of Recording	Interactive?	HIPAA Compliant
Gandsas, McIntire, and Park[4]	2002	Laproscopic surgery	iPAQ	WLAN	15 s lag	320 × 240	Not mentioned	Yes	No
Gandsas, McIntire, and Park[5]	2004	Laproscopic splenectomy	iPAQ	WLAN	15 s lag	320 × 240	2 h	Yes	Yes
Schneider et al.[6]	2007	General surgeries	Pocket PC	WLAN	8 fps	320p × 240p	Not mentioned	No	Yes
Bizzotto et al.[7]	2014	Orthopedic surgeries	GoPro HERO3	Recorded on Device	30 fps	1080p	1.5 h	No	No
Armstrong et al.[8]	2014	Plantar defect closure	Google Glass	Bluetooth	Not mentioned	640	4 h	No	No
Davis and Rosenthal[9]	2015	Plastic surgery	Google Glass	WIFI	Not mentioned	Not mentioned	Not mentioned	Yes	No
Muensterer et al.[10]	2014	Pediatric surgery	Google Glass	WIFI	"choppy"	720p	Not mentioned	No	No
Knight et al.[11]	2015	Loop recorder placement	Google Glass	Bluetooth	No lag	640	4 h	No	No
Collins et al.[12]	2015	Robotic urology surgeries	Livearena company	Live stream via Internet	15 s lag	Not mentioned	24 h	No	No
Moshtaghi et al.[13]	2015	Otolaryngology surgeries	Google Glass	Live stream via Pristine	Not mentioned	640	Not mentioned	No	No
Baldwin et al.[14]	2016	Lung transplants	Google Glass	Live stream via Internet	Not mentioned	640	4 h	Yes	No
Vara et al.[15]	2016	Upper extremity surgery	GoPro HERO4	Recorded on Device	Not mentioned	4K	1.05 h	No	Yes
Hiranaka et al.[16]	2017	Knee arthroplasty	InfoLinker Smartglasses	WLAN	15 fps	1922p × 1216p	"Prolonged"	No	Yes
Nakhla et al.[17]	2017	Craniotomy and discectomy	Google Glass	Recorded on Device	Not mentioned	Not mentioned	49 min	No	No
Ho et al.[18]	2017	Scleral buckle placement	GoPro HERO4	Bluetooth	30 fps	4K	1.05 h	No	No
Moore et al.[19]	2018	AVF creation	GoPro	Recorded on device	Not mentioned	Not mentioned	Not mentioned	No	Yes
Lee et al.[20]	2017	Spine surgery	Google Glass	Bluetooth	30	720	570 min	No	No
Lee et al.[21]	[illegible]	Spine surgery	GoPRo and Panasonic	WIFI	15–240	1080 (4K)	1–1.5 h	No	No
Diaz et al.[22]	[illegible]	Meningioma resection	Google Glass	Live stream via Internet	"Adequate"	640	4 h	No	No
Ganry et al.[23]	2019	Otolaryngology surgeries	GoPro HERO6	Recorded on Device	60 fps	1080p	14.5 h	No	No
Jack et al[24]	2020	Neurosurgery	GoPro HERO5 and Zoom	WIFI	30 fps	1081 (4K)	Not mentioned	Yes	Yes
Yuen et al[25]	2020	Plastic surgery	GoPro 7 and Zoom	WIFI	30 fps*	1080 (4K)	4 h	Yes	Yes

* GoPro recorded in 30 fps, but because the video transmission was going through ZOOM (wifi), the reception on the students' end was only 2–3 fps. Sessions streamed were 4 hours long, but battery pack can last up to 8 plus hours.

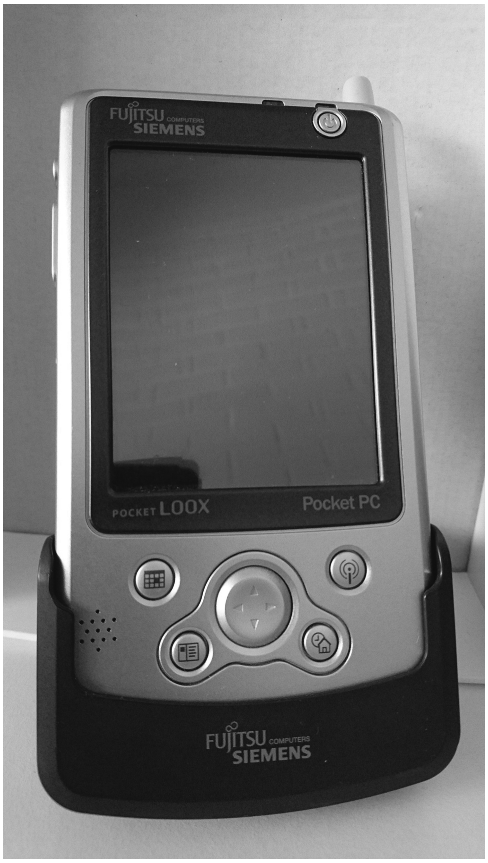

FIGURE 2. First PocketPC used for surgical streaming (5.2 × 3.2 × 0.7 in, 6.2 oz).

with the surgical case, but this is typical with most video systems. Head and camera position need to be adjusted and are challenging to change once starting the case. The weight of the device and the compression of the elastic band can also lead to increased surgeon discomfort and fatigue.[19]

Previously, there was no means of using Go-Pro to live stream a surgical case until this year. An emerging technique combines Go-Pro and Zoom streaming technology. Jack et al[24] and Yuen et al[25] were able to stream surgical cases via Zoom access. Jack et al successfully was able to demonstrate the use of Zoom and GoPro; however, they were still primarily tethered which could hamper surgeon ease of access. Yuen et al. showed that this can be done untethered (Fig. 5). A GoPro camera mounted on a headlight was connected to a wireless transmitter, which then sent video feed to the laptop via its USB-attached wireless receiver.[25] The headset was connected to a waist holster with a battery and transmitter via HDMI and power cords, allowing the surgeon to be untethered to any stationary device or power source.[25] Another advantage of this technique is it is HIPAA-compliant, cost-effective, and

FIGURE 3. Use of smart-glasses in live-surgical streaming

FIGURE 4. Raspberry Pi that can be purchased and used for surgical streaming.

fast and independent way to live stream long operations for residents and students. In addition, the setup is light weight and allows for interaction between the surgeon and the learners.

Future Innovations

Although the field of live streaming surgery is new, a new idea that has developed some traction in the last year is virtual reality (VR) streaming of surgery. Virtual reality is the use of computers to simulate a realistic environment. Tokyo's Women Medical University recently pioneered with a streaming company to live stream a surgery in VR.[40] Learners can put on a VR head-set and look in any of the composite fields recorded by the 360° camera located in the OR. They are fully immersed in the OR and can turn left and right and see the operating room surroundings. Virtual reality as a means of surgical education has already been well documented and is the newest means of training surgery residents and students.[39] Live streaming cases via VR can allow learners to feel more comfortable in the OR from the office or home. Although the use of VR may be more cumbersome in the setting of observation and learning of a specific surgery, the technology is exciting and offers a new way for learners to engage in their education.

DISCUSSION

The capability to live stream surgery can help trainees to learn surgical techniques, in real time, with an unparalleled first-person view. This approach combines theater observation, group discussion, and didactic lecture format in 1 modality. Learners can see the anatomic structures and interact with instructors as they try to comprehend anatomy. In addition, they can watch and understand operative technique as they see approach through the surgeon's eyes while being able to clarify with colleagues and other instructors. The surgeon can engage with students in the OR. Hu et al[41] conducted a cohort study on students (n = 365) who attended live streaming sessions alongside dissection demonstrated that regular attendees had significantly higher scores on clinical-anatomy testing ($P < 0.05$), which showcased the efficacy of this learning method. This method can be incorporated into existing medical school curriculum to streamline education. Surgeons also benefit greatly from watching these procedures.[12] In a survey of 32 surgeons viewing a live streamed surgery, 96% reported the surgery as an excellent viewing experience, 92% reported comfort in doing the surgery after watching the procedure, and 100% wanted to participate in an additional live streaming surgery again.[42] Most importantly, live streaming surgery do not have a negative effect on patient outcomes, as seen in 1 article that analyzed patient outcomes after heart surgery[43] and another article that looked at live robotic surgery outcomes.[44] These guidelines were created to ensure these

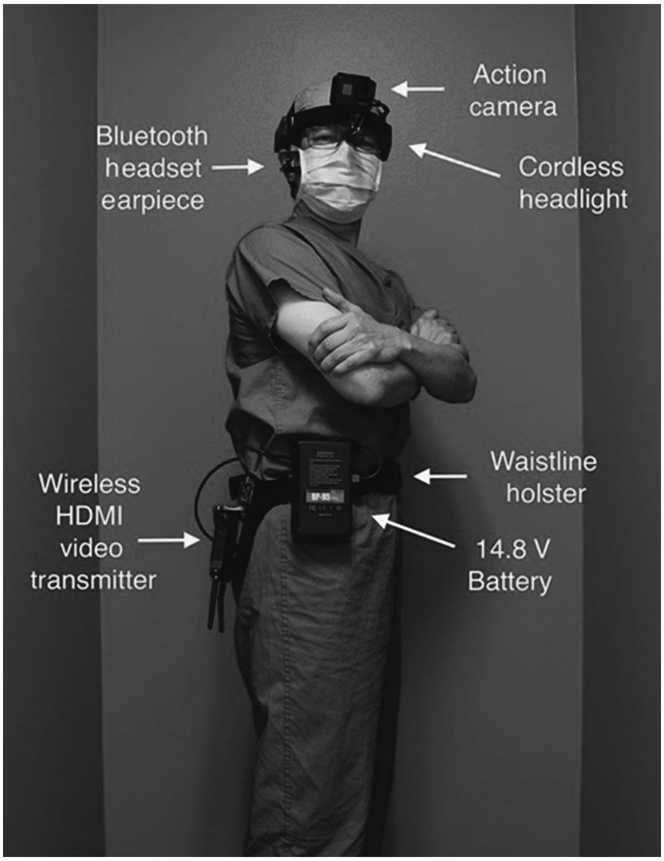

FIGURE 5. Use of Go-Pro in live-surgical streaming.[39]

teaching methodologies will not compromise patient safety. Besides medical students and residents, live streaming surgery educate patients and their families on the operations about which they are apprehensive.[45]

Most articles have expressed decrease in image quality varying on network speed. Although this has been fixed somewhat by improvement in camera quality, the limiting factors expressed in most articles is still the ability to upload the information and stream it seamlessly. Possible ways to address these issues may include improvement of compression algorithms and updating network infrastructure. As early as 2007, use of HD equipment and fiber optic cables with network bandwidth of 1.6 Gbps lead to 92% surgeon satisfaction in image quality.[46] 5G is a new development in the area of streaming. 5G networks deliver 1000× higher mobile data volume per area, 100× higher number of connected devices, 100× higher user data rate, 10× longer battery life for low power massive machine communications, and 5× reduced End-to-End (E2E) latency.[47] Requirements for telehealth and telesurgery include 4K/8K video streaming with low-latency and low jitter with a secure, uninterrupted network access.[48] Current 5G technology uses Multiple Input Multiple Output and Ultra Reliable and Low Latency Communication, which sends and receives multiple data transmissions to enhance data transmission at low latency.[47,48] New algorithms and technology are beginning to use a collection of 5G small cells to pool data to transmit multilayer, 360° video content to mobile VR clients at high quality.[49] 5G has already been used with success in a “track and trace” program in the OR with high feasibility and accuracy and with successful data streaming at rates sin of 900 kb to 1 MB/s with latency of 2 to 60 ms.[50] Studies like this show the potential for widespread access to surgical streams that extends to mobile platforms.

An additional concern includes protecting patient information. Although it may be easier to use systems, such as Google Glass and Google Hangout, to transmit information, these techniques are not supported under HIPAA. This risks a breach of information that puts the patient at risk. There have been a few organizations like the American Association for Thoracic Surgery Ethics Committee[51] that requires specific criteria before live streaming surgery. Alternatives include deferred live streaming and prerecorded surgical cases; however, students will miss opportunities to interact with the surgeon during the case. Using HIPAA-compliant software already existing on the marketplace can be an effective way to address this issue, as done by Yuen et al[25] while remaining untethered. Although there are justifiably many concerns, such as operator interruption, additional stress, and case timing, ultimately patient safety and privacy are most important and are up to the discretion of the surgeon.

Finally, there are ethical concerns regarding the use of the video. What happens if an adverse event was recorded? Can the patient demand to see the recording afterwards? Should patient be concerned about lower-quality care if they say no? Establishing guidelines for surgical streaming can protect patients against HIPAA violations while improving care. A novel set of guidelines for streaming surgical content has been developed for surgical streaming.[52] The following guidelines expand on these guidelines in the context of surgical streaming:

1. Ask for consent to stream their surgical procedure for education or broadcast. Patients should have the capacity to make that decision and if the patient cannot make that decision (ie, incapacitated, unresponsive, etc.), streaming should be deferred unless consent can be obtained from decision maker. If the patient is younger than 18 years, parental consent should be obtained unless the minor is emancipated.
2. The consent should be prewritten in advance and include the type of streaming, platforms used, protection of this information as a part of the medical record, and documentation that the patient is allowed to view later.[53]
3. Should the patient consent to recording, all identifying information including face, tattoos, birthmarks, and demographic information should be censored.[54] If the patient agrees to having this information displayed, an additional provision on the consent document should be added.
4. If possible, all recordings/streamings should be done through HIPAA-compliant software to further ensure protection of patient information.
5. Patient has the right to refuse the recording and will not affect their quality of care.
6. Inform the patient that if the surgery is used online, their images may be downloaded by others. If the patient requests their video be deleted, it will be removed from the plastic surgeon's website/page; however, patients must know that other users may download and view the data.
7. If an adverse event happens, in addition to being preserved in the medial record, the hospital may use the video to learn what happen. Patients will still be allowed to view the video as this would preserve beneficence and justice.[55]
8. Surgeons should follow the standards of professionalism as determined by the American Society of Plastic Surgeon Code of Ethics

CONCLUSIONS

This article establishes the current technology used in live streaming and maps the future of the field. This article educates medical schools, motivated surgeons, and other clinicians on the variety of streaming technologies available to use in medical education. Especially in the time of the COVID-19 pandemic, medical schools have had to change curriculums to provide students with the experiences needed to learn about the surgical field while protecting staff and learners and minimizing consumption of PPE. Although the impacts on medical education from this pandemic are yet to be determined, it has anecdotally affected medical student education. This article hopefully provides an analysis of current technologies with the hope medical schools can pick which technology suits their budget and medical education needs so schools can be prepared in case medical disruption is again interrupted.

Review of the medical literature proved that live streaming of surgery for educational purposes has not yet been widely accepted in our medical schools and surgical residency training programs. The technology to implement streaming has significantly advanced over the past 2 decades, largely driven by industries' quest to gain market share from the general public. However, little has been done to configure turnkey devices to allow for live streaming of surgery in a HIPAA-compliant manner to trainees. Our review uncovers this shortfall in our medical education system, and we welcome innovation in merging wearable devices with enhanced adaptive streaming protocols and HIPAA-compliant teleconferencing platforms.

REFERENCES

1. Yuen JC, Gonzalez SR. Addressing the surgical training gaps caused by the COVID-19 pandemic: an opportunity for implementing standards for remote surgical training. *Plast Reconstr Surg*. 2020;146:109e–110e.
2. Anvari M. Telesurgery: remote knowledge translation in clinical surgery. *World J Surg*. 2007;31:1545–1550.
3. Live Stream Definition. *Merriam-Webster* (2021).
4. Gandsas A, McIntire K, Palli G, et al. Live streaming video for medical education: A laboratory model. *J Laparoendosc Adv Surg Tech A*. 2002;12:377–382.
5. Gandsas A, McIntire K, Park A. Live broadcast of laparoscopic surgery to handheld computers. *Surg Endosc Other Interv Tech*. 2004;18:997–1000.
6. Schneider A, Wilhelm D, Doll D, et al. Wireless live streaming video of surgical operations: An evaluation of communication quality. *J Telemed Telecare*. 2007;13:391–396.
7. Bizzotto N, Sandri A, Lavini F, et al. Video in operating room: GoPro HERO3 camera on surgeon's head to film operations—a test. *Surg Innov*. 2014;21:338–340.
8. Armstrong DG, Rankin TM, Giovinco NA, et al. A heads-up display for diabetic limb salvage surgery: a view through the google looking glass. *J Diabetes Sci Technol*. 2014;8:951–956.
9. 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.
10. Muensterer OJ, Lacher M, Zoeller C, et al. Google Glass in pediatric surgery: An exploratory study. *Int J Surg*. 2014;12:281–289.
11. Knight HM, Gajendragadkar PR, Bokhari A. Wearable technology: using Google Glass as a teaching tool. *BMJ Case Rep*. 2015;2015:bcr2014208768.
12. Collins JW, Verhagen H, Mottrie A, et al. Application and integration of live streaming form leading robotic centres can enhance surgical education. *Eur Urol*. 2015;68:747–749.
13. Moshtaghi O, Kelly KS, Armstrong WB, et al. Using Google Glass to solve communication and surgical education challenges in the operating room. *Laryngoscope*. 2015;125:2295–2297.
14. Baldwin AC, Mallidi HR, Baldwin JC, et al. Through the looking glass: real-time video using 'smart' technology provides enhanced intraoperative logistics. *World J Surg*. 2016;40:242–244.
15. Vara AD, Wu J, Shin AY, et al. Video recording with a GoPro in hand and upper extremity surgery. *J Hand Surg [Am]*. 2016;41:e383–e387.
16. Hiranaka T, Nakanishi Y, Fujishiro T, et al. The Use of Smart Glasses for Surgical Video Streaming. *Surg Innov*. 2017;24:151–154.
17. Nakhla J, Kobets A, De la Garza Ramos R, et al. Use of Google Glass to enhance surgical education of neurosurgery residents: "proof-of-concept" study. *World Neurosurg*. 2017;98:711–714.
18. Ho VY, Shah VG, Yates DM, et al. GoPro HERO 4 Black recording of scleral buckle placement during retinal detachment repair. *Can J Ophthalmol*. 2017;52:416–418.
19. Moore MD, Abelson JS, O'Mahoney P, et al. Using GoPro to give video-assisted operative feedback for surgery residents: a feasibility and utility assessment. *J Surg Educ*. 2018;75:497–502.
20. Lee CK, Kim Y, Lee N, et al. Feasibility study of utilization of action camera, GoPro Hero 4, Google Glass, and Panasonic HX-A100 in spine surgery. *Spine*. 2017;42:275–280.
21. Lee BR, Png DJ, Liew L, et al. Laparoscopic Telesurgery between the United States and Singapore. *Ann Acad Med Singap*. 2000;29:665–668.
22. Diaz R, Yoon J, Chen R, et al. Real-time video-streaming to surgical loupe mounted head-up display for navigated meningioma resection. *Turk Neurosurg*. 2017. doi:10.5137/1019-5149.JTN.20388-17.1.
23. Ganry L, Sigaux N, Ettinger KS, et al. Modified GoPro Hero 6 and 7 for intraoperative surgical recording—transformation into a surgeon-perspective professional quality recording system. *J Oral Maxillofac Surg*. 2019;77:1703.e1–1703.e6.
24. Jack MM, Gattozzi DA, Camarata PJ, et al. Live-streaming surgery for medical student education—educational solutions in neurosurgery during the COVID-19 pandemic. *J Surg Educ*. 2020;78:99–103.
25. Yuen JC, Gonzalez SR, Osborn T, et al. Untethered and HIPAA-compliant interactive livestreaming of surgery to residents and medical students. *Plast Reconstr Surg Glob Open*. 2020;8:e3165.
26. Mann G. S., Stefanski S., Duffin J. M., Snyder T. R. I.S. (Isadore Schwaner) Ravdin Papers. *University of Pennsylvania: University Archives and Records Center* https://archives.upenn.edu/collections/finding-aid/upt50r252 (1995).
27. DeBAKEY ME. Telemedicine has now come of age. *Telemed J*. 1995;1:3–4.
28. Schulam PG, Docimo SG, Saleh W, et al. Telesurgical mentoring. Initial clinical experience. *Surg Endosc*. 1997;11:1001–1005.
29. Rinde E, Hartviksen G. Telelaparoscopy: user experiences. *Telenor Rep*. 2000;93.
30. Micali S, Virgili G, Vannozzi E. Feasibility of telementoring between Baltimore (USA) and Rome (Italy): the first five cases. *J Endourol*. 2000;14:493–496.
31. Netto NR, Mitre AI, Lima SV, et al. Telementoring between Brazil and the United States: Initial experience. *J Endourol*. 2003;17:217–220.
32. Gandsas A, McIntire K, George IM, et al. Wireless live streaming video of laparoscopic surgery: A bandwidth analysis for handheld computers. *Stud Health Technol Inform*. 2002;85:150–154.
33. Oliver M. UAB doctor performs surgery using Google Glass. Available at: https://www.al.com/spotnews/2013/10/uab_surgeon_performs_surgery_u.html (2013). Accessed February 25, 2021.
34. Shenai MB, Dillavou M, Shum C, et al. Virtual interactive presence and augmented reality (VIPAR) for remote surgical assistance. *Neurosurgery*. 2011;68(1 Suppl Operative):200–207.
35. Albrecht UV, von Jan U, Kuebler J, et al. Google glass for documentation of medical findings: evaluation in forensic medicine. *J Med Internet Res*. 2014;16:e53.
36. Times T. N. Y. Why Google Glass Broke. *Nytimes.com* (2015).
37. Levy S. Google Glass 2.0 Is a Startling Second Act. *Wired Mag*. 2017.
38. Chaves RO, De Oliveira PAV, Rocha LC, et al. An innovative streaming video system with a point-of-view head camera transmission of surgeries to smartphones and tablets: an educational utility. *Surg Innov*. 2017;24:462–470.
39. Valente DS, Silveira Eifler L, Carvalho LA, et al. Telemedicine and plastic surgery: a pilot study. *Plast Surg Int*. 2015;2015:187505.
40. Burkhart M. World's Most Futuristic Operating Room Now Live Streams Surgery in 8K VR. *Insta360* https://blog.insta360.com/worlds-most-futuristic-operating-room-now-live-streams-surgery-in-8k-vr/ (2020).
41. Mullins JK, Borofsky MS, Allaf ME, et al. Live robotic surgery: are outcomes compromised? *Urology*. 2012;80:602–607.
42. Kim Y, Kim H, Kim YO. Virtual reality and augmented reality in plastic surgery: a review. *Arch Plast Surg*. 2017;44:179–187.
43. Shiozawa T, Butz B, Herlan S, et al. Interactive anatomical and surgical live stream lectures improve students' academic performance in applied clinical anatomy. *Anat Sci Educ*. 2017;10:46–52.
44. Hu M, Wattchow D, de Fontgalland D. From ancient to avant-garde: a review of traditional and modern multimodal approaches to surgical anatomy education. *ANZ J Surg*. 2018;88:146–151.
45. OR Video Management and Recording Live Streams for Educating, Teledocs for Surgery and More. *Advantech Blog* https://blog.advantech.com/sites/intelligent-solutions-us/2020/06/09/or-video-management-and-recording-live-streams-for-educating-teledocs-for-surgery-and-more/ (2020).
46. Seeburger J, Diegeler A, Dossche K, et al. Live broadcasting in cardiac surgery does not increase the operative risk. *Eur J Cardiothorac Surg*. 2011;40:367–371.
47. Osseiran A, et al. Scenarios for 5G mobile and wireless communications: the vision of the METIS project. *IEEE Commun Mag*. 2014. doi:10.1109/MCOM.2014.6815890.
48. Siriwardhana Y, Gür G, Ylianttila M, et al. The role of 5G for digital healthcare against COVID-19 pandemic: opportunities and challenges. *ICT Express*. 2020. doi:10.1016/j.icte.2020.10.002.
49. Chakareski J. Viewport-adaptive scalable multi-user virtual reality mobile-edge streaming. *IEEE Trans Image Process*. 2020;1. doi:10.1109/TIP.2020.2986547.
50. Jell A, Vogel T, Ostler D, et al. 5th-generation mobile communication: data highway for surgery 4.0. *Surg Technol Int*. 2019;35:36–42.
51. Sade RM, American Association for Thoracic Surgery Ethics Committee; Society of Thoracic Surgeons Standards and Ethics Committee. Broadcast of surgical procedures as a teaching instrument in cardiothoracic surgery. *J Thorac Cardiovasc Surg*. 2008;136:273–277.
52. Dorfman RG, Vaca EE, Fine NA, et al. The ethics of sharing plastic surgery videos on social media: systematic literature review, ethical analysis, and proposed guidelines. *Plast Reconstr Surg*. 2017;140:825–836.
53. Augello T. A. *Legal report: should video cameras be in operating rooms?* (2010).
54. Council, G. M. General Medical Council. Making and using visual and audio recordings of patients
55. Surgeons., A. S. of P. Code of ethics of the American Society of Plastic Surgeons. (2012).