Chapter 22
Introducing Mixed Reality for Clinical Uses

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ABSTRACT

The advent of mixed reality (MR) has revolutionized human activities on a daily basis, striving for augmenting professional and social interactions at all levels. In medicine, MR tools have been developed and tested at an increasing rate over the years, playing a promising role in assisting physicians while improving patient care. In this chapter, the authors present their initial experience in introducing different MR algorithms in routine clinical practice from their implementation in several neurosurgical procedures to their use during the COVID-19 pandemic. A general summary of the current literature on MR in medicine has also been reported.

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INTRODUCTION

Mixed reality (MR) allows to visualize the real world and holographic 3D objects at simultaneously. In medicine, the real-time interaction of these two elements may allow improved understanding of the human anatomy. Detailed knowledge of each patient's represents the mainstay for optimal surgical planning. This is especially true in neurosurgery, where the target diseases are frequently located into deep sited and critical regions of the brain, needed to be treated with concurrent preservation of adjacent functionally-intact brain structures to ensure patient's optimal quality-of-life and survival. While the currently available technology in daily neurosurgical practice allows physicians only to look at a distant monitors during real-time operations, mixed reality (MR) allows to visualize directly "through" the patient's anatomy. In this way, the patient's anatomy is perceived with a greater detail, and the surgical planning may be devised within the surgeon's mind with more confidence. The hybrid visualization of virtual objects and real-world's anatomy represents the most recent advancement, which further offers the ability to customize the surgical planning and to share it with the surgical team, the patients, and their family. In this chapter we present the MR applications performed at the department of neurosurgery of the Cannizzaro Hospital, Catania, Italy, and in the two departments of C19-ICU unit and clinic for Vascular and Endovascular Surgery of the University Clinical-Hospital Centre "Dr Dragiša Mišović-Dedinje", Belgrade, Serbia.

BACKGROUND

The hardware that we use is HoloLens 2 (HL2) (Microsoft TM). It is a head-mounted display unit connected with a remote cloud for images reconstruction and audio-video storage (Figure 1).

Figure 1. HoloLens 2 (HL2) (Microsoft TM)

The headset can be adjusted on the user head and tilted up, down, forward, or backward through a posterior crown (Davies, 2015). The anterior part of the device contains several sensors and their related hardware, including the processors, cameras and projection lenses. The visor is dark-coloured and includes two transparent combiner lenses, in whose inferior portion are shown the projected images (Kipman & Juarez, 2015). The device's settings can be personalized based on the user's vision characteristics (the interpupillary distance (IPD), or accustomed vision of the user) (Hachman, 2015; Hollister, 2015). Two 3D audio speakers are site close to the user's ears, allowing to simultaneously listen sounds from the real world and virtual reality. Using head-related transfer functions (HRTF), the HL2 produces binaural audio, offering a real-life virtual experience (Holmdahl, 2015; Microsoft., 2020).

The frontal portion of the device contains two buttons, one at the right for volume control and one at the left for brightness control. The posterior portion has a concave power button and 5 lightning spots, showing battery levels (Munzer et al., 2019). Connectivity include Wi-Fi 802.11 ac, Bluetooth 5.0 e USB C and overall technical characteristics can be summarized as follows: transparent holographic lenses, resolution 2k 3: 2 LED light engine, radians> 2.5k, eye-based rendering optimization of the display for 3D eye position, tracking for head and eyes, depth by Azure Kinect sensor, accelerometer, gyroscope, magnetometer, camera: 8MP still images, 1080p30 video (Hempel, 2015; Holmdahl, 2015; Microsoft, 2015; Rubino, 2018).

MIXED REALITY TESTS IN NEUROSURGERY

Informed Consent

MR offers the opportunity to record video and audio during the holographic representation. This is of special interest during informed consent as it can enhance and augment patient's understanding of surgical risks and goals. The possibility to record the discussion between physicians, patients and family members may be also useful to minimize the risk of possible legal issue related to patient's misunderstanding of the therapeutic plan.

Head Tumor

At our institution, we use MR for preoperative and intraoperative navigation during brain tumor surgery. In the preoperative phase, the holographic rendering offers an immersive experience, increasing the understanding of the patient's brain anatomy and contributing to highlight the safer surgical corridor and the adjacent critical brain areas. During surgery, MR can be combined with the standard optic navigation, used as comparison to evaluate the accuracy of MR holographic rendering. In a period of 1 year, we tested MR in 53 brain tumor patients and compared its performance to the standard optic navigation in terms of real-time "geolocation" within the brain anatomy. The holographic navigation proved to be accurate, reliable, and with equal accuracy compared to the standard optic navigation. The only limitation we encountered was characterized by the overlapping of the hologram, which is manual, based on the visual overlapping of the 3D object over the patient's anatomy, and, thus, operator dependent (Figure 2).

Interestingly, the device allows to scroll the dataset not only with the MR reconstruction, but in any spatial orientation (Figure 3).

Figure 2. 3D hologram of the patient's CT scan of the cervical spine overlapping with the patien's anatomy

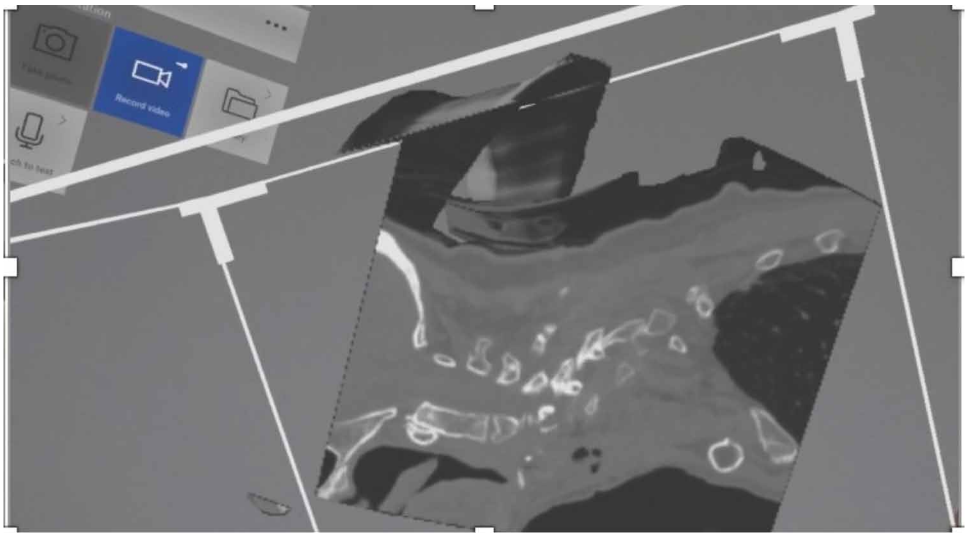
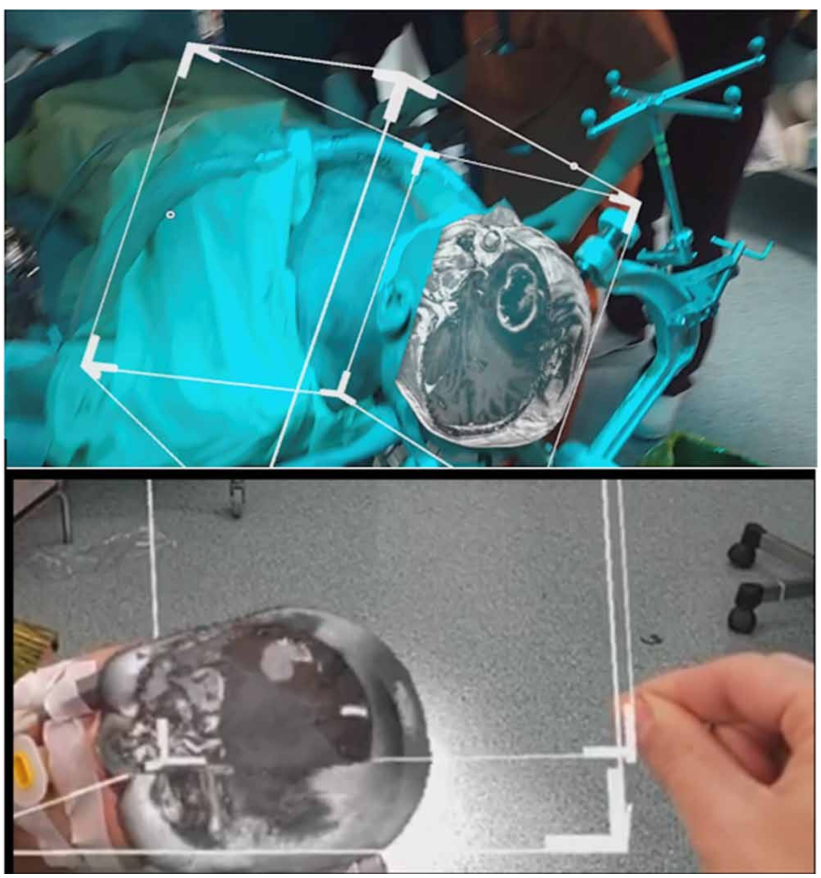


Figure 3. Real-time scrolling of the MR 3D hologram overlapped with the patient's anatomy

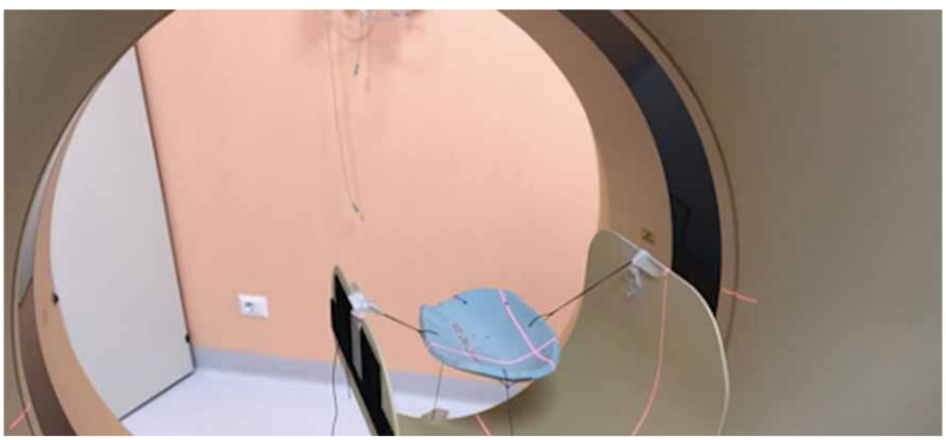


To improve the visibility of the hologram, we used greenlight in our OR. Greenlight offers a good visibility of the 3D virtual object and allow to safely perform surgery in real-time with minor chromatic limitations (e.g., the blood is perceived as dark-blue colored). On the other hand, the use of the direct illumination with white light, prevents to visualize the hologram, thus forcing the surgeon to move away from the white light field while using the MR navigation.

Head Trauma

Head trauma is one of the most important causes of major disability in the young population (Montemurro et al., 2020). In selected cases, decompressive craniectomy (i.e., removal of part of the skull) is required as a life-saving procedure to reduce the intracranial compression of the brain by post-traumatic intracranial hematomas. In survivor patients, cranioplasty (e.g., surgical placement of custom-made skull prostheses) is performed to reconstruct the skull as a cosmetic and therapeutic measure (Montemurro et al., 2021). Prostheses are custom-made, aimed to perfectly fit with the patient's anatomy to be correctly positioned at the level of the bone defect (Figure 4).

Figure 4. CT scanning of the skull prosthesis to plan th surgical implant



MR rendering can be used alongside templates to evaluate the accuracy of the prosthesis before surgery and during the operation (Figure 5).

Giving that cosmetic results is one of the main goals in these patients, the ability to share with the patients the expected outcome before the surgery is of outmost importance, and helps to increase patients' confidence in undergoing this type of surgery. MR is also a useful tool to improve the visualization of fracture classification of the base of the skull and safely plan best treatment strategies (Umana et al., 2022) (**Figure 6**).

Figure 5. A) modified "n" shaped skin flap scar and the phantom prosthesis over it. The peculiarity of this skin flap is represented by the vascular sparing of the afferent vessels. Note the posterior end of the incision, that finish at the level of the parietal prominence, securing blood supply from the posterior auricular artery and from the superficial temporal artery as well. This nuance, prevent necrosis of the posterior portion of the scar and its related complications; B) final intraoperative positioning of the custom-bone cranioplasty. C1-D1-E1) 3D MR rendering of the bone defect; C2-E2) intraoperative overlapping of the 3D MR object of the skull and the planned cranioplasty simulation; C3-D3-E3) skin flap scar before the cranioplasty procedure; C4-D4-E4) soft tissue MR rendering of the bone defect; D2) holographic intraoperative navigation of the cranioplasty prosthesis offers a similar visial feedback of the usual phantom; E) post-cranioplasty MR skin and temporalis muscle reconstruction rendering

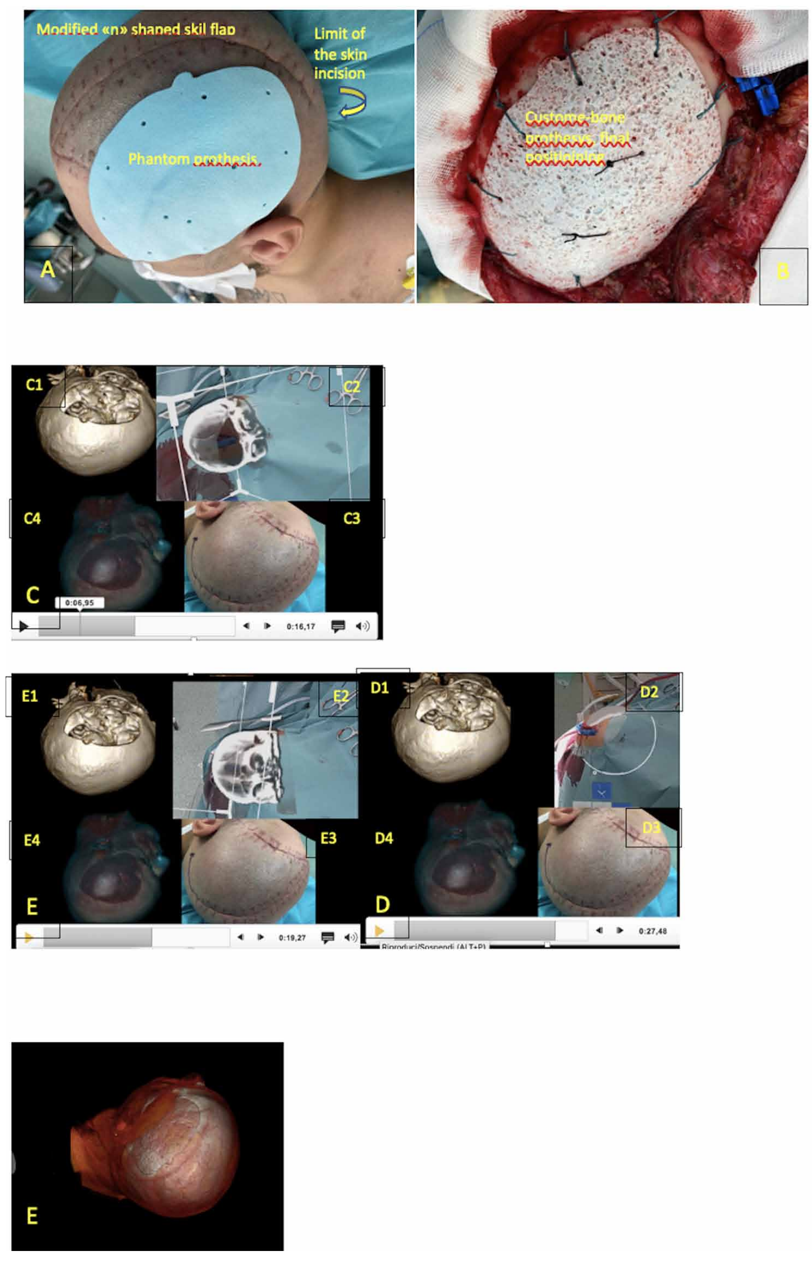
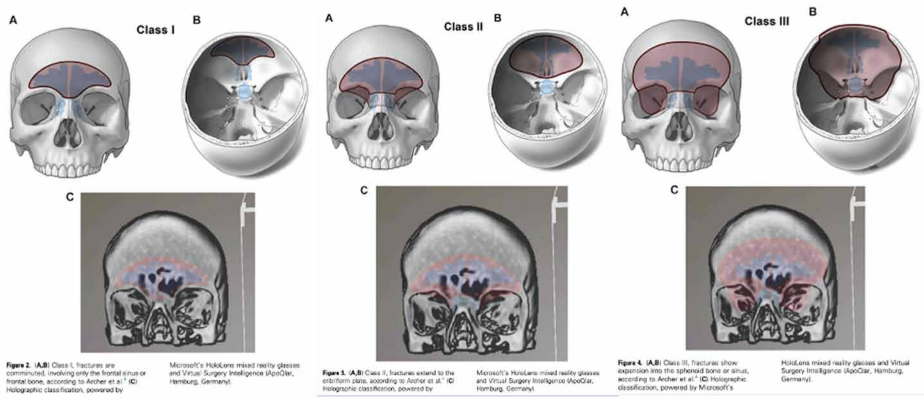


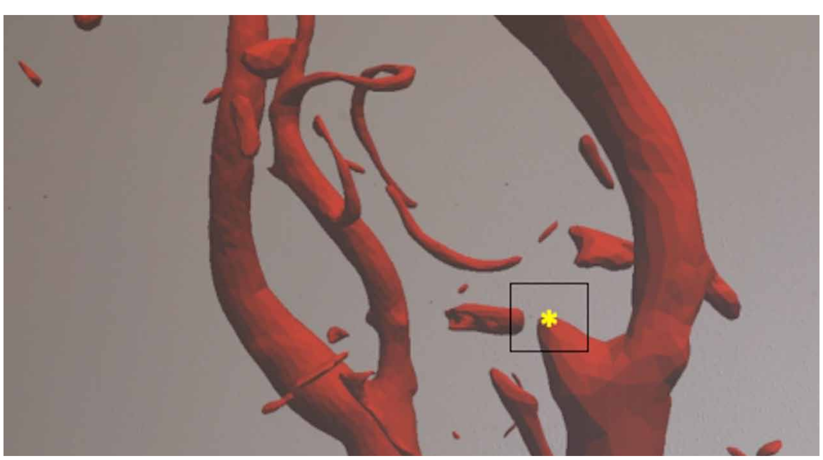
Figure 6. 3D holographic classification of anterior skull base fractures



Cerebrovascular Surgery

Aneurysms and arteriovenous malformations (AVM) represent a unique challenge for neurosurgeons. The surgical plan must take into account the spatial development of the vascular dilatation or malformation to customize the surgical approach accordingly. MR allows to see through the patient's head both before surgery and during patient's positioning, so to allow to identify the exact location of the target disease. This is currently performed using 3D reconstruction visualized on a computer after prior elaboration by a neuroradiologist. The possibility to visualize the 3D objects, rendering the aneurysm or the AVM directly "in" the patient, further improves the quality of the information available for the surgeon in the preoperative settings, likely to improve performances and outcomes (Figure 7).

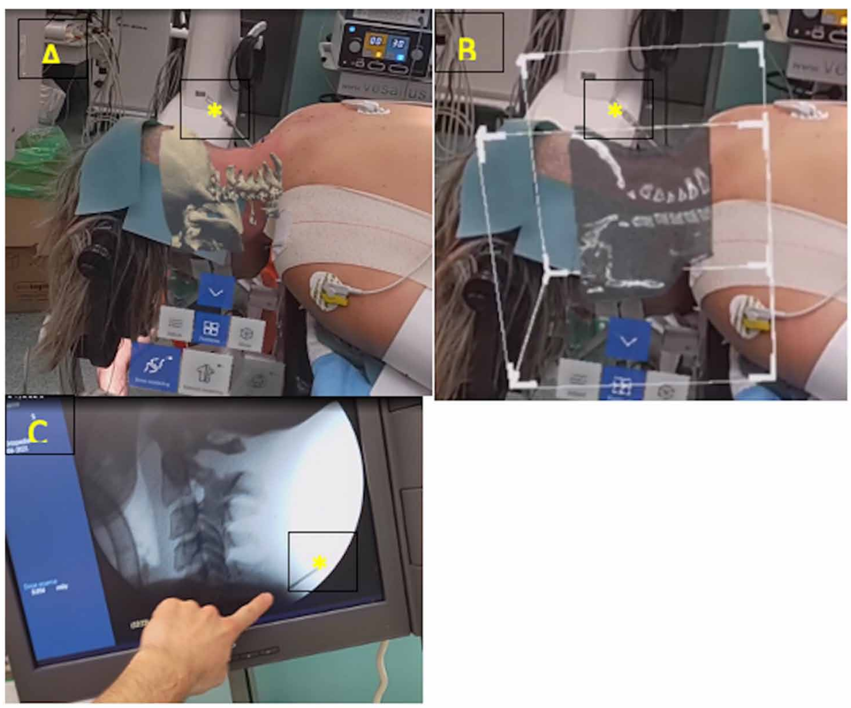
Figure 7. MR rendering is helpful to improve the three-dimensional perception of the vascular malformation in the planning phase, both for brain vascular malformation and stroke. The figure shows (*) the occlusion of the internal carotid artery in its extracranial tract, in a case of tandem occlusion of a stroke patient



Spine

Pilot studies in spine surgery have been conducted for cervical spine reconstruction in complex degenerative and traumatic cases, and for preoperative spinal level identification to plan surgical strategies. The possibility to visualize radiologic datasets through the patient during surgery offers the ability to modify the surgical technique and reduce the surgical invasiveness. However, at the present stage, the overlapping of the hologram over the patient requires the use skin markers and integration with intraoperative imaging (**Figure 8**).

Figure 8. MR used for intraoperative level definition. Figure 8A shows a 3D MR rendering of the spine overlapped over the patient after positioning. Figure 8B shows the overlapping of the CT scan dataset, that offers the possibility to scroll the CT of the spine directly through the patient, after her final surgical positioning. Figure 8C shows the intraoperative X-ray control that documents the correspondence of the cervical level with the three modalities, as shown by the inserted needle (*)



Remote Proctoring

With the advances of both surgical techniques and devices, new approaches and new instrumentations are a common and positive component of the modern clinical practice. To speed up the learning curve, experienced surgeons with peculiar expertise in selected techniques move to hosting hospitals, also in other countries, to support the surgical equip in the early stages of new types of surgeries. New surgical routes and new devices are usually associated to a less familiar anatomy, and thus proctors play a crucial role during their early implementations. Experienced surgeons with minor knowledge of that particular approach may promptly improve their new skills if supported in real-time. MR can play an important role in proctoring activities, reducing the need of moving physically into different hospital. This could be of special interest not only in the actual pandemic situation but above all to support surgeons in remote areas.

Figure 9. (A) 3D computer-based simulation, showing the entry point definition based on anatomical landmarks, to both the right and left, Evans' evaluation, simulation of the catheter placement (B-F), bilaterally obtaining grade A positioning (G) (Umana et al., 2021)

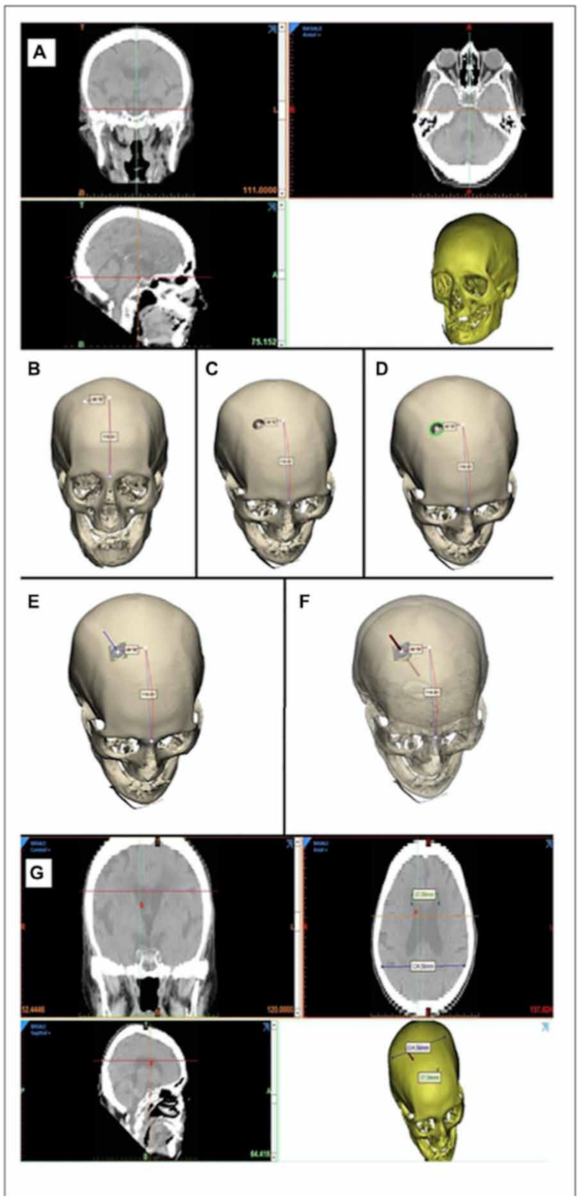


Figure 10. Finceramica plaster model navigation after merging the patient's CT scan (already treated for post-traumatic craniotomy, but with no midline shift). (A,B). Superficial tracing for navigation registration (BrainLab) of the plaster model. (C) Entry point definition with a holographic representation of the device. (D). Positioning of the real device on the defined entry point. (E) Overlap of the holographic device with the real one, to match the entry point. (F) Introduction of the navigated stylet inside the device. (G). Its representation with the standard navigation. (Umana et al., 2021)

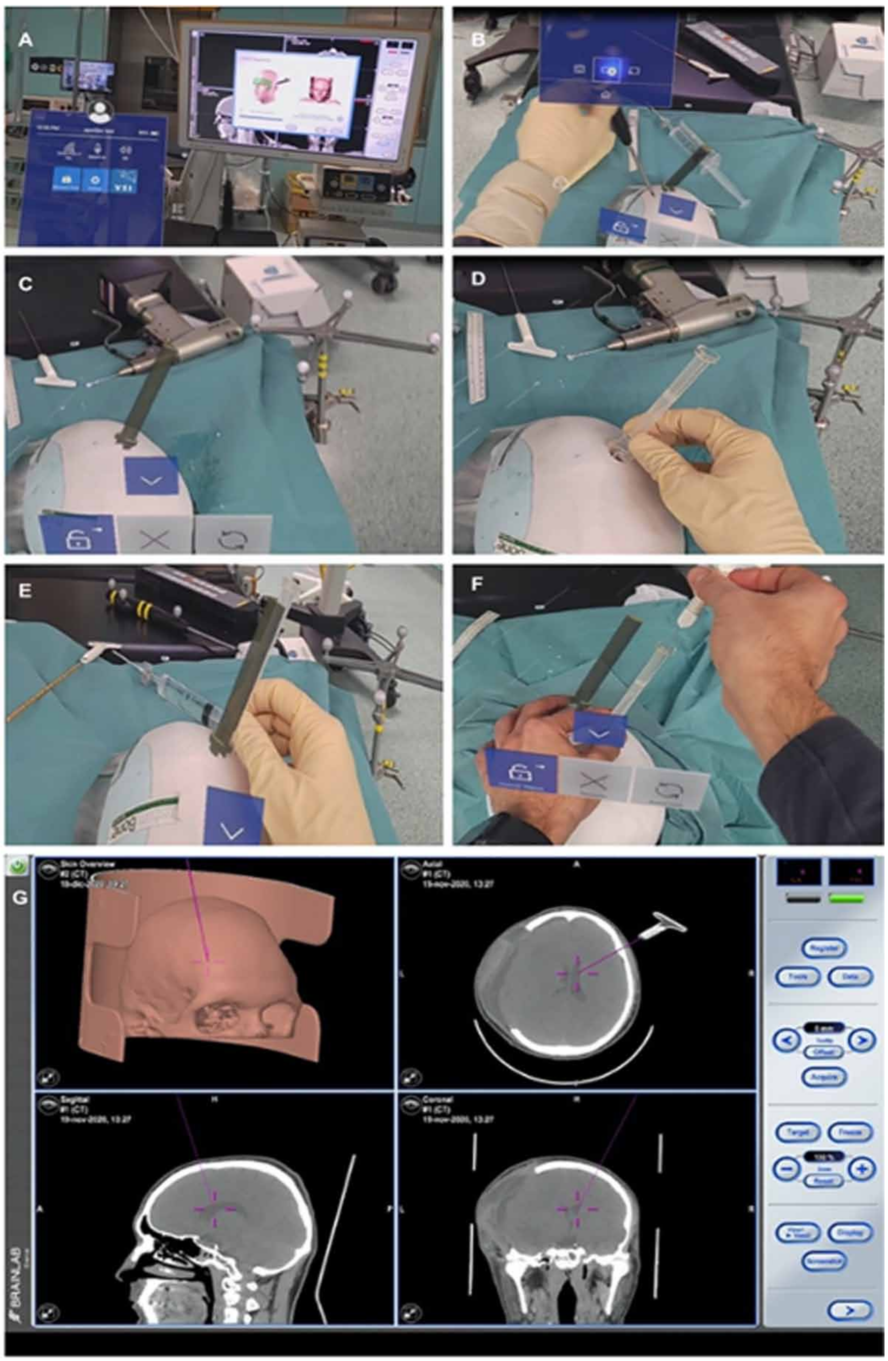
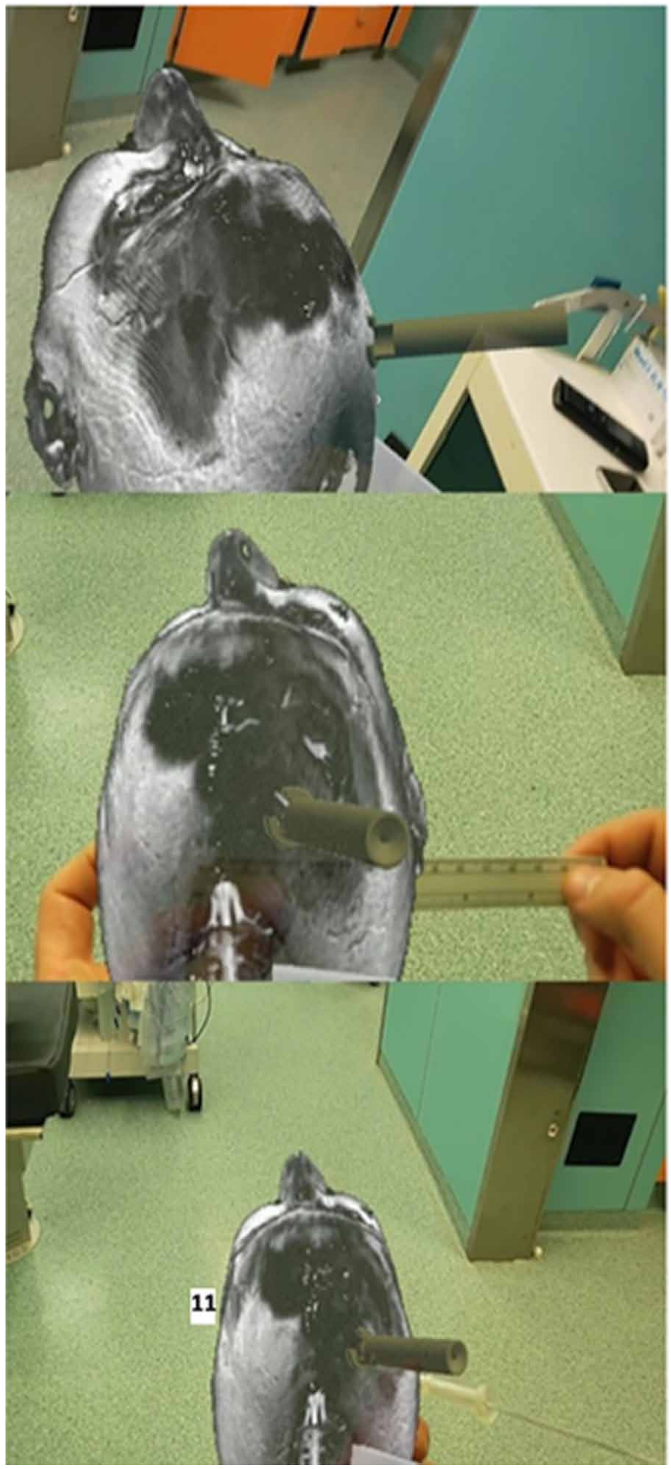


Figure 11. Augmented reality-based simulation (ApoQlar) to locate the entry point. A real ruler was overlapped on the hologram based on both MRI and CT scans; the actual device was overlapped over its holographic reconstruction, and the navigated stylet was introduced to improve familiarity with the procedure and technology (Umana et al., 2021)



Laboratory Simulation

MR can be proficiently used for surgical simulation, and this is of benefit for new devices, needed to be preliminarily tested. We applied MR technology for a novel device for external ventricular drain placement. Compared to other technologies like standard optical navigation, plaster model, computer-based simulation for geometrical considerations, MR offered similar results (Umana et al., 2021) (Figures 9-11).

Telemedicine

The complex organization of the healthcare network, contemplate the institution of hub and spoke centers. This is associated with an increased need for remote advice for high specialty disciplines. There are several platforms that allow to share dataset and to record the consultation, which can later be printed and added to the patient's files. MR allows to visualize datasets in a more familiar way, offering to the colleagues located at spoke centers the possibility to chat with specialist in a conversation similar to an in-person one. The possibility to share over distances the elaboration of the images and to focus the critical situation with other colleagues in other hospitals also improves the understanding of both the spoke center's doctors and the hub center's specialist. The efficacy of the remote consultation can only benefit from the perception of being in the same place of the patient, side-by-side with other colleagues requiring immediate support, as augmented with MR tools (Montemurro, 2022).

Education

The main advantage of MR is to offer an immersive experience, which greatly assists the learning process in medical education. Learning in an immersive environment helps simplify the spatial relation between the anatomical structures, and this strongly supports neuroanatomy study. In particular, the main difficulty on neuroanatomy is represented by the presence of a large number of complex structures contained in such a small intracranial space. The possibility to highlight with colors and to enlarge the radiological images is an important tool to boost the learning curve and to maintain a deep-seated learning of these concepts.

MIXED REALITY TESTS IN SARS-COV-2 INTENSIVE CARE UNIT

The COVID-19 pandemic has overstrained even the most developed healthcare systems (Moghadas et al., 2020; WHO, 2022). Within a short period of time, traditional hospital treatment has faced numerous challenges. The protection of health and safety of healthcare professionals is a key priority for maintaining the quality of care provided to patients, as well as for preserving the health systems' capability of providing care on a large scale (The PanSurg Collaborative Group, 2020). The uncommonly large number of COVID-19 patients in a short period of time has led to an excessive engagement of healthcare professionals, which has in turn resulted in the problem being compounded by chronic stress and exhaustion at work, with an even more frequent incidence of the burnout syndrome (Lacy & Chan, 2018; Munzer et al., 2019; Raudenská et al., 2020).

The existing shifts doctors need to carry-out, the infection transmission risk, and the long duration of the pandemic impose the need for reduction of the staff's exposure in SARS-CoV-2 highly contagious environment. Young and less experienced clinicians have accessed the red zones in large numbers. Consequently, the most demanding patients in the COVID-19 intensive care unit (C19-ICU) often aren't treated by the most experienced physicians. The risk of communication errors is higher than in the pre-pandemic period. Problems have also been detected in the continuity of the treatment, the sharing of data and information on the patients' condition is usually reduced to the basic information, which is not always sufficient. The communication between physicians of red zone with the outside staff is difficult, while the need for such communication is important. Difficult decisions are to be made, which directly affects the patient's survival and success of treatment. Another important logistic problem is the large use of protective equipment (PPE). The risk of shortages is constantly present (Fadela, 2020). There is an urgent need for new strategies to optimize the use of the PPE and protect the healthcare professionals and patients from the spread of COVID-19 (The Lancet, 2020; Tomasi et al., 2020).

In order to improve the quality and the efficiency of the services delivered to patients, everyday medical practice has in the past few years been enhanced with the introduction of innovative technological tools, which allow a less stressful engagement of medical staff, an improvement of the professional comfort and of the job productivity (Uohara et al., 2020). In our department Microsoft's Hololens 2 (HL2) was tested for potential clinical uses. It allows the use of artificial intelligence (AI) and mixed/augmented reality (MR/AR) in everyday practice. MR/AR represents a combination of the physical and virtual worlds, in which users can interact with virtual objects while keeping their presence in the physical (real) world. HL2 produces and provides virtual visual, auditory and tactile experiences along with the possibility of interaction with the holographic enhanced environment. As opposed to the virtual reality which enables the user to interact with entirely artificial environment, the augmented (mixed) reality generates 3D computer objects on real-world surfaces, thus providing mixed stereoscopic visualization. While observing the real world, the user can manipulate digital contents in the form of holograms generated by the device (Proniewska et al., 2021). This creates a stereoscopic image resulting from combining a three-dimensional virtual model made up of images taken from diagnostic devices (CT, MRI, PET etc.), with real-world surfaces (Proniewska et al., 2021).

There are many studies on the use of augmented reality for surgeries in the operating theatre, in emergency wards and in medical education (Mishra et al., 2022; Munzer et al., 2019; Ogdon, 2019; Schoeb et al., 2020; Sirilak & Muneesawang, 2018; Umana et al., 2021, 2022).

We have found studies in literature which present the experiences with the use of HL2 for reducing healthcare professionals' exposure to aerosol formation procedures in the London Imperial College nephrology ward during the COVID-19 pandemic (Levy et al., 2021; Martin et al., 2020; Tomasi et al., 2020). So far, we found no studies on the usability of HL2 in treating C19-ICU patients.

THE GOAL OF THE HL2-ICU RESEARCH

A pilot study was carried out in the C19-ICU unit of the University Clinical-Hospital Centre "Dr Dragiša Mišović-Dedinje", Belgrade, Serbia, in May 2021. The primary goal was to investigate whether the use of HL2 device in a C19-ICU environment may reduce time to exposure to C19-ICU red zone doctors. A secondary goal was to assess the usability and acceptability of this new technology. The measure of the anesthesiologists' exposure to the SARS-CoV-2 was taken to be the average time per-doctor per-shift spent in the intensive care unit. The device usability and acceptability were assessed by sharing a survey with the involved medical teams.

Before the introduction of the HL2 device, the clinical practice consisted of the entry of the whole team of doctors into a 20-bed C19-ICU. The team consisted of 3 or 4 doctors depending on the shift. During an 8-hour shift they took breaks according to their needs and the circumstances. All the work related to patients was carried out in C19-ICU. Prior to the start of the pilot study, physicians were trained to work with HL2 during April 2021. During the pilot study they were not aware that time spent in C19-ICU is measured for both, regular and HL2 groups. The measurement was blind, performed by persons who were not aware of its purpose. The measure of the doctor exposure to the COVID-19 infectious agent zone was taken to be the total time spent in the C19-ICU during the morning shift, as well as the number of C19-ICU entries. These variables were recorded for each doctor respectively for a 30-day period, i.e. 15 days without, and 15 days with the use of the HL2 device. After completion of the study, average time per-doctor per-measurement was calculated. The anesthesiologists' impressions on the usability and acceptability of this new technology, and their satisfaction, were assessed through a survey (enclosure 1). During the use of the HL2 device, one doctor from the team entered the C19-ICU red zone with the device on (Figure 12).

In this setting, the morning ward rounds started with one doctor of the morning shift inside the C19-ICU zone, while the rest of the team would take part from the green zone via the Microsoft Teams platform. Both, doctor in C19-ICU and the team members outside the red zone had a direct view of the patients, monitoring devices, the parameters on the ventilators or other life support devices. In addition to that, device's MR technology enables all the participants to see laboratory results, radiological diagnostic findings, captured notes with personal observations of the previous shift physicians – all in form of holograms, placed around the patient (placed in patient proximity) (Figure 13).

Figure 12. The doctor wearing protective equipment suit, and the HoloLens 2 headset

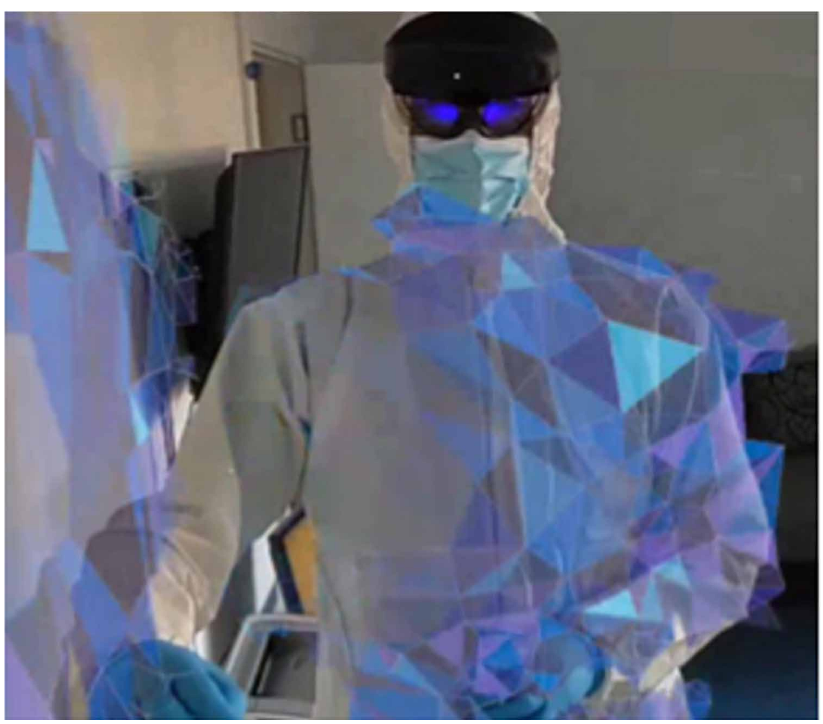


Figure 13. A holographic presentation of radiological scans with a direct view of the patient

In this way all the team members were able to take an active part in decision-making. The green-zone team members would then write the therapy and the daily information updates for the patients and share pointers for further analyses required. We measured the time each physician spent in the red zone with the use of the Hololens2 device. After the conclusion of the 15-day of test with the HL2 device, the employees were asked to complete a survey, which purpose was to investigate their previous familiarity with the mixed reality characteristics, the users' satisfaction with the device and their view of the benefits of its application and the possibility of its daily use, both during the pandemic and in other areas of medicine as well.

Statistical Analysis

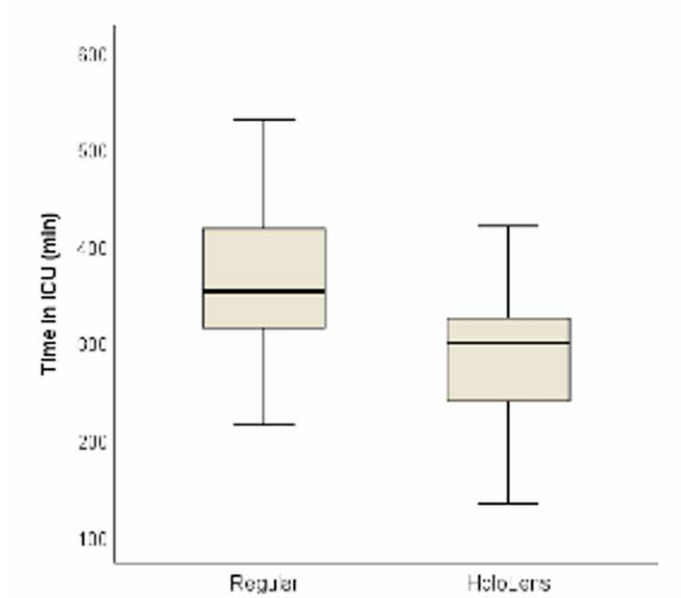
Results are presented as count (%), means ± standard deviation with 95% confidence interval. Groups are compared using linear mixed model and paired samples t test. All p values less than 0.05 were considered significant. All data were analyzed using SPSS 20.0 (IBM Corp. Released 2011. IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY: IBM Corp.) and R 3.4.2. (R Core Team (2017). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.).

C19-ICU Results

The study included 21 doctors (7 males, and 14 females, who were evaluated in regular mode (without the HL2) and with HL2. In Regular mode, 155 measurements were performed, while in HoloLens mode, 104 measurements regarding the ICU were performed.

The average time spent in regular mode for the 155 measurement was 364±71 (95% CI 353-375) minutes, minimum 215-maximum 530; while in HL2 mode, in 104 measurements the average time spent in ICU was 288±59 (95% 276-299) minutes, minimum 134, maximum 420. Using linear mix model, with time as dependent, scale identity matrix for repeated covariance type, mode (regular or Hololens) as factor variable and subject ID as random effect, significant difference of 76 (95% CI 59-93) minutes in average (21% average decrease) was obtained between the modes ($p<0.001$). Figure 14 reveals the difference between the modalities used in the time spent in C19-ICU.

Figure 14. Difference in the time spent in C19-ICU between the modalities used



Each doctor time is averaged in Regular and Hololens mode and the average change for each participant is showed in Figure 15. The average time per doctor significantly decreased ($p<0.001$) of 74±52 (95% CI 50-97) minutes (20,5% average decrease), from 361±45 (95% CI 341-381) minutes in regular mode to 287±33 (95% CI 272-302) in Hololens mode.

Before the use of HL 2, only one doctor had any experience with the mixed reality technology. At the end of the study fourteen doctors completed the questionnaire, and the results are shown in Table 1.

Large majority thought that the use of the HL2 device is not complicated to use, does not interfere with or impact their routine work, but rather helps them in making better informed decisions and easier resolving of any critical incidents in C19-ICU. Eleven of 14 anesthesiologists think that this work method contributes to better communication among colleagues. Overall satisfaction with the use of the HL2 device in treating critically ill COVID- 19 patients was reported by 85.7% of the surveyed.

Figure 15. Time spent by each doctor using without (Regular) and with (HoloLens) the use of the HoloLens

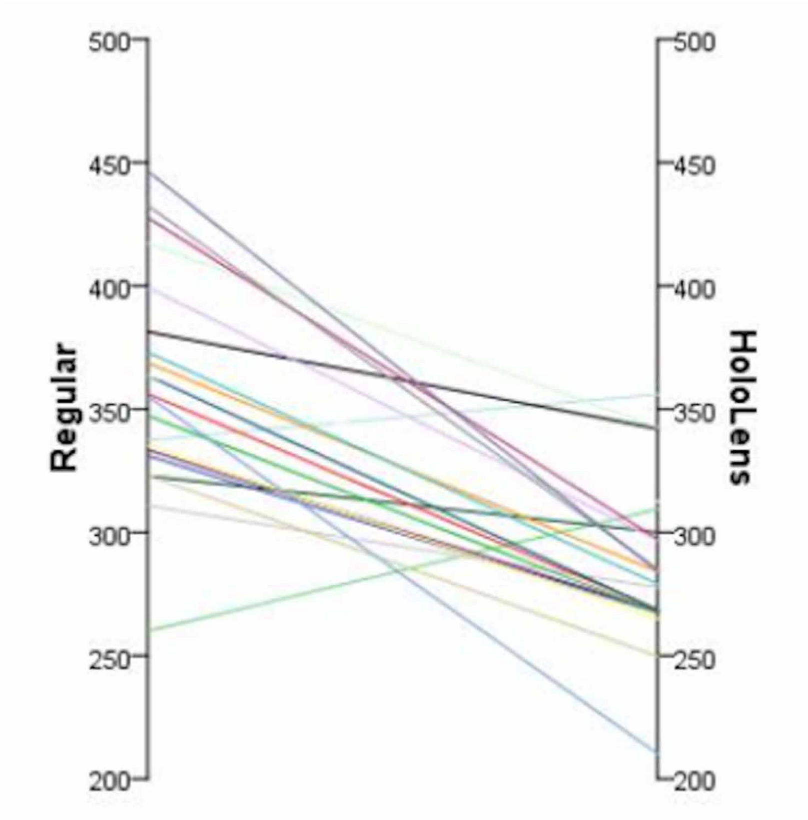


Table 1. The results of the survey conducted among the doctors who used Hololens 2 device.

Question	Yes	No	Don't know
Was the use of HoloLens 2 device complicated for you?	5 (35.7%)	9 (64.3%)	0 (0%)
Do you think that the use of HoloLens 2 device helped you in making decisions in your work?	12 (85.7%)	0 (0%)	2 (14.3%)
Do you think that the use of HoloLens 2 device contributes to better treatment of patients?	12 (85.7%)	1 (7.1%)	1 (7.1%)
Do you think that the use of HoloLens 2 device could also be used in other fields of medicine?	13 (92.9%)	0 (0%)	1 (7.1%)
Would you like to use the HoloLens 2 device in your daily work in the future?	11 (78.6%)	0 (0%)	3 (21.4%)
Do you think that the use of HoloLens 2 device contributes to better communication among colleagues?	11 (78.6%)	1 (7.1%)	2 (14.3%)
Had you been familiar withe the mixed reality technology before the use of the HoloLens 2 device?	1 (7.1%)	13 (92.9%)	0 (0%)
Are you satisfied with the use of the HoloLens 2 device during treatment of patients infected with COVID-19?	12 (85.7%)	0 (0%)	2 (14.3%)

VASCULAR SURGERY

Decision making and performing procedure of abdominal aortic aneurysm repair in a complex patient

Modern vascular surgery has evolved into independent surgical specialization that is dynamic, supported by technology and show different options. As life expectancy is extended, incidence of vascular diseases is increasing, together with patient's complexity. Fragile patients with several comorbidities in advanced age are very difficult to deal with, both for surgery and anesthesiology. One of the most frequent vascular diseases is abdominal aortic aneurysm that usually develop in the subrenal segment of abdominal aorta. Rupture of such an aneurysm is a devastating, life threatening complication and traditional medicine has only one solution to prevent rupture – surgical repair. Abdominal aneurysm surgery is a complex procedure, and its difficulty increases progressively with the proximal extension of the aneurysm aortic section, where visceral or renal branches take origin, or with the more distal site with the involvement of the iliac and femoral arteries.

As a response to these challenges different vascular and endovascular techniques arose providing less invasive options to treat such patients in acceptable manner. Abdominal aortic aneurysm repair can be performed either by opening abdominal cavity and replacing the aneurysm with synthetic (Dacron-poliester) lumen or by implanting a stent graft (combination of stent and Dacron conduit) into the aneurysm. Endovascular techniques are providing treatment usually from the groin or axillar access, or both, without opening abdominal or thoracic cavities. Procedures performed from remote access and control, like that one where stent graft is implanted in the abdominal aorta controlled from the groin, need to be plan thoroughly. On the other hand, planning but also the execution of such procedures depends on technology, especially imaging technology. Nowadays, very frequently image fusion technique is used when preoperative images are fused with intraoperative ones, to improve the accuracy of procedure, to reduce the radiation exposure and the quantity of contrast medium used during the operation. Accurate image processing and interpretation are crucial for preoperative planning, but also during multidisciplinary team meeting assessment. Presentation of vascular problems and decision making depends on image transfer and image analysis. It is not uncommon that doubled or even tripled exams are performed to patients just because image transfer is not possible. If adequate image transfer is possible than making multidisciplinary teams on event international levels are possible.

A challenging case is presented, discussed in a multidisciplinary meeting between equips in different countries and aided by MR for the data sharing (Figure 16). By using HL2 technology, the case was presented to an expert colleague from Malta, prof Cassar, who offered his contribution by sharing his experience in treating such complex patients.

The reported case is a patient with abdominal aortic aneurysm that extends in the juxtarenal section, classified as juxtarenal abdominal aortic aneurysm. In addition, the patient was affected by cardio and respiratory comorbidities and hostile abdomen (multiple previous abdominal operations), that makes new abdominal procedures risky and technically challenging. By using MR, all aspects of the problem were presented in detail, with very clear and detailed image presentation that made discussion and decision very professional and realistic. It was possible to go through images repeatedly, to augment them and communication was efficient. The surgical procedure was then performed and during procedure it was possible to continue to share information thanks to MR to show the intraoperative findings and discuss the final result. After discussion among vascular surgeon, interventional radiologists, anesthesiologist present in the operating room and professor, expert, from remote location, it was decided to treat these patients with endovascular means by using "chimney" parallel graft for one renal artery and to implant stent graft in the infrarenal aorta. For this procedure we used bilateral groin and right brachial incision. Communication and presentation of the patient was performed by operator, who was already in the operating room by the patient in anesthesia (patient signed informed consent that this technology will be used for such procedure). By wearing HoloLens glasses operator was able also to assist images, see them repeatedly and have interactive and immediate consultation making his work easier during the operation by comparing previous images with image on the screen, replacing image fusion technology. In addition, wearing such glasses had no interruption on real work besides digital reality that was happing in his peripheral vision.

Figure 16. Prof Cassar with HoloLens based in Malta and observing images presented in the operating room in Belgrade, where anonymized angiography of abdominal aortic aneurysm are presented. Moving, changing and controlling of the images was done by operator standing by the patient in general anesthesia. Patient signed informed consent that this technology will be used for such procedure

Figure 17. Multiplanar vision of MDCT angiography guided by linear ray made by finger of the operator oriented towards the image

DISCUSSION

The time spent by doctor in C19-ICU was certainly reduced, in several ways. Fewer doctors had to stay in the infectious area at the same time, the number of entries were reduced, while the average time spent there was reduced by 21%, i.e. by 76 minutes. Less exposure to a highly virulent aerosol reduces the likelihood of transmitting the infection to a doctor, while long-term benefits can be expected in terms of reducing the physical and mental strain to which physicians at C19-ICU are exposed.

The possibility to carry out all the administrative work from a distance, such as daily patient information updates, issuing requests in the healthcare information system, and any other analysis, which take a lot of time for physicians in the red zone, enables them to devote more time to the patients. Joint decision-making with senior doctor taking part from a distance should improve the quality of treatment and provide better solutions to numerous problems, but also lessen the pressure felt by anesthesiologists in the red zone in case of making the hardest decisions and clear the doubts relating to treatment methods. In this way it is also possible to organize expert consultative examinations from a distance, with specialists not working in the same institution, which is all too often required in the COVID-19 pandemic (Montemurro et al., 2021).

The HL2 device enables audio and video communication to the team outside of the red zone. At the same time, the patients, their radiological scans and results can also be seen by physicians from a distance, which raises the quality of assessment of the patient's condition and contributes to making better treatment plans. All this enables the physicians to prescribe the essential therapy outside the infectious zone and then bring the lists into the zone, thus saving time to physicians in the red zone.

Using HL2 in red zone enables medical staff to achieve even more than pulling-in the team of doctors through the video call for consultation, brainstorming and decision-making. The device itself allows the user to operate with ease while wearing it.

As the medical staff needs to be equipped with the viro-protection gear all the time (sometimes even wearing 2 pairs of gloves) it is almost impossible to use any kind of modern electronic device in covid19 red-area, through which the person could access the latest medical- related data (blood analysis, X-Ray/CT-scan/MRI imagery), as phones and tablets rely on touchscreen technology, and devices with keyboard. "Handsfree" moment of HL2 device enables the user to overcome these impediments, as the device itself offers such UI (User Interface) which is consumed with ease (outside of the main view field important for primary work), while the in-build AI (Arteficial Intelligence) recognizes the hand gestures the user makes while controlling device.

In addition to hand-gestures, the device AI also observes the eye-movement and detects when user is focusing on particular option which is offered in the UI, with extra-option of selecting the option by eye-blinking.

Furthermore, the HL2 is also equipped with Speech-Recognition technology as another set of AI-powered tools which can be used for UI selection and environment control, but more importantly – for dictating the notes for each patient which can be stored, shared, or even preserved in same spatial environment for all other users which will use the device in the same workspace.

As mentioned in the previous bullet, the device itself is empowered with such equipment and Machine Learning algorithms that it can map the surrounding space, recognize its characteristics, and even "remember" the entire room as the spatial environment in which it operates multiple times, if the room is re-entered or event if the device is powered-off. This opened-up such use cases which increased the work efficiency tremendously while scaling-down the exposure to virus the medical staff had.

The mixed reality generated by HL2 provides a unique possibility to position by the patient's bed the current and past scans, laboratory results and other analyses which remain there, and may be immediately revisited with each new use of the device. As the doctors from the nightshift were doing the final patient visits, they captured the medical context of each patient by placing the holograms above or beside the patient: holographic radiographic and laboratory findings, hologram of captured notes with personal observations, and optional holographic indicators if some patient needs to be prioritized or handled with special care and preparing the work environment entirely for the next shift of doctors (Rubino, 2018).

Finally, when a doctor in the morning shift enters the red-zone, all the necessary pieces of medical context for each patient are in place, and all the handoff between the shifts had already been done with Augmented Reality features this device brought-in. This saves the time otherwise lost in searching for the scans of each individual patient in the information system, which previously reduced the time spent with the patient.

The survey carried out with the engaged physicians has demonstrated that most anesthesiologists are satisfied with their experience. Most of the staff feel more secure and satisfied when using this technology, which we suppose results from the possibility to share responsibility with other physicians from a distance. This does not jeopardize the care and treatment of patients, but rather improves the continuity of treatment through an easier exchange of information with the colleagues who are about to enter the red zone. Many instances of consultative decision-making related to further activities in the red zone certainly improve the quality of treatment and reduce the responsibility of red-zone physicians, and the mental pressure they feel as a result.

This way of work organization may help in a pandemic, when there are not enough physicians for working in intensive care units, with the most critically ill patients. There is not a country in the world with enough health professionals trained to work with the most serious, critically ill patients in conditions such as these imposed by the COVID-19 pandemic.

Given that a great majority of doctor (92.9%) find themselves for the first time before a device emitting mixed reality, it was necessary to carry out training before the first use. According to the results of the survey, 64.7% users found that the use of HoloLens 2 was not complicated. Finally, most of the surveyed, 78.6% of them, would like to use the HL2 device in their everyday work, and as many as 92.9% see the application of this technology in medical practice even beyond the COVID-19 pandemic.

The use of HL2 in clinical practice is subject to certain limitations. They include battery duration limits, the internet connection stability and rate issues (which can be overcome with mobile internet routers), while some users were dissatisfied with this technology for not being in direct contact with the patient, which can negatively affect the physician-patient relationship (Microsoft., 2020; Rubino, 2018).

The COVID-19 pandemic has been present on a global scale since December 2019, responsible for 271 963 258 cumulative cases and over 5 331 019 cumulative deaths, and that it has imposed new conditions on medical work organization as well (Afonso et al., 2021). These conditions have been present for a while now and have been leading to an ever higher incidence of the burnout syndrome in the staff working with the most critically ill patients in intensive care units. Besides physical exhaustion, we can by no means disregard the mental issues caused by the high fatality rates in the most seriously ill COVID-19 patients. The long- term consequences for the staff working in intensive care units are yet to be seen, but this is not an optimistic issue. For that reason, the most recent technological devices are being brought into play to reduce both the physical and mental engagement of the medical professionals. Although this pilot study was carried out in a short period of time, it still points towards steps to be taken to resolve certain problems facing doctors working in C19- ICU and suggest future work organization methods. The results of our study are optimistic, but they require an additional, more comprehensive, and stricter evaluation.

LIMITATIONS AND FUTURE DIRECTIONS

The use of MR is in its infancy and, of course, Hololens 2 shows several limitations. The superimposition of the hologram on the patient's anatomy, at the moment, is manual or semi-automatic, making this process dependent on the operator, negatively affecting its accuracy. Furthermore, the interaction with real objects, which should be recognized by the hologram, is still unresolved. These two main limitations represent the biggest obstacle to introducing Hololens 2 into daily practice. Improvement of the device, which should include a version dedicated to clinical use, should help overcome these and other minor problems.

CONCLUSION

Although this pilot study was carried out in a short period of time, it shows key points that should be addressed to solve the actual issues to help doctors facing working in C19- ICU and to improve the efficiency of the work chain. The results of our study are optimistic, but they require an additional, more comprehensive, and stricter evaluation. In a pandemic, any way to reduce health workers' exposure to the viral environment is significant. HL2 is just one of the logistic solutions, although its use and role in medicine has yet to be shown beyond the conditions imposed by the pandemic. MR promises to disrupt of clinical practice in several contexts. From education to intraoperative navigation, MR improves the familiarity with the anatomy of the patients, favoring safer treatments. The only limitations to its introduction for clinical use are technical, but the great interest on this technology is expected to quickly achieve the required improvements in the next future, changing our practice, offering better treatments to our patients.

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KEY TERMS AND DEFINITIONS

Burnout: Physical, emotional, or mental exhaustion, accompanied by decreased motivation, lowered performance and negative attitudes towards oneself and others.

COVID-19: Viral infection spread in the year 2020 responsible for a worldwide pandemic.

Intensive Care Unit: Special department of a hospital catering to patients with severe or life-threatening illnesses and injuries, which require constant care, close supervision from life support equipment and medication in order to ensure normal bodily functions.

Mixed Reality: Science within the realm of virtual reality, allowing direct interactions between the physical and digital worlds through intuitive 3D human, computer, and environmental actions.

Neurosurgery: Medical subspecialty focusing on the treatment of patients with pathologies involving the brain and/or the spine.

Proctoring: In medicine, objective evaluation of a physician's clinical competence by someone serving as a proctor who represents and is responsible to the medical staff.

Telemedicine: Distribution of health-related services and information via electronic information and telecommunication technologies.