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## Virtual Interactive Presence in Global Surgical Education: International Collaboration through Augmented Reality

Matthew C. Davis, M.D.<sup>1</sup>, Dang Do Thanh Can, M.D.<sup>2</sup>, Jonathan Pindrik, M.D.<sup>1</sup>, Brandon G. Rocque, M.D.<sup>1,3</sup>, and James M. Johnston, M.D.<sup>1,3</sup>

<sup>1</sup>Department of Neurological Surgery, University of Alabama at Birmingham, Birmingham, Alabama, USA

<sup>2</sup>Neurosurgical Department, Children's Hospital #2, Ho Chi Minh City, Vietnam

<sup>3</sup>Section of Pediatric Neurosurgery, Children's of Alabama, Birmingham, Alabama, USA

### Abstract

**Introduction**—The global shortage of neurosurgeons demands tools to geographically extend the reach of expert surgeons. Technology allowing a remote, experienced surgeon to provide real-time guidance to local surgeons has great potential for training and capacity building in medical centers worldwide. Virtual interactive presence and augmented reality (VIPAR), an iPad<sup>®</sup>-based tool, allows surgeons to provide long-distance virtual assistance wherever a wireless internet connection is available. Local and remote surgeons view a composite image of video feeds at each station, allowing for intraoperative telecollaboration in real time.

**Methods**—Local and remote stations were established in Ho Chi Minh City, Vietnam, and Birmingham, Alabama, as part of an ongoing neurosurgical collaboration. An endoscopic third ventriculostomy with choroid plexus coagulation (ETV/CPC) utilizing VIPAR was used for subjective and objective evaluation of system performance.

**Results**—VIPAR allowed both surgeons to engage in complex visual and verbal communication during the procedure. Analysis of five video clips revealed video delay of 237msec (range: 93–391msec) relative to the audio signal. Excellent image resolution allowed the remote neurosurgeon to visualize all critical anatomy. The remote neurosurgeon could gesture to structures with no detectable difference in accuracy between stations, allowing for sub-millimeter precision. Both local and remote neurosurgeons felt the system improved procedural safety and efficacy.

**Conclusion**—Evolving technologies allowing long-distance, intra-operative guidance and knowledge transfer hold great potential for highly efficient international neurosurgical education. VIPAR is one example of an inexpensive, scalable platform for increasing global neurosurgical capacity. Efforts to create a network of Vietnamese neurosurgeons using VIPAR for collaboration are underway.

### Keywords

Neurosurgery; Pediatrics; Telecommunications; Global Health

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**Correspondence:** Matthew C. Davis, M.D., Department of Neurosurgery, University of Alabama at Birmingham, 1720 Second Avenue South, FOT 1062, Birmingham, AL 35294-3410, Phone: 205-777-2632, matthewdavis@uabmc.edu.

## Introduction

In much of the world, subspecialty surgical care is not readily available. (11–13,28,48,55,58,67,71) The absence of local subspecialty care has a demonstrable impact on morbidity and mortality,(53,35) and time to surgical intervention is critical in many conditions.(18,53,59) Hands-on training of local surgeons in their home country is the optimal method for increasing global surgical capacity, and technology allowing a remote, experienced surgeon to provide real-time guidance to local surgeons has great potential for training and capacity building.(8,30,38)

Telesurgery, the use of robotic actuators allowing a geographically remote surgeon to perform a procedure, has attracted growing interest over the past two decades, (2,3,5,8,9,14,25,27,29,32–34,42,44–46,50,51,54,62–64,69) and robotic tools have been used in multiple subspecialties and across long distances.(8,10,25,30,31,33,37,38,42,45,46,63,65) However, the adaptation of telesurgical systems to developing countries is hampered by issues of cost,(8,17,44) connectivity,(51,52,62) and the continued need for skilled operators at the surgical site. Additionally, most neurosurgical procedures are not amenable to existing robotic technology, and the cost of complex systems has limited the role of robotic tools in neurosurgery.(20,41)

Telepresence involves nonrobotic tools to support interactive video and audio telecollaboration in which a remote surgeon provides guidance and training without directly performing the procedure. Telepresence systems have grown in popularity alongside telesurgical tools,(69) but prior systems were limited to providing assistance through verbal exchange or use of a pointer tool.(21,56)

Virtual Interactive Presence and Augmented Reality (VIPAR) is a recently developed tool which allows surgeons to provide real-time virtual assistance and training wherever a standard internet connection is available.(60,61) The technology provides a hybrid perspective of local and remote video feeds, allowing a remote surgeon to digitally “reach into the surgical field”, highlighting anatomic structures and providing visual demonstration of complex operative techniques.

VIPAR can be rapidly deployed under sterile conditions,(47) and has been used in orthopedic surgery for training of resident surgeons with an attending surgeon immediately available in an adjoining room.(49) VIPAR has been shown to be feasible for long-distance telecollaboration in neurosurgical studies on cadaveric specimens,(61) but the use of long-distance VIPAR has never been reported in neurosurgical patients or for international collaboration.

Here we describe the performance, utility, and feasibility of implementing VIPAR as a tool for global surgical education and telecollaboration between neurosurgeons in the United States and Vietnam.

## Materials and methods

### Overview

Neurosurgeons from the Children's of Alabama Hospital in Birmingham, Alabama, USA traveled to Children's Hospital #2 in Ho Chi Minh City, Vietnam, to provide lectures, in-clinic instruction, and intra-operative training to local neurosurgeons on advanced techniques in pediatric neurosurgery. The VIPAR system was implemented and trialed in neuroendoscopy and cases requiring use of the operative microscope, and used for international telecollaboration and continuing education following the return of the visiting team to Children's of Alabama. Institutional Review Board approval was obtained from both the University of Alabama at Birmingham as well as the Ethical Review Committee at Children's Hospital #2.

### VIPAR

The VIPAR system consists of a local station and a remote station connected over a local wireless or 3G mobile connection, providing worldwide point-to-point connectivity. Local and remote stations were established at Children's Hospital #2 and Children's of Alabama Hospital, respectively.

Both local and remote surgeons view a composite image of video feeds at each station, allowing for visual demonstration and tele-collaboration. The proprietary software performs real-time calibrations to spatially match the local and remote visual feeds, and uses a merging feature to overlay the two images. The distant station image appears as a semitransparent overlay on the local station image,<sup>(60)</sup> and a single hybrid image is displayed to both parties. While early iterations required complex video capture and display systems,<sup>(60,61)</sup> newer versions run on iPad devices, and use a commercially available app, Lime™, downloaded onto the device. The forward-facing camera on each iPad provides video and audio capture, while the iPad screen provides video display. An iPad Air 2 was used at both local and remote stations to provide 1080p HD video recording (30 frames per second). A schematic of the VIPAR system is presented in Figure 1.

VIPAR runs on iOS6.0 or later. Information is transmitted between users using AES 128 encryption. Servers record the instance of the communication, including the start and end times of the connection. No data about content of the communication is known or recorded by the vendor servers, and neither video nor audio may be directly recorded using the VIPAR software, allowing for secure data transfer.

### Local station at Children's Hospital #2

The local station was constructed in the neurosurgery operating room at Children's Hospital #2 in Ho Chi Minh City, Vietnam, using an iPad Air 2 and locally available internet connection. The local device was fixated to either the endoscopy tower or the operative microscope using a commercially available flexible support arm (Hoverbar 3®). Positioning of the device entails directing the camera toward the endoscopic or microscope video projection, while the iPad screen is left visible to the operating surgeon, and located outside of the surgical field. The local station setup is shown in Figure 2, left.

### **Distant station at Children's of Alabama Hospital**

The distant station was set up in a conference room at Children's of Alabama Hospital in Birmingham, Alabama, USA, using a separate iPad Air 2 and local wireless internet connection. A pediatric neurosurgeon directed the forward-facing iPad camera at a white background, and placed their hands and instruments into the camera capture field. The distant station also carries a telestration feature on the iPad screen which allows the expert surgeon to freeze the screen or draw on the image using a two-dimensional pen tool. The distant station setup is shown in Figure 2, right.

### **Connectivity**

While early VIPAR models required high-speed fiber-based local connectivity, the latest iteration allows the system to function with upload and download speeds within the throughput capacity of wireless network and 3G mobile internet connectivity. Connection between stations uses commercial codecs (Polycom vsx7000, and Tanberg, Cisco Systems).

Both local area wireless network and 3G mobile internet connectivity at the local station were evaluated. A Linksys WRT54GL Wi-Fi Wireless-G Broadband Router installed in the operating theater provided connectivity to the local internet service provider. The XCom Global Mobile Wi-Fi Hotspot<sup>®</sup>, which uses a local 3G mobile phone network to deliver internet connectivity, was also evaluated. A local area wireless network was used at the distant station for both trials. Upload speeds, download speeds, and mean transit times were measured for each method of connectivity using Network Analyzer<sup>™</sup> a commercially available application downloadable onto iOS devices.

### **Audio and video composite latency and accuracy analysis**

Time difference between images depends on local processing times, which are typically fixed, and internet transmission delay, which can fluctuate. Delays in internet transmission and image compilation were assessed through off-line video analysis. An endoscopic third ventriculostomy and choroid plexus coagulation (ETV/CPC) utilizing VIPAR was used for evaluation of system performance. Independent videos of the local and remote composite fields were recorded. Video clips were synchronized to audio and identifiable movements at each station, and the delay between each video assessed in milliseconds. Composite accuracy was assessed by each surgeon touching the same indicated point and providing verbal confirmation they see the other surgeon touching the same point.

### **Clinical utility analysis**

Both the local and distant surgeons were queried on overall utility of the tele-collaboration experience via questionnaire using a five-point Likert scale. Both surgeons were asked to rate the VIPAR system on the following criteria, where 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, and 5 = strongly agree:

Use of the tele-communication system:

- a. changed the course of the procedure (1–5)
- b. resulted in a safer procedure (1–5)

- c. resulted in a more effective procedure (1–5)
- d. was useful overall (1–5)
- e. resulted in increased fatigue (1–5)

### **Cost analysis**

Assessment of both direct and indirect costs associated with institution of the VIPAR system was performed. Expense data were subdivided as follows: visiting team expenses, local station hardware, distant station hardware, proprietary software, internet connection, technical support.

### **Source of funding**

Use of proprietary software was provided by Vipaar, LLC. This work was additionally supported by a grant from the Children’s of Alabama Global Health Program Initiative and the Kaul Foundation.

### **Results**

Successful implementation and trial of the VIPAR telecollaboration system took place as part of ongoing neurosurgical collaboration between Children’s of Alabama Hospital and Children’s Hospital #2 in Ho Chi Minh City, Vietnam. A strong relationship exists between these institutions, with regular exchange of general surgery and neurosurgery teams. Cases requiring either the endoscope or operative microscope were performed using VIPAR assistance. Following return of the visiting team to their home institution, VIPAR was effective in providing transnational intraoperative assistance.

### **Local hospital**

All cases were performed at Children’s Hospital #2 in Ho Chi Minh City. Five pediatric neurosurgeons provide care for the full spectrum of pediatric neurosurgical disease, and train one pediatric neurosurgeon per year. Southern Vietnam, with a population of nearly fifty million, is served by ten pediatric neurosurgeons (personal communication, 2015, D. Can), with varying levels of subspecialty training. In certain cases, pediatric neurosurgery training is distinct from adult neurosurgery residency, and consists of a three-year program started immediately following completion of medical school, which lasts either four or six years. There are two pediatric neurosurgery training programs for all of Vietnam, one located in Ho Chi Minh City, and the second located in Hanoi. For the calendar year 2014, 613 total pediatric neurosurgical procedures were performed at Children’s Hospital #2 (breakdown of cases provided in Table 1).

### **VIPAR local trial**

Initial trials took place while the visiting team was present to provide immediate hands-on intraoperative assistance if needed.

### Endoscopic trials

**Case 1:** An ETV/CPC was performed in a seven-month old male with hydrocephalus and a Dandy-Walker malformation variant. A STORZ 2.2mm flexible endoscope was used with display on a high-definition 26-inch, 16:9 HD format, 1920 × 1200 pixel resolution digital monitor. The local station was set up as described above (Figure 2). One expert neurosurgeon remained scrubbed throughout the case, while a second visiting neurosurgeon set up the distant station in an adjacent room. Stations were connected over the same local area wireless network. One episode of dropped call occurred, requiring less than 1 minute to correct. Several sub-second episodes of noticeable transient video delay occurred. No audio delay was detected. Excellent registration was observed. VIPAR was used for a total of 2 hours and 11 minutes, with 16% battery usage over that time.

**Case 2:** ETV/CPC with biopsy of a third ventricular mass was performed on a 2 year-old male using the set-up described above. No episodes of dropped call, audio or detectable video delay occurred during a 40 minute run period.

### Operative microscope trial

**Case 3:** A right pterional craniotomy was performed for biopsy of an enhancing infundibular mass in a five year-old female who presented with diabetes insipidus. The local iPad was fixated to the operative microscope and directed at the display screen, while still viewable by the operating surgeon (Figure 3). Resolution was adequate to allow the remote surgeon to identify all relevant microsurgical anatomy.

### VIPAR international trial

An attending pediatric neurosurgeon in the United States was contacted using VIPAR while a visiting neurosurgeon remained scrubbed during an ETV/CPC on a 6 month-old female, allowing collaboration spanning 14,904 kilometers. VIPAR was used throughout the endoscopic portion of the procedure, without noticeable interaction delay or appreciable difference in resolution between the two sites. The system allowed for discussion of procedural strategy and visual conveyance of surgical maneuvers which would not have been possible with standard video conferencing. Video 1 demonstrates the system in use at both the local and remote stations.

**Audio latency**—Optical fiber cables provide long distance telecommunication through the transmission of light impulses. Minimum latency time is dependent on the speed of light (299,792 kilometers per second in a vacuum) and a standard fiber delay ratio, estimated at 1.52 for the purpose of this study. Most telecommunications networks connect between multiple nodes, significantly increasing total distance a signal must travel between each station. Even if a single fiberoptic cable connected directly between the two stations in this study, a minimum lag time of 75.54 msec would be expected simply for light to travel from one station to the other. Despite the great distances involved, audio delay was not perceptible to participants at either station.

**Video composite latency**—Off-line analysis was performed using independent videos of the local and remote stations. Video clips which included unique movements and audio were

used for synchronization and frame-by-frame analysis. The local-to-remote station video latency averaged 237 msec relative to the audio signal (range: 93–391 msec). While the surgeon at each station therefore viewed their counterparts' field as slightly delayed relative to their own, this did not interfere with performing the procedure. The number of elapsed frames between the synchronized videos was used as the metric of latency time between the two stations.

**Composite accuracy**—Confirmation of accuracy between stations was performed by the distant surgeon pointing at specific anatomic structures at the request of the local surgeon, and tracing clearly identifiable borders of the local video feed. Each participant agreed the spatial accuracy was sufficient such that any difference was imperceptible. This was confirmed on off-line video analysis.

### Connectivity

Local station area wireless upload speeds ranged from 7.25 to 8.24 Mbps, with download speeds from 3.97 to 5.54 Mbps (IP address 192.168.4.187). Distant station wireless upload speeds ranged from 26.39 to 27.62 Mbps, with download speeds from 31.90 to 34.43 Mbps (IP address 138.26.72.17). Round trip time ranged from 321.71 to 363.41msec over 200 test packets. 3G mobile wireless upload speeds ranged from 2.39 to 3.31 Mbps, with download speeds from 2.98 to 5.28 Mbps.

### Set-up and disassembly

Setting up the local station and breakdown at the end of a case took less than 10 minutes to complete. Setup time for the distant station consists only of finding a white background toward which to direct the iPad camera. Operative times were not felt to be significantly affected by use of the VIPAR system.

### Cost

Financial data collected included visiting team expenses, local station hardware, distant station hardware, proprietary software, internet connection, and technical support. Three main internet service providers in Ho Chi Minh City, Vietnam Posts and Telecommunications group, Viettel, and FPT, offer fiber-based and 3G mobile wireless connectivity. Internet costs for this study included \$80 USD for placement of a Linksys WRT54GL Wi-Fi Wireless-G Broadband Router within the neurosurgery operating theater, with no additional cost incurred for use of Children's Hospital #2 internet access. Individual subscriber internet access ranges from 260,000–2,070,000 Vietnamese Dong (12\$–96\$ USD) per month in Ho Chi Minh City based on connection speeds and data usage, and these rates are used for cost analysis. Total costs for establishing the VIPAR system were \$14,930.39 USD for one calendar year. \$12,504.60 of this was associated with the two-week visiting team experience. A breakdown of financial data is presented in Table 2.

### Ongoing collaboration

Following return of the visiting team, VIPAR continues to be used for intraoperative assistance and training for neuroendoscopic cases. Fifteen additional ETV/CPC procedures

have been performed using VIPAR for long distance collaboration since return of the visiting surgical team, each without complication or hardware failure. As above, excellent registration and resolution were observed in fourteen cases. In one case, there was a transient loss of audio connectivity without disturbance of video connectivity. This did not interfere with the procedure as visual graphics tools were used to point out anatomy and suggestions for location of the ETV. Twelve of the fifteen patients remain shunt-free as of last follow-up. There have been no other complications observed in any cases. Over the six months immediately prior to the introduction of VIPAR, twenty seven ETV/CPCs were performed at Children's Hospital #2, all for aqueductal stenosis. Complications prior to VIPAR included severe intraventricular bleeding requiring an external ventricular drain in two patients (7.4%), subdural hematoma in one patient (3.7%), postoperative CSF leak in one patient (18.5%), and death due to hemorrhage from a basilar artery injury in one patient (3.7%).

VIPAR has additionally been utilized for global telecollaboration during cases requiring use of the operative microscope, including resection of a large cerebellar tumor and clipping of a distal posterior inferior cerebellar artery aneurysm.

### Clinical utility

Local and distant surgeons reported the VIPAR telecommunication system to be very useful for operating neurosurgeons in Ho Chi Minh City, Vietnam. On a 5-point Likert scale where 1=strongly disagree and 5=strongly agree, each surgeon strongly agreed that VIPAR was useful overall (5) and resulted in a more effective procedure (5). Each surgeon also agreed VIPAR changed the course of the procedure (4) and resulted in a safer procedure (4), and disagreed with the statement: "VIPAR resulted in increased fatigue" (2).

### Discussion

In the coming years the global shortage of surgeons is only expected to worsen.<sup>(58,67)</sup> Surgical disease makes up one of the top fifteen causes of global disability,<sup>(40)</sup> and surgical intervention fills a crucial role in global public health.<sup>(22)</sup> This gap necessitates the development of tools to geographically extend the reach of expert surgeons. While robotic systems provide an extended geographic reach of a single surgeon, the VIPAR system allows long-distance assistance during complex cases as well as training of local surgeons. Though the VIPAR system was initially created for use through a binocular videoscope or attachment to the operative microscope, the technology has been adapted to other commercially available systems in which both video recording and display are possible, such as Google Glass or iPad. These devices are relatively inexpensive, and may prove to be valuable tools for global neurosurgical education and capacity building. Endoscopic, endovascular and microsurgical cases already rely on video projection for the critical portion of the procedure, and are ideally suited to implementation of VIPAR technology. ETV/CPC, increasingly utilized for primary treatment of infant hydrocephalus throughout the world, <sup>(64)</sup> provided an excellent example in our series.

Surgical outcomes are heavily influenced by technical acumen, and unexpected intraoperative situations may arise which would benefit from the expertise of a more experienced or specialized surgeon. Additionally, geographically remote surgeons may be



called upon to assist with an emergent procedure which cannot wait for transfer to higher levels of care. In both instances, the value of a feasible paradigm permitting the digital presence of an expert surgeon within the operative field becomes clear. Telecollaboration has been demonstrated for the education of orthopedic surgery residents,(49) but has never been used for international surgical training. The VIPAR system is both practical and simple, and provides a visual adjunct to verbal description of complex surgical procedures and techniques.

Expert surgeons may have the ability to spend short periods of time providing hands-on training in developing countries, but not able to commit to longer periods. The number of short-term surgical trips has increased dramatically over the past thirty years,(68) but the lack of emphasis on training and frequent absence of skilled follow-up have led to criticisms of the short-term trip model.(16,36) While surgeons hailing from developing countries may alternatively visit the United States for longer term observerships, actual participation in surgery is largely prohibited. Immersive learning paradigms emphasizing active participation are essential for developing new skills.(6,15) As a result, the ideal method for capacity building involves hands-on training of surgeons in their home country, performing cases on their own patients. In trauma and critically ill patients, non-virtual interactive tools for extending the expertise of sub-specialists are associated with reduced morbidity and mortality.(39,70) A versatile and scalable digital telecollaboration technology to enmesh the expertise of a remote surgeon into the operative field could serve as a valuable adjunct to in-person training efforts. In this study, VIPAR allowed for ongoing skill and knowledge transfer following return of the visiting team to their own clinical practice.

The complexity of surgical execution cannot be easily conveyed by face-to-face video, and evolving technologies provide novel solutions for surgical training and remote assistance. General and orthopedic surgery programs have adopted surgical simulators for training in laparoscopic, arthroscopic and robotic techniques,(4,66) observing shortened trainee learning curves and no decline in patient outcomes.(1,19,23,24,26,43,57,72) While sophisticated, high overhead costs limit the application of simulators in the developing world, and current simulators cannot reproduce the wide range of potential complications. Additionally, surgical simulators do not presume even the most basic training. By contrast, complex and cumbersome robotic actuators still require highly skilled local surgeons to cope with unstable circumstances or system failure, limiting their application in neurosurgery (41). Interactive telecollaboration systems such as VIPAR serve as a bridge, providing new domain skills to local surgeons who already possess a functional skill set.

Such technology is not meant to replace standard neurosurgical training, but rather act as a complementary method that facilitates mentoring without physical presence of the experienced surgeon. We envision this technology as providing that last bridge of mentorship, taking a competent surgeon with fundamental neurosurgical skills and providing real-time feedback to coach them towards true expertise. While telecollaboration has great potential for capacity building, elective cases should not be performed without local expert support readily available, unless the local surgeon has adequate training to complete the case without VIPAR assistance. Technical delays or loss of internet connectivity may leave the local surgeon without expert assistance, and thus caution is warranted if use of long-distance

telecollaboration tools leads a local surgeon to “over-reach” in case selection. For emergent cases, backup internet access using mobile 3G wireless internet connectivity is recommended in the event of local area wireless internet failure, to decrease the risk of losing all contact with the distant expert.

Ongoing efforts are underway to create a network of Vietnamese neurosurgeons using VIPAR technology to increase collaboration both within Vietnam and with our group in Alabama. Within the United States, VIPAR is currently under evaluation for utility in the outpatient setting as well. Issues facing the widespread adoption of digital telecollaboration tools include reimbursement and liability, as well as rigorous assessment of the impact on patient outcomes.

## Conclusions

Giving remote experts the ability to guide and mentor less experienced surgeons has great potential for global surgical education and capacity building. VIPAR is one example of evolving interactive technology allowing for real-time global surgical telecollaboration and education through commercially available and inexpensive platforms. Use of such technology may increase the safety of surgical intervention, and has great potential for training, research, assessing surgical competence for maintenance of certification, and fostering relationships between geographically isolated physicians.

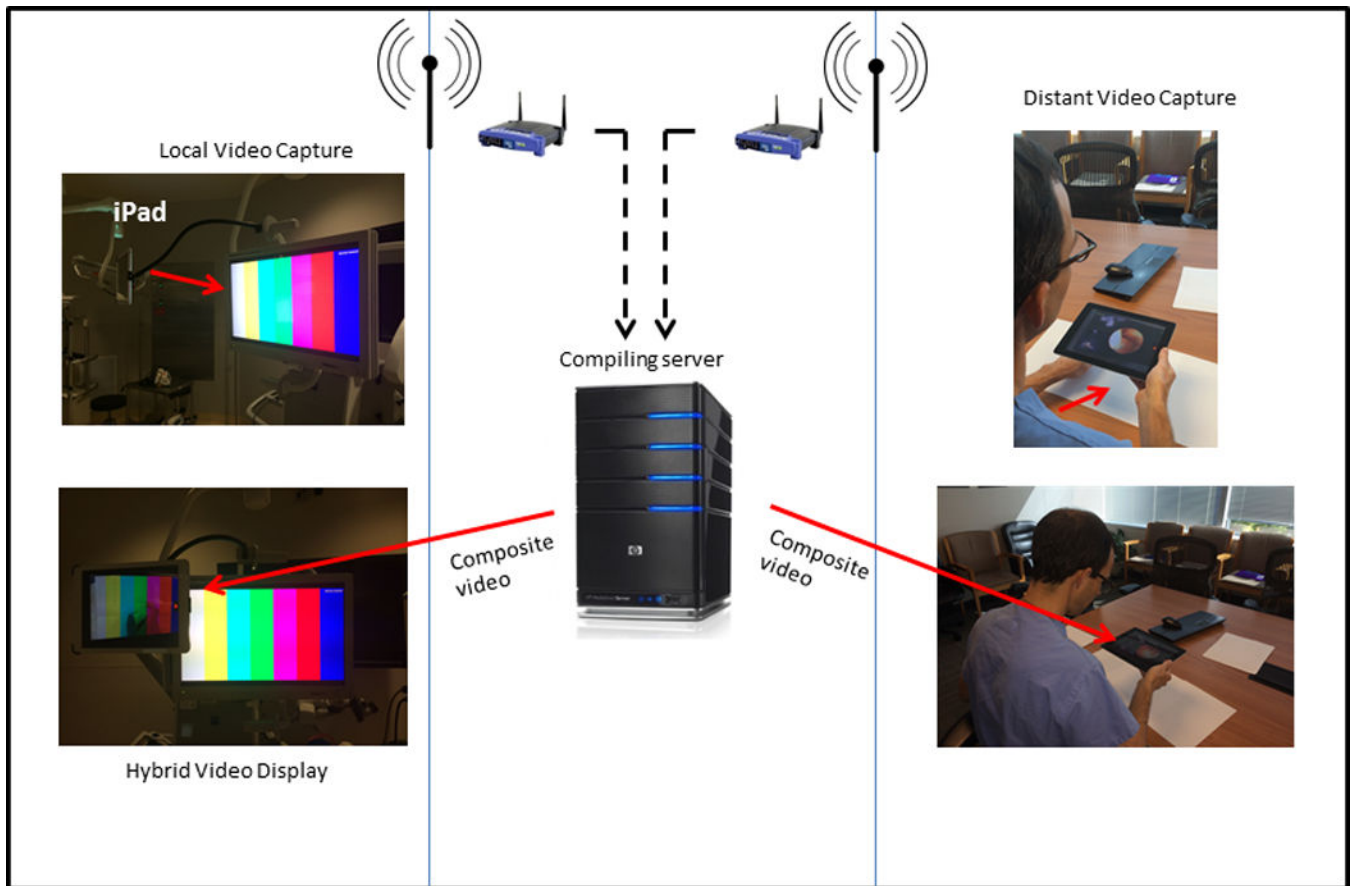
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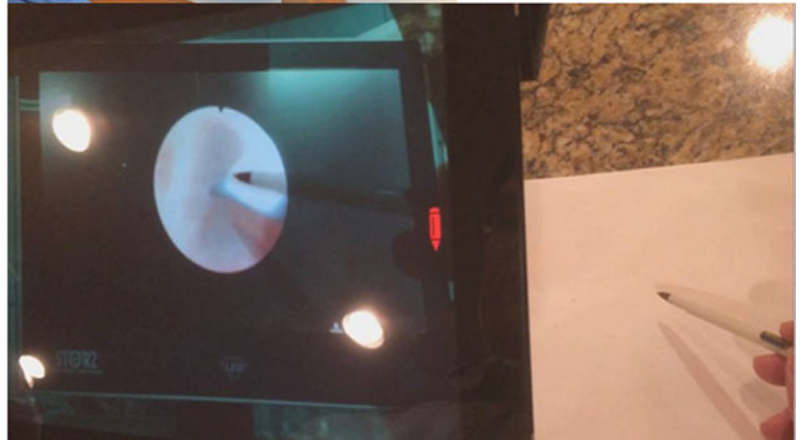
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**Figure 1. Diagram of the VIPAR system**  
 Local and distant video and audio feeds are compiled to create a single composite with each surgeon viewing a common field. The distant video feed is seen as a semitransparent overlay on the background of the local video feed



**Figure 2. Setup of local and distant stations for neuroendoscopy**  
The local station within the operative suite is depicted on the left, while the setup for the distant station is shown on the right.



**Figure 3. Setup of local station for cases requiring use of the operative microscope**  
The local iPad is pointed toward the microscope display, while the screen is directed toward the surgeon, outside of the operative field.



**Table 1**

Neurosurgical cases performed at Children's Hospital #2 during 2014

Case Type	Number of Cases
Craniotomy for trauma	96
Craniotomy for tumor or biopsy	123
Craniotomy for infection <sup>*</sup>	38
Ventricular shunt <sup>†</sup>	127
ETV/CPC	44
Craniosynostosis correction	18
Craniotomy for vascular pathology <sup>‡</sup>	14
Craniotomy for other <sup>§</sup>	49
Diagnostic cerebral angiogram	44
Neuroendovascular intervention	1
Spine for trauma	2
Spine for tumor or vascular lesion	14
Spine for neural tube defects	43

<sup>\*</sup> includes primary brain abscess, empyema

<sup>†</sup> includes placement of new ventricular shunts, revisions, exploration, removal, and replacement

<sup>‡</sup> includes evacuation of spontaneous intracranial hemorrhage, encephaloduroarteriosynangiosis

<sup>§</sup> includes Chiari malformation repair, encephaloceles, wound washout, and other miscellaneous cases

**Table 2**

Financial outlay of establishing an international telecollaboration system for one year

<b>Breakdown of Costs (USD)</b>		
<b>Local station</b>		<b>1,576.89</b>
iPad Air 2	548.90	
Lime™ subscription (1 subscriber, \$25 per subscriber per month)	300.00	
Wireless internet access (12 months, mean \$54 per month)	648.00	
Wireless Router	79.99	
<b>Visiting team expenses</b>		<b>12,504.60</b>
Flights (3 participants, round-trip flights)	7254.60	
Accommodations (2 hotel rooms, 14 total days)	4200.00	
Meals (3 participants, \$25 per diem)	1050.00	
<b>Distant station</b>		<b>848.90</b>
iPad Air 2	548.90	
Lime™ subscription (1 subscriber, \$25 per subscriber per month)	300.00	
<b>TOTAL EXPENDITURE</b>		<b><u>14,930.39</u></b>

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