Unequal distribution of medical resources is a serious problem worldwide.¹,² In China, there are huge gaps in medical resource distribution among different parts of the country.³ Therefore, to increase access to health interventions and healthcare services for patients in resource-limited areas, strategies for the allocation of medical resources across geographic boundaries,³,⁴ such as telemedicine, must be developed and implemented.

Internet-based telecollaboration is the main form of surgical telemedicine. This system allows experienced surgeons to perform complex visual and verbal communication during the operation. The average video delay time is 184.25 msec (range 160–230 msec) with 4G mobile internet, and 23.25 msec (range 20–26 msec) with 5G mobile internet. Excellent image resolution enabled remote neurosurgeons to visualize all critical anatomical structures intraoperatively. Remote instructors could easily make marks on the surgical view; then the composite image, as well as the audio conversation, was transferred to the local surgeon. In this way, a real-time, long-distance collaboration can occur. This system was used for 20 neuroendoscopic surgeries in various cities in China and even across countries (Boston, Massachusetts, to Jingzhou, China). Its simplicity and practicality have been recognized by both parties, and there were no technically related complications recorded.

The MIMIT system allows for real-time, long-distance telecollaborative neuroendoscopic procedures and surgical training through a commercially available and inexpensive system. It enables remote experts to implement real-time, long-distance intraoperative interaction to guide inexperienced local surgeons, thus integrating the best medical resources and possibly promoting both diagnosis and treatment. Moreover, it can popularize and improve neurosurgical endoscopy technology in more hospitals to benefit more patients, as well as more neurosurgeons.

**KEYWORDS** telemedicine; endoscopy; telecollaboration; mixed reality
surgical specialists to guide surgeons in remote areas who have little or no relevant experience in a real-time interactive manner. The first case of telecollaborative systems used in surgery was reported in the 1960s when physicians performed open heart surgery via satellite broadcast videoconferencing. Since then, more and more surgical telecollaboration systems have been used for various surgical procedures. However, the application of telecollaboration in neurosurgery is not as comprehensive as in other disciplines. Limited space and high-precision micromanipulation requirements in neurosurgery limit the applications of telecollaboration.

Long-distance collaboration can be divided into three types: 1) real-time video conferencing, in which telemedicine specialists train local surgeons visually or verbally through live video and voice streaming or freehand sketching, 2) robot-assisted remote surgery, where remote surgical experts operate remote robots directly through the network, and 3) virtual interactive presence and augmented reality (VIPAR) systems, in which these systems display information on the screen of a flat-panel monitor or smart glasses, allowing the local operator to simultaneously perceive the surgical field and virtual instructions. However, as described in the literature, the VIPAR system has some limitations. The first limitation is that erroneous interactions or serious surgical complications can result from network latency or outages in connectivity. Furthermore, due to the complexity of the system construction, highly skilled local surgeons are still required to address possible system failure or instability. Third, the software or hardware of the system is often customized, which limits its widespread adoption in remote areas.

In this paper, we describe a mobile internet-based mixed-reality interactive telecollaboration (MIMIT) system for neurosurgical procedures. The technical feasibility, clinical implementation, and possible business model for this telecollaborative system are reported and analyzed.

**Methods**

**System Overview**

The MIMIT system consists of a head-mounted mixed-reality device (HoloLens, Microsoft Inc.), a local video processing (LVP) station installed at the site of the procedure, and a remote mobile device (smartphone or tablet PC) connected over a 4G or 5G wireless connection, providing worldwide connectivity.

The LVP station captures a video feed from an endoscope system or a microscope and sends it to the remote station. The remote instructor marks on the mobile device (a smartphone or a tablet PC), and the composite video is then sent back to the LVP station so that it can be displayed and viewed with a HoloLens connected to the LVP station.

In this paper, we describe a mobile internet-based mixed-reality interactive telecollaboration (MIMIT) system for neurosurgical procedures. The technical feasibility, clinical implementation, and possible business model for this telecollaborative system are reported and analyzed.
the following link: https://drive.google.com/file/d/1-15w4-lQNs0u-ozH7NySoP4NxtOucNYAR/view?usp=sharing. Use of this app makes it a very straightforward process for the remote specialist to get detailed information of the case, perform the intraoperative telecollaboration, and collect payment after surgery.

Local Station and Connectivity

The LVP station is placed in the operating room of the local hospital, and the video of a neuroendoscope or an operating microscope is captured by the LVP station through a DVI/SDI video port. The LVP station is connected to a 4G or 5G mobile network. A head-mounted mixed-reality device is used to provide a virtual holographic display screen panel in front of the operator’s eyes for intraoperative real-time guidance. The intraoperative mixed-reality view is shown in Fig. 3 and Video 1.

VIDEO 1. Clip showing an intraoperative telecollaboration from case 1. Note the holographic display panel in front of the local neurosurgeon. In the small video window in the lower right corner, the remote instructor can be seen performing the collaboration with a conventional laptop PC. © Xiaolei Chen, published with permission. Click here to view.

Remote Station and Connectivity

A standard iPad, Android phone, tablet PC, or conventional Windows PC can be used as a remote workstation. In addition to the real-time audio conversation between the remote instructor and the local surgeon, the local operation video, transferred from the LVP station, can be displayed on the operation interface of our dedicated app so that a more experienced instructor can draw marks using his or her fingers or a mouse directly on the screen (Figs. 3 and 4). Before drawing the marks, the instructor can freeze the surgical view, so that different marks can be drawn on a steady surgical view. The color, size, and shape of the marks can be customized by the instructor. In this way, the remote instructor can provide real-time, long-distance interactive audio and video guidance with our telecollaboration app as long as there is mobile internet service, which makes telecollaboration available anywhere, without special meeting rooms. This novel setting even made a real “curbside consult” possible (case 3; Fig. 4A).

Audio and Video Composite Latency

For telecollaborative surgical procedures, audio and video latency is critical for both safety and clinical efficacy. In this study, both audio and composite video are transmitted via the 4G/5G mobile network. The latency depends on the transfer rate between the two workstations. Previous reports on remote interaction assessed the delay of internet transmission and video synthesis by intercepting offline video and performing frame-by-frame analysis.20,21 This requires too many human resources and is relatively subjective. To test the precise end-to-end latency, we programmed accurate time display software (millisecond clock; https://www.dropbox.com/s/umtllvl31fi70c2/Millisecond%20Clock.rar?dl=0), which can display the instant system time to a millisecond level. The program is installed on both the LVP station and a standard Windows PC at the remote site. Before each telecollaboration procedure, the LVP workstation, the remote station/device, and the standard Windows PC at the remote site are synchronized with internet time. Then, our millisecond clock program is started on both the LVP station and the PC at the remote site. The LVP workstation transmits the workstation millisecond clock video to the remote mobile device.
The remote mobile device, with the LVP time display, was then placed beside the PC running the millisecond clock, so that the remote instant time as well as the LVP local instant time (displayed on the remote mobile device screen) can be displayed in the same picture. Photographs of the remote PC screen and remote mobile device screen were taken every minute until 10 photos were taken for analysis. By comparing the screen-displayed millisecond time of the mobile device and remote station, a precise end-to-end latency can be calculated and recorded. The time difference (subtracting one time from the other) is the precise latency of the composite video in the visual field of both participants (Fig. 5A). We calculate the time difference of 10 photos and take the average. The linear distance between the local and remote sites is recorded for each collaboration procedure (Table 1).

**Payment Solution**

To make a sustainable business model, we included a payment solution in our telecollaboration app. The consulting fee is approximately renminbi (RMB) 1000 yuan ($158 USD) per hour. The patient’s representatives can pay with Alipay or credit cards online, just like many other popular online medical consulting apps. Fifty percent of the payment is used for telecollaboration online platform maintenance, 30% of the payment is collected by the remote instructor, while the rest (20%) is collected by the
local surgeon. In this way, a legal payment system could be established.

**Liability Issues**

To avoid malpractice and potential liability issues, only qualified neurosurgeons who finished basic neuroendoscopic training can operate at the local site. For the remote instructor, only specialists who have more than 10 years of experience in neuroendoscopy can be enrolled. All the instructors are registered to an internet hospital (Jincheng Internet Hospital, China). A consent form for telecollaboration surgery was obtained from the patient or patient’s representatives before every procedure. The local hospital takes full responsibility in case of any liability issues.

**Results**

From February 2017 to December 2019, 20 cases were included in our study. Twenty telecollaborative neuroendoscopic procedures were successfully performed. A consent form for telecollaboration surgery was obtained from each patient or patient’s representatives before every procedure. The local ethics committee approved our study. A successful implementation and trial of the MIMIT system took place between cities in China and the United States. The linear distance between the local site and remote site ranged from 0.1 km (case 1, same building, different rooms) to 11,923 km (case 14, from Boston, Massachusetts, to Jingzhou, China). General information on all 20 cases, as well as the distance between them, is shown in Table 1. In all cases, a stable network connection and telecollaboration could be achieved. There were no technically related complications or liability issues recorded. All surgical procedures were completed uneventfully.

**Illustrative Cases**

**Case 1**

Case 1 was the first case in our study. An intracerebral cavernous malformation was removed by endoscopic port surgery. The LVP station was located in a standard operating room, while the remote instructor was seated in a different room in the same building. The instructor used one laptop PC to conduct the telecollaboration and marked on the surgical view using a mouse (Fig. 3, Video 1). The MIMIT telecollaboration was satisfactory with a mean latency of 160 msec. The delay was mild but still notable.

**Case 3**

Case 3 involved transsphenoidal endoscopic removal for a recurrent pituitary adenoma. Intraoperatively, the local surgeon (in Nanchang, China) was confused by the abnormal anatomy. Hence, he requested telecollaboration with an experienced instructor in Beijing. At that time, the instructor was off duty and out of the hospital. Therefore, the instructor used his mobile phone and performed the telecollaboration in the street (Fig. 4A). This special situation made this case a true “curbside consult.” The surgery

| Case No. | Station Remote | Station Local | Procedure | Mobile Network | Distance Btwn Stations (km) | Mean Latency (msec) |
|----------|----------------|--------------|-----------|----------------|---------------------------|--------------------|
| 1        | Beijing        | Beijing      | Endoscopic port surgery for an intracerebral CM | 4G             | 0.1                        | 160                |
| 2        | Beijing        | Beijing      | ETV       | 4G             | 30                        | 162                |
| 3        | Beijing        | Nanchang     | Transsphenoidal endoscopic removal of a recurrent pituitary adenoma | 4G             | 1249                       | 180                |
| 4        | Beijing        | Guangzhou    | ETV       | 4G             | 1901                      | 178                |
| 5        | Beijing        | Jingzhou     | ETV       | 4G             | 1128                      | 182                |
| 6        | Beijing        | Wuhan        | Transsphenoidal endoscopic removal of a recurrent pituitary adenoma | 4G             | 1045                       | 170                |
| 7        | Beijing        | Xi’an        | ETV w/ tumor biopsy | 4G             | 900                        | 180                |
| 8        | Beijing        | Sanya        | ETV w/ tumor biopsy | 4G             | 2489                       | 198                |
| 9        | Sanya          | Beijing      | ETV w/ tumor biopsy | 4G             | 2489                       | 196                |
| 10       | Beijing        | Jingzhou     | ETV       | 4G             | 1128                      | 178                |
| 11       | Beijing        | Guangzhou    | ETV       | 4G             | 1901                      | 180                |
| 12       | Sanya          | Beijing      | ETV w/ tumor biopsy | 4G             | 2489                       | 196                |
| 13       | Sanya          | Beijing      | ETV w/ tumor biopsy | 4G             | 2489                       | 190                |
| 14       | Boston         | Jingzhou     | Endoscopic fenestration of a trapped temporal horn | 4G             | 11,923                     | 230                |
| 15       | Beijing        | Guangzhou    | ETV       | 4G             | 1901                      | 182                |
| 16       | Beijing        | Guangzhou    | ETV       | 4G             | 1901                      | 186                |
| 17       | Sanya          | Beijing      | ETV w/ tumor biopsy | 5G             | 2489                       | 23                 |
| 18       | Sanya          | Beijing      | ETV       | 5G             | 2489                      | 20                 |
| 19       | Beijing        | Sanya        | ETV       | 5G             | 2489                      | 26                 |
| 20       | Beijing        | Sanya        | Endoscopic fenestration of an arachnoid cyst | 5G             | 2489                       | 24                 |

CM = cavernous malformation.

All locations (remote and local) were in China, except for the remote location in case 14 (Boston, Massachusetts).
was finally successfully performed. The telecollaboration lasted 1.5 hours. The tumor was completely removed and no complications occurred.

Case 14
Case 14 suffered from a trapped temporal horn following intraventricular hemorrhage. A telecollaborative endoscopic fenestration of the temporal horn was planned. The local surgeon was performing surgery in Jingzhou, Hubei, China, while the remote instructor was in Boston, Massachusetts (Fig. 4B and C, Video 2).

**VIDEO 2.** Clip showing MIMIT telecollaboration in case 14. The first part of the video was taken in Boston, Massachusetts, showing that the instructor collaborated with the local neurosurgeon for an endoscopic fenestration of the trapped temporal horn. The second part of the video was captured by the LVP station at the same time in Jingzhou, Hubei, China, showing clear and almost instantly updated marks on the endoscopic view. © Xiaolei Chen, published with permission. Click here to view.

The instructor used an iPad connected to 4G internet service. The linear distance between the local and remote sites in this case was the longest in our study (11,923 km). The latency was 230 msec, which was notable but still acceptable.

Case 17
Case 17 was the first case for us to test our MIMIT system on 5G mobile internet. An endoscopic third ventriculostomy (ETV) with pineal region tumor biopsy was successfully performed using the MIMIT system. The local surgeon was in Beijing, while the instructor was in Sanya, Hainan, China. The distance between these two sites is 2489 km. With 5G high-speed mobile internet, the average latency was as low as 23 msec (Fig. 5A). The audio and video delay was simply not perceptible.

**Video Composite Latency**

Video composite latency analysis was performed with the data calculated by our millisecond clock program (Fig. 5A). The local station to remote station video latency averaged 184.25 msec (range 160–230 msec) with 4G mobile internet and significantly lower (23.25 msec, range 20–26 msec) with 5G internet. Of the 20 telecollaboration procedures that have been successfully completed, the shortest straight-line distance was 0.1 km (same building, different rooms), and the longest distance was 11,923 km (Boston, Massachusetts, to Jingzhou, China). In the statistical graph (Fig. 5B), we can see that the latency increases with the straight-line distance. The delay is mild but still perceptible. After we started our MIMIT system over 5G internet, there was a noticeable drop in latency. Despite the distances involved, video latency did not significantly interfere with the surgical procedures. The relationship between latency, distance, and network connection is shown in Table 1 and Fig. 5B.

**Setup and Disassembly**
The LVP workstation is encased in a single conventional computer case, which makes the setup and disassembly very easy. Setting up the LVP station and breakdown at the end of a case took less than 5 minutes. For the remote site, because we use personal mobile devices such as mobile smartphones and tablets, the setup time for the distant station consists only of starting our telecollaborative app and logging into the system, which takes less than 1 minute. Surgical procedure times were not believed to be significantly affected by the use of the MIMIT system.

**Clinical Implementation Analysis**
MIMIT was used throughout the endoscopic procedures, without unacceptable interaction delay or obstacles affecting communication between the two sides. Although noticeable video and audio delays occasionally happened when we used a 4G connection, the internet connection was never lost during the procedures. There were no hardware failures or surgical complications. Each participant strongly agreed that the system was very helpful for the successful implementation of surgery and professional real-time guidance. Up to the last follow-up evaluation, no technically related complications had been recorded. Before the use of our system, many endoscopic operations could not be performed in local hospitals, even if the relevant endoscopy equipment in local hospitals was complete.

**Discussion**
In China, high-end medical resources are unequally distributed. Most experienced neurosurgery specialists usually work in metropolitan areas along the east coast, such as Beijing, Shanghai, or Guangzhou. There are huge gaps between these metropolitan areas and inland cities in west China, both in medical technology and in the number of neurosurgical specialists. In recent years, with economic development, more investments in medical equipment are possible for inland cities. Hence, the gap in new equipment between the two regions has been gradually closed. However, the complexity of neurosurgical execution cannot be easily conveyed by only purchasing new equipment. Well-trained, experienced neurosurgeons are essential. In our study, the full set of neuroendoscopic equipment is available in all local hospitals. Unfortunately, most neurosurgeons in local hospitals have limited experience in neuroendoscopic procedures. This situation necessitates the development of technologies to geographically extend the reach of expert neurosurgeons. Although traditional remote robotic surgery has expanded the scope of geographic intervention for surgeons, many shortcomings remain in the application of robotics in neurosurgery, such as expensive investment, delayed movement-related safety issues, and the need for skilled robotic surgeons, which limit its neurosurgical use. In recent years, remote interactive systems have developed rapidly, allowing surgeons to conduct long-distance, real-time surgical guidance, which plays a vital role in surgeon training and telecollaborative complex surgical procedures.

For the MIMIT system we developed, the hardware is inexpensive and the system has proven to be technically feasible and helpful for improving local medical services as well as skill-building for local neurosurgeons. Theoretically, endoscopic, microscopic, and endovascular procedures, which can all export video signals, are ideally suited for implementation using our system.
to the implementation of our MIMIT technology. In our system, the LVP software is commercially available, while the remote instructor app is free and downloadable in the iOS or Android app store. The local site composite video can be viewed using either a HoloLens (holo-graphic display panel) or an inexpensive standard PC panel monitor. This feature makes our system more flexible for different medical centers and different procedures. For example, during future possible microsurgical or endovascular procedures, use of a head-mounted HoloLens may not be possible, but a simple panel monitor can easily take its place.

We used our MIMIT system to successfully perform 20 telecollaborative neuroendoscopic procedures. Compared with previously reported remote interactive systems,13,16,20,21 in our system we objectively and precisely evaluated the composite video delay of all 20 procedures. The distance between the two sites where we perform long-distance, real-time operative interaction ranges from 0.1 to 11,923 km, and the latency of the composite video is 184.25 msec when we use a 4G mobile network. This latency was significantly shortened to 23.25 msec when we used the 5G network in 2019. The 5G network greatly reduces latency and brings a better and safer interactive experience for both participants, which is consistent with previously reported laparoscopic surgery.13 With the rapid deployment of 5G networks in China, we expect that our MIMIT technology can be used between more centers via this faster network.

For the training of local neurosurgeons, expert surgeons may spend short periods of time providing hands-on demonstration or training in local hospitals. The number of short-term surgical trips has increased dramatically over the past 30 years,24 but the lack of emphasis on training and the frequent absence of follow-up have led to criticism of the short-term trip model.25,26 Although less experienced surgeons may alternatively visit the more experienced expert for longer-term observerships, actual participation in surgery is largely prohibited. As a result, the ideal method for skill-building involves hands-on training of surgeons in their local centers, performing cases on their own patients. In trauma and critically ill patients, nonvirtual interactive tools for extending the expertise of subspecialists are associated with reduced morbidity and mortality.27,28 A versatile and easy-to-use telecollaboration technology to integrate the expertise of a remote surgeon into the surgical field could serve as a valuable adjunct to in-person training efforts. In our study, the MIMIT system allowed long-distance skill training and knowledge transfer between different hospitals.

To make our MIMIT technology sustainable, we designed and tested a feasible business model. A reasonable payment rate ($158 USD/hr) for telecollaboration is collected and distributed legally between the online platform, the local neurosurgeon, and the remote instructor. In this way, the patient actually paid much less than with a typical expert short-term travel model; the patient no longer needs to pay for travel and accommodation expenses, as well as the honorarium of the expert. For the expert specialist, he or she no longer needs to travel more than 12 hours just for a 2-hour endoscopic procedure. Comfortably seated in his/her own office or home, he/she can easily finish 3 or 4 tele-collaborative cases in 1 day and collect enough payments. For the local neurosurgeons, interactive telecollaboration systems such as the MIMIT serve as a bridge, providing new skills to local surgeons who are already generally trained for basic neurosurgical skills. They can gain not only firsthand operative experiences but also hands-on demonstrations from experts. In addition, their payments for telecollaboration can serve as a motivation. Lastly, the telecollaboration service company in our MIMIT system designates 50% of the payment for hardware and online platform maintenance. The hardware of the LVP station and a HoloLens cost approximately RMB 30,000 yuan ($4743 USD), which is not expensive. The local hospital can easily cover this part of the cost. However, the development of the MIMIT system, including hardware and software development, took 6 months and cost about RMB 800,000 yuan (about $126,000 USD). For maintenance, it costs about RMB 25,000 yuan ($4000 USD) per month for the rental fee of a web server and relevant cost of labor. The development cost and the later maintenance fee are first covered by a company (Guangzhou Jincheng Airui Technology Co., Ltd.). Like most companies providing an internet-based service, such as Uber, it is reasonable for the company to take 50% of the payment to reimburse the previous development and later maintenance costs. It is inexpensive for the local hospital to obtain the LVP hardware and start the business. The company also has ways to balance the development and maintenance investment in the long run, making the MIMIT system sustainable. Hence, our business model makes a win-win situation possible for the patients, local neurosurgeons, experts, and the online telecollaboration platform company.

Our MIMIT technology is not meant to replace standard neurosurgical training, but instead acts as a complementary method that facilitates mentoring without the physical presence of the experienced expert. We expect that this technology will act as a mentorship bridge, i.e., taking a neurosurgeon with fundamental neurosurgical skills and providing real-time feedback to coach them toward true expertise.

Our ongoing efforts are underway to build a smart online case/mission recruitment and distribution system, as well as an online rating/comment system for both local neurosurgeons and remote instructors. We believe that some basic concepts of successful online businesses, such as Uber or Facebook, can be carefully adopted for the redistribution of medical expertise and relevant resources in China. Future issues facing the widespread adoption of digital telecollaboration systems include reimbursement and liability, as well as rigorous assessment of the impact on patient outcomes.

Conclusions

The MIMIT system allows for real-time, long-distance telecollaborative neuroendoscopic procedures and surgical training through a commercially available and inexpensive system. It enables remote experts to implement real-time, long-distance intraoperative interaction to guide inexperienced local surgeons, thus integrating excellent medical resources and possibly promoting both diagnosis
References

1. Anwar SL, Harahap WA, Aryandono T. Perspectives on how to navigate cancer surgery in the breast, head and neck, skin, and soft tissue tumor in limited-resource countries during COVID-19 pandemic. *Int J Surg*. 2020;79:206-212.

2. Aldawoodi NN, Muncey AR, Serdukt AA, et al. A retrospective analysis of patients undergoing telemedicine evaluation in the preanesthesia testing clinic at H. Lee Moffitt Cancer Center. *Cancer Control*. 2021;28:10732748211044347.

3. Chai KC, Zhang YB, Chang KC. Regional disparity of medi- neurosurgical endoscopic technology in more hospitals to and treatment. Moreover, it can popularize and improve neurosurgical endoscopic technology in more hospitals to benefit more patients, as well as more neurosurgeons.

Acknowledgments

This study was funded by the National Key Research and Development Program of China (grant no. 2018YFC1312602) and the National Natural Science Foundation of China (grant no. 81771481). We would like to thank Mrs. Winnie Chen for programming the millisecond clock app. We would also like to thank Guangzhou Jincheng Airui Technology Co., Ltd., for their support in developing the infrastructure of the MIMIT system.

10. McGillion M, Ouellette C, Good A, et al. Postoperative remote automated monitoring and virtual hospital-to-home care system following cardiac and major vascular surgery: user testing study. *J Med Internet Res*. 2020;22(3):e15548.

11. Xu X, Zeng Z, Qi Y, et al. Remote video-based outcome measures of patients with Parkinson’s disease after deep brain stimulation using smartphones: a pilot study. *Neuro surg Focus*. 2021;51(5):E2.

12. Zhou X, Zhang H, Feng M, Zhao J, Fu Y. New remote centre of motion mechanism for robot-assisted minimally invasive surgery. *Biomed Eng Online*. 2018;17(1):170.

13. Zheng J, Wang Y, Zhang J, et al. 5G ultra-remote robot-assisted laparoscopic surgery in China. *Surg Endosc*. 2020;34(11):5172-5180.

14. Xiong R, Zhang S, Gan Z, et al. A novel 3D-vision-based collaborative robot as a scope holding system for port surgery: a technical feasibility study. *Neurosurg Focus*. 2022;52(1):E13.

15. Swanson M, MacKay M, Yu S, Kagiliery A, Bloom K, Schwebel DC. Supporting caregiver use of child restraints in rural communities via interactive virtual presence. *Health Educ Behav*. 2020;47(2):264-271.

16. Dream S, Kuo JH, Wang TS. Virtual interactive presence, a novel approach to remote proctoring for the adoption of innovative technologies and interventions. *Am J Surg*. Published online September 14, 2021. doi:10.1016/j.amjsurg.2021.09.007

17. Kothgassner OD, Goreis A, Kafka JX, et al. Agency and gender influence older adults’ presence-related experiences in an interactive virtual environment. *Cyberpsychol Behav Soc Netw*. 2018;21(5):318-324.

18. Gromer D, Reinke M, Christner I, Pauli P. Causal interactive links between presence and fear in virtual reality height exposure. *Front Psychol*. 2019;10:141.

19. Schwebel DC, MacKay JM, Redden D. Study protocol: a randomised non-inferiority trial using interactive virtual presence to remotely assist parents with child restraint installations. *Inj Prev*. 2020;26(3):289-294.

20. Shenai MB, Tubbs RS, Guthrie BL, Cohen-Gadol AA. Virtual interactive presence for real-time, long-distance surgical collaboration during complex microsurgical procedures. *J Neurosurg*. 2014;121(2):277-284.

21. Davis MC, Can DD, Pndrik J, Rocque BG, Johnston JM. Virtual interactive presence in global surgical education: international collaboration through augmented reality. *World Neurosurg*. 2016;86:103-111.

22. Qi Z, Li Y, Xu X, et al. Holographic mixed-reality neuroravitation with a head-mounted device: technical feasibility and clinical application. *Neurosurg Focus*. 2021;51(2):E22.

23. Mendez I, Hill R, Clarke D, Kolyvas G, Walling S. Robotic long-distance telementoring in neurosurgery. *Neurosurgery*. 2005;56(3):434-440.

24. Warf BC. Neurosurgical humanitarian aid. *J Neurosurg Pediatr*. 2009;4(1):1-3.

25. Dupuis CC. Humanitarian missions in the third world: a polite dissent. *Plast Reconstr Surg*. 2004;113(1):433-435.

26. Maki J, Qualls M, White B, Kleefield S, Crane R. Health impact assessment and short-term medical missions: a methods study to evaluate quality of care. *BMC Health Serv Res*. 2008;8:121.

27. Marttós A, Kelly E, Gragvo J, et al. Usability of telepresence in a level 1 trauma center. *Telemed J E Health*. 2013;19(4):248-251.

Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: Chen. Acquisition of data: Chen, S Zhang, Li, J Wang, Q Wang, H Zhang. Analysis and interpretation of data: Zhao, Xiong, Gan, J Zhang. Drafting the article: Chen, S Zhang, Zhao, Gan. Critically revising the article: Chen, S Zhang, Li, Gan, Xu. Reviewed submitted version of manuscript: Chen, Xiong, Gan, J Zhang. Approved the final version of the manuscript: Chen. Study supervision: Chen.

Supplemental Information

Videos

*Video 1.* https://vimeo.com/694473370.

*Video 2.* https://vimeo.com/694476338.

Correspondence

Xiaolei Chen, Chinese PLA General Hospital, Beijing, China. chxlei@mail.sysu.edu.cn.