Telemedicine via Smart Glasses in Critical Care of the Neurosurgical Patient—COVID-19 Pandemic Preparedness and Response in Neurosurgery

Thangaraj Munusamy[1,2], Ravindran Karuppiah[1], Nor Faizal A. Bahuri[1], Sutharshan Sockalingam[1], Chun Yoong Cham[1], Vicknes Waran[1]

■ OBJECTIVE: **The coronavirus disease 2019 pandemic poses major risks to health care workers in neurocritical care. Recommendations are in place to limit medical personnel attending to the neurosurgical patient as a protective measure and to conserve personal protective equipment. However, the complexity of the neurosurgical patient proves to be a challenge and an opportunity for innovation. The goal of our study was to determine if telemedicine delivered through smart glasses was feasible and effective in an alternative method of conducting ward round on neurocritical care patients during the pandemic.**

■ METHODS: **A random pair of neurosurgery resident and specialist conducted consecutive virtual and physical ward rounds on neurocritical patients. A virtual ward round was first conducted remotely by a specialist who received real-time audiovisual information from a resident wearing smart glasses integrated with telemedicine. Subsequently, a physical ward round was performed together by the resident and specialist on the same patient. The management plans of both ward rounds were compared, and the intrarater reliability was measured. On study completion a qualitative survey was performed.**

■ RESULTS: **Ten paired ward rounds were performed on 103 neurocritical care patients with excellent overall intrarater reliability. Nine out of 10 showed good to excellent internal consistency, and 1 showed acceptable internal consistency. Qualitative analysis indicated wide user acceptance and high satisfaction rate with the alternative method.**

■ CONCLUSIONS: **Virtual ward rounds using telemedicine via smart glasses on neurosurgical patients in critical care were feasible, effective, and widely accepted as an alternative to physical ward rounds during the coronavirus disease 2019 pandemic.**

INTRODUCTION

The coronavirus disease 2019 (COVID-19) was declared a pandemic by the World Health Organization on 11 March, 2020.[1] It causes a severe respiratory disease that often culminates in fatality, especially in elderly patients or those with comorbidities. Its primary mode of transmission is airborne via droplets, and the rate of transmission is alarmingly high.[2] Health care workers are at high risk of contracting the infection, particularly when they are exposed to COVID-19–positive patients during aerosol-generating procedures and interventions as warned by the Centers for Disease Control and Prevention. Merely being present in close proximity or in the vicinity of the patient could increase the risk significantly as the droplets can aerosolize up to 4 m.[3]

Neurosurgery is a specialty where acute patients are often ventilated and managed in the intensive care unit (ICU); hence health care workers who are involved in their care would be exposed to aerosols and airborne particulates. In addition, many neurosurgical patients are admitted to the hospital in a comatose or confused state, and their identity and COVID-19 risk status are initially unknown. Thus reviewing and managing an acute neurosurgical patient in the ICU would predispose the health

Key words
- Critical care
- Neurosurgery
- Pandemic
- Smart glasses
- Telemedicine

Abbreviations and Acronyms
COVID-19: Coronavirus disease 2019
ICU: Intensive care unit
PPE: Personal protective equipment
SOP: Standard operating procedure

From the [1]Division of Neurosurgery, Faculty of Medicine, University of Malaya, Kuala Lumpur, Malaysia; and [2]Global Health Research Group on Neurotrauma, National Institute for Health Research, Cambridge, United Kingdom

To whom correspondence should be addressed: Vicknes Waran, M.D. [E-mail: cmvwaran@gmail.com]

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care worker to a higher risk of occupational transmission of COVID-19.[4]

In view of these risk factors, ideally all health care workers who are present in the same treatment room or cubicle as the acute neurosurgical patient in the ICU should be made mandatory to wear the full armamentarium of personal protective equipment (PPE). This is neither practical nor cost-effective in a resource-constrained setting, especially when the global and nationwide supply of PPE is running low.[5] One potential solution would be to reduce the number of health care workers who interact with the neurosurgical patient to the bare minimum as recommended by the World Health Organization.[6] This may prove to be difficult as most ICU ward rounds usually involve a number of doctors and nurses simultaneously. In a neurosurgical ICU there may be the need for intensivists, neurosurgical specialists, residents, and nurses for multidisciplinary consultation on complex problems and also training.[7] Specifically, during ward rounds, multiple staff members are required for both examination and documentation purposes. However, during this difficult period, attempts have been made in many units to try and only have a single doctor and a single nurse to interact and examine the patients during ward rounds or clinical review sessions.[8] Unfortunately, this may lead to suboptimal management as often a junior doctor would assume the role and subsequently relays the information and findings to the specialist verbally in a delayed fashion. The junior doctor may not have the necessary expertise and experience to holistically manage a neurosurgical patient who may be ridden with complex medical and surgical issues. On the other hand, the specialist may miss certain clinically relevant information when he or she is not physically present by the bedside. This limitation becomes glaring when there is a need to convey visual or graphical representation from essential bedside devices in the ICU such as physiologic and intracranial pressure monitors, ventilators, infusion pumps, and computer and imaging terminals.

Thus a safer and practical option would be to facilitate the virtual presence of key medical personnel in the ICU, both routinely and when a need arises. This is possible via synchronous telemedicine, which offers a real-time and contemporary solution to mitigate the shortcomings and bridge the communication gap during the COVID-19 pandemic.[9,10] Moreover, it can be applied to any clinical scenario to facilitate remote assessment and consultation with a high degree of clinical accuracy without compromising on patient care and safety.[11] Combining wearable technology, such as smart glasses with telemedicine, offers the added advantage of operation with a degree of freedom and unobtrusiveness as it provides view from the examining doctor's perspective with minimal line of sight impediment.[12] Such an integrated system has the potential to coexist with and streamline current clinical workflows, and their synergistic combination would no doubt be useful in the transformation of health care to meet the clinical demands of the pandemic.

Therefore we have devised a simple yet effective solution using telemedicine via smart glasses to facilitate optimal management of neurosurgical patients in the ICU. In this article, we share our method and experience in implementing and sustaining this alternative management model to safeguard neurosurgical patients and health care workers during the COVID-19 pandemic.

METHODS

We have installed and integrated a secure mobile telemedicine system (MEDCOM Vision, Centre for Biomedical and Technology Integration, Kuala Lumpur, Malaysia) into commercially available smart glasses (Vuzix M400 Smart Glasses, Vuzix Corporation, Rochester, New York, USA). The cost of a pair of smart glasses was approximately $1800 USD, whereas the software was developed locally to conform to national and institutional regulations with emphasis on secure data storage and retrieval together with recognition, monitoring, and control of registered users.

In this study, the customized smart glasses were specifically used during the daily ward round on neurosurgical patients in the Neurosurgery ICU at the University of Malaya Medical Centre in Malaysia. Protocols on the identification of staff involved, patients being reviewed, and steps in the examination, consultation, and documentation processes were developed and compiled into a standard operating procedure (SOP) manual. A summary of the key steps for each patient review in a virtual ward round was compiled into a flow diagram (Figure 1).

A training session was conducted for all neurosurgery team doctors. They were taught how to assemble, activate, and effectively use the glasses with and without full PPE to initiate and receive consultations with real-time transmission of audiovisual and clinical data (Figure 2). The training session for each individual took 30 minutes, which included a trial of navigation around the ward and a mock presentation of a clinical scenario. At the end of the session, all doctors attained competence and were able to assemble, activate, and start using the smart glasses and telemedicine system in <5 minutes. A copy of the SOP was provided as a reference, which included a guide on the sequence and essential parameters for teleconsultation in neurosurgery together with an exemplary script. The smart glasses wearers were residents, and they were taught how to safely disinfect the glasses after each use. On the other hand, the receiving doctors were specialists who were taught how to participate in teleconsultation via any mobile device.

Once the neurosurgery team doctors were familiar and competent in teleconsultation via smart glasses, the study was commenced with institutional and ethical approval. This study used a single-subject design consisting of 10 virtual and 10 physical ward round sessions.

Each ward round team consists of a random pair of resident and specialist from a pool of 3 residents and 2 specialists. The team conducted 2 consecutive morning ward rounds daily, starting with a virtual ward round where the resident wore smart glasses and consulted the specialist in real time and subsequently followed by a physical ward round where both resident and specialist conducted the ward round together (Video 1). A log of all usage of the smart glasses was kept, and the associated clinical interaction and conversation were recorded for analysis purposes.

Video

Video available at www.sciencedirect.com

The 2 ward rounds were compared and analyzed, particularly the problem list and management plans. If the outcome of both

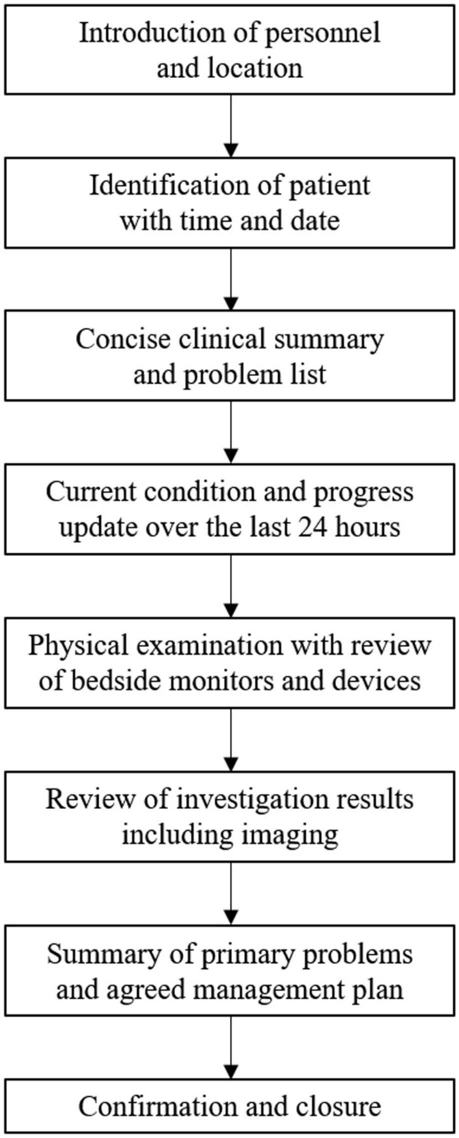

Figure 1. Flow diagram of the key steps for each patient review in a virtual ward round.

ward rounds differed from each other, a note was made on the reason and whether it was due to inaccuracy or inadequacy of the virtual ward round or availability of new information during the time interval. Consistency and intrarater reliability for the 2 ward rounds were evaluated using the Cronbach alpha coefficient and intraclass correlation coefficient. The following scale was used for both coefficients: excellent (>0.9), good (> 0.8), acceptable (> 0.7), questionable (>0.6), poor (>0.5), and unacceptable (<0.5).[13] A survey was sent to the users on completion of the study to assess acceptance, satisfaction, overall impact, efficacy, and potential of this alternative method of teleconsultation. The team also convened regularly to discuss the difficulties and problems encountered in implementing the virtual ICU ward rounds during the COVID-19 pandemic.

RESULTS

Ten pairs of ward rounds were performed in the study involving 103 patients. The summary of each paired ward round is shown in Table 1, and the total summary of all paired ward rounds combined is shown in Table 2. The number of changes made to decisions or management plans according to reason is shown in Table 3.

Intrarater Reliability

Nine out of the 10 paired ward rounds show good to excellent internal consistency (Cronbach alpha > 0.8). The remaining paired ward round had an acceptable internal consistency (Cronbach alpha = 0.75). The overall intrarater reliability for all 10 ward rounds was excellent with an intraclass correlation coefficient of 0.936. The reasons for changes to decisions or plans in the physical ward rounds were either due to inadequate information in the virtual ward rounds or availability of new information in the time interval between the 2 ward rounds. There were no inaccuracies observed in the information relayed during the virtual ward rounds.

Qualitative Analysis

Table 4 summarizes the overall user experience in this study. The mode score of all attributes that compose user experience was either 4 or 5, thus indicating wide acceptance and high satisfaction with this alternative method of conducting ward rounds in the pandemic. Furthermore, Table 5 shows that the majority of users recognize the potential usage and application for smart glasses in a variety of health care settings.

DISCUSSION

The use of smart glasses in medicine was pioneered in the early 2010s, and the initial specialties that adopted its use were primary care, dermatology, and pediatric surgery.[14] Alas, the idea did not take off in earnest and usage was limited to a single-user setting (e.g., physicians used it to simultaneously access patient data by the bedside. These glasses, however, have been successfully used in business and industry to revolutionize and improve safety and productivity, especially in warehouse inventory management, high-risk jobs that required safeguarding, or when the supervision of more junior workers was required from a distance.[15-17]

The COVID-19 pandemic created a situation similar to dealing with a hazardous work environment where smart glasses have found necessity and success. Thus our team decided to adapt its usage to a critical care environment within a hospital that was gazetted as a COVID-19 treatment center but at the same time was continuing to manage routine neurosurgical patients.

By using the smart glasses, specialists monitoring the ward rounds were able to direct residents and junior staff members through the routine daily review of patients requiring critical care. This included physical examination, review of physiologic parameters (both spot values and trends over a 24-hour period or longer), review of medications, blood results, radiologic imaging, and wound management. Therefore the specialist was able to

Figure 2. Photographs of a resident wearing smart glasses. (**A**) Side view with N95 respirator only. (**B**) Front view with N95 respirator only. (**C**) Side view with full personal protective equipment (PPE). (**D**) Front view with full PPE.

holistically and continuously "see" the exact first-hand clinical information in real time and in a "bedside" manner to advise and guide the resident confidently and accurately. In all instances, visibility and audiovisual propagation were not a problem. The limitation during clinical examination was the inability for the specialist to observe a detailed physical examination including listening to the auscultation of chest and abdomen.[18,19] Specialists were also unable to interact directly with patients who were conscious and able to communicate.

In addition to the above, in the early phase of our study, we discovered that the residents may have difficulty adjusting and adapting to the smart glasses without prior training. During the first paired ward round in our study, the resident who used the smart glasses for the first time quickly became overwhelmed with nausea and dizziness. Hence the study could not proceed beyond 5 patients. Post hoc analysis revealed that the resident was continuously shifting focus between the smart glasses display screen and the environment; thus he experienced a phenomenon similar to simulator sickness experienced by users of virtual reality glasses.[20,21] Additionally, constantly focusing the eyes on a display screen at close focal distances causes visual fatigue, which immensely affected the duration of optimum usage of the smart glasses.[22] Moreover, as the resident focused his central eye gaze on the display screen, his multitasking ability was significantly

Table 1. Individual Paired Ward Round Summary and Intrarater Reliability

Paired Ward Round Number	Number of Patients	Number of Virtual Ward Round Decisions/Plans	Number of Changes to Decisions/Plans in Physical Ward Round	Cronbach Alpha
1	5	12	1	0.750
2	11	34	3	0.949
3	8	25	1	0.948
4	9	18	0	1.000
5	10	19	0	1.000
6	12	27	1	0.970
7	10	22	2	0.899
8	14	30	6	0.804
9	10	14	3	0.875
10	14	28	2	0.903

affected. Remarkably, despite the impediments, the first paired ward round was still able to achieve an acceptable internal consistency with a Cronbach alpha score of 0.75.

To improve user adaptability to the smart glasses, we organized a training session for all the residents and specialists before the subsequent paired ward rounds. In the training session, the residents were taught strategies to minimize sickness (e.g., by adjusting the display screen to avoid significant obstruction of their field of view and refrain from looking at the display screen unless to localize an area of interest or prompted by the specialist). In addition, the residents were also taught how to conduct the virtual ward round seamlessly and present optimally to the specialist based on the SOP guidance.

Ingeniously, a single training session was able to facilitate user adaptability and mitigate the shortcomings encountered during the first paired ward round. The residents were able to overcome the learning curve and attain confidence in using the smart glasses independently and effectively. This was reflected in the subsequent paired ward rounds, which show good to excellent internal consistency (Cronbach alpha > 0.8). Arguably, repeated learning may have contributed to the improvement over time.

The use of technology can be seen as both an essential tool and a barrier in critical care.[23-25] New technology is known to pose extra challenges; thus in order to be able to implement and use it as an aid rather than a hindrance or distraction, user acceptance and satisfaction are essential. Facilitating factors for sustainability of any new technology are clear benefits, active end-user involvement, adequate education and training, user-friendliness, clear policies, and seamless integration into existing frameworks or standards of care.[26,27] These areas were addressed in our study and played a part in its success.

Overall, our questionnaire findings show that there is significant potential for smart glasses in critical care of neurosurgical patients. Users accept incorporation of smart glasses into their daily work to aid management and clinical decision making. In our study, the smart glasses and telemedicine system proved to be user friendly, reliable, and accurate with high-quality data transmission, hence clinically effective and sustainable. Some concerns were raised in the literature about a reduced presence of specialists, thereby potentially compromising patient safety and quality of care.[28] However, this was not observed in our study, which showed a high degree of intrarater reliability between the virtual and physical ward rounds. Furthermore, no inaccuracies were observed in the communication and transfer of information via smart glasses.

Nevertheless, as with any technology that improves efficiency and eases workflow, the primary danger would be that medical personnel may become complacent and depend entirely on this method of teleconsultation. As such, safe usage protocols and guidelines are necessary and periodic monitoring is recommended. Extrapolation for other use cases and to other specialities would require a similar approach before smart glasses can be deemed safe to be adopted as standard practice.

Use Cases Within and Beyond Critical Care and COVID-19

Clinical demands in the ICU differ from other clinical areas due to rapid changes in patient condition and the need for immediate specialist consultation or intervention. ICU telemedicine is a

Table 2. Total Paired Ward Rounds Summary and Intrarater Reliability

Total Number of Paired Ward Rounds	Number of Patients	Number of Virtual Ward Rounds' Decisions/Plans	Number of Changes to Decisions/Plans After Physical Ward Rounds	Intraclass Correlation Coefficient
10	103	231	19	0.936

Table 3. Reason for Changes in Clinical Decision/Plan in Physical Ward Round

	Number of Changes According to Reason		
Total Number of Changes to Decision/Plan	Inadequate Information in Virtual Ward Round	Inaccurate Information in Virtual Ward Round	New Information in Time Interval Between Rounds
19	7	0	12

promising mechanism to improve outcomes for critically ill patients.[29] Moreover, with smart glasses, the ability to view the patient as a first-hand reviewer and provide accurate advice or remote guidance is highly desired and advantageous.[30,31] Smart glasses can give the clinician information such as patients' data, clinical parameters, or imaging studies within their field of vision so that the clinician can use it simultaneously while performing other tasks or procedures. This can be useful as it helps to avoid looking away from the area of intervention or stepping away from the patient.[32] In addition, smart glasses' integration with a mobile communication network permits real-time consultation with another authorized clinician.[33]

This method of consultation can be used in a variety of areas and settings other than the ICU. These include on board an ambulance to facilitate communication between paramedics and receiving hospital, out-of-hours consultation by the junior doctor with the specialist who is not on site or even in-hours consultation if the specialist is away or busy at another clinical area. From the neurosurgical perspective, this method would also support long-distance management via real-time evaluation of patients and teleconsultations between nurses or general doctors in remote facilities and centrally located specialists or qualified neurosurgeons. This capability can potentially be cost-effective in avoiding unnecessary emergency transfer of patients, as well as optimizing patient safety.[34]

Additionally, smart glasses can be widely used in training and education, from telementoring to remote supervision and guidance during procedures and interventions. For example, surgical trainees can use it intraoperatively during open surgeries to consult the senior surgeons for advice in the event of problems. Not only that, added features such as virtual reality, augmented reality, and holographic images enrich the learning experience. Thus it is not surprising that residents and students respond positively to this method of education.[35] It can help trainees to gain independence and confidence earlier and allow recording of their training experience and evaluations as an electronic portfolio.

Limitations

Our study had several limitations. Firstly, it was limited by the small sample size of 10 paired ward rounds. However, we managed to recruit >100 patients; thus data analysis and interpretation of findings were reliable. To adhere to infection control guidelines during the pandemic, we used a single-subject design. We measured intrarater reliability, which is generally considered to be inferior to interrater reliability as decisions may be contaminated by prior knowledge and repetition. This may result in overestimation of intrarater reliabilities.[36,37]

The study findings, specific to our specialty and institution, may be the result of the existing workflow in our hospital, where mobile technology is routinely used to support information sharing. Furthermore, given the different needs and experiences of each responder, the subjectivity of response and recorded information are potential contributors to bias.[38] We also have not conducted an evaluation in regard to the economic and ergonomic benefit of using smart glasses.[39] Nevertheless, our approach can be considered as the first step to improve the critical care management of neurosurgical patients during the COVID-19 pandemic while adhering to local regulations, resource constraints, and physical distancing measures.

Table 4. User Experience of Smart Glasses Teleconsultation in Neurocritical Care*

		Response (%)					
Number	Attributes	1—Very Poor	2—Poor	3—Fair	4—Good	5—Excellent	Mode Score
1	Technical quality	0	0	0	60	40	4
2	Clinical accuracy	0	0	0	40	60	5
3	Reliability	0	0	0	40	60	5
4	Overall efficacy	0	0	0	40	60	5
5	User friendliness	0	0	40	0	60	5
6	User satisfaction	0	0	0	40	60	5

*Attributes scored on a 5-point Likert scale.

Table 5. User Perception of Potential Usage for Smart Glasses in Health Care

Number	Clinical Setting/Application	Response (%)		
		No	Maybe	Yes
1	During pandemic	0	0	100
2	Daily routine use	20	20	60
3	Out-of-hours ward round	0	20	80
4	Emergency cases	0	40	60
5	Nonemergency cases	0	20	80
6	Infection risk areas	0	0	100
7	Other use cases in Neurosurgery	0	20	80
8	Other specialty	0	20	80

Smart glasses themselves are subject to several technical limitations.[40] The wireless connection to the mobile network occasionally exhibited a brief lag; however, this did not affect the conduct or flow of the virtual ward round. Smart glasses would need to be disinfected while their battery would need to be charged after each use. Besides, our study was also limited to the evaluation of only 1 particular type of smart glasses. As the technology evolves, especially in this trying time, more types of smart glasses would become available to clinicians and medical educators. Therefore head-to-head studies will be important here to explore their individual benefits, advantages, and ability to revolutionize health care and education.[41] With more research to come, the solution using smart glasses would only get better and popular.

CONCLUSIONS

We have shown that virtual neurocritical care ward rounds using telemedicine via smart glasses are feasible, effective, and acceptable as an alternative to physical ward round to circumvent manpower shortage, physical distancing measures, and key shortage of PPE during the COVID-19 pandemic. Nevertheless, as with any health care technology, attention must be paid to certain technical details, training requirements, and clinical nuances to achieve optimal outcomes.

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Thangaraj Munusamy: Conceptualization, Methodology, Formal analysis, Writing - original draft, Visualization. **Ravindran Karuppiah:** Investigation, Formal analysis, Writing - original draft. **Nor Faizal A. Bahuri:** Methodology, Investigation. **Sutharshan Sockalingam:** Investigation, Visualization. **Chun Yoong Cham:** Investigation, Visualization. **Vicknes Waran:** Conceptualization, Methodology, Formal analysis, Writing - review & editing, Supervision.

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