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ORIGINAL ARTICLE

Pre-surgical planning with extended reality in neurosurgery: a survey-based study describing a preliminary experience in Italy

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ABSTRACT

BACKGROUND: Extended reality (XR) systems play an increasingly role in preoperative planning in different surgical fields including neurosurgery. Considering educational purposes, not all residents have the same opportunities to learn and deal with XR. Thus, the authors sought to evaluate the perspectives of an Italian sample of neurosurgical trainees on XR, and to size the impact of these developing technologies on the learning curve of a small group of residents coming from different Italian Institutions.
METHODS: A 23-question cross-sectional survey was administered to 32 neurosurgery residents nationwide to evaluate their perspectives and experience on XR in a neurosurgical setting. A specific 20-question survey was administered to a pilot group of 5 trainees, working at the Bambino Gesù Children's Hospital, to evaluate their experience with daily-use of XR and to probe its impact on their learning curve a period of 3 months.
RESULTS: The majority of the interviewed perceived XR as effective in simulating the real surgical scenario both in terms of anatomy and surgical trajectory. These results also reflect the subjective perception of the five trainee-pilot group which report a progressive confidence on the surgical case management.
CONCLUSIONS: This preliminary study suggests XR as an effective tool which can positively influence trainees' education. There is a broad perception of its beneficial impact even in contexts where XR is not frequently available. Further and larger studies are necessary in our country to better understand and standardize these results.

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KEY WORDS: Virtual reality; Learning curve; Neurosurgical procedures.

Today, the knowledge and use of various technologies, from neuroimaging software to neuronavigation tools, is mandatory for educational and clinical purposes. As a matter of fact, through these technologies it is possible to figure out neuroanatomical details and to plan surgery. Among the above mentioned, the extended reality (XR) including virtual reality (VR), augmented reality (AR) and mixed reality (MR) systems, allows an immersive experience that drives the surgeon to an accurate and less invasive surgical approach. From the educational point of view, it can therefore impact on the training and learning curve of young neurosurgeons.

However, during the residency of neurosurgery trainees, the opportunities to familiarize with different XR systems are few, mostly because of the small availability of these tools nationwide.

The aim of this work is twofold: on the one hand, it wants to probe the perception, use and degree of interest of a sample of Italian residents, among different residency schools nationwide, towards the application of XR to pre-surgical planning; on the other hand, to highlight the experience of a small trainee-group attending the Neurosurgery Unit of the Bambino Gesù Children Hospital in Rome, which made XR systems available for clinical and educational purposes.

Materials and methods

Study design and survey administration

The first section of the study was a cross-sectional and web-based survey administered to a sample of Italian neurological surgery trainees from different Institutions within Italy: Bambino Gesù Children's Hospital, Polytechnic University of Marche, University of Brescia and University of Insubria Varese, and University of Milan-Bicocca; notably, the survey assessed the perception and use of extended reality in preoperative surgical planning. Junior residents were defined as trainees that have not completed half of their residency; Senior residents are in their two final years of residency program. Together with the questionnaire, a demo video simulation of a case of virtual pre-operative planning, made with Surgical Theatre (Beachwood, OH, USA), was sent for those who had never seen an XR model. Questions were broken up into sections. Initially, demographic information was gathered including institution and year of training; reporting of institutional affiliation was optional to maintain respondent anonymity.

The first block of questions (1-11) had multiple choice answers regarding the use and the role of XR in the specific belonging Institution while the second part of the survey (questions from 12 to 23) tried to standardize the answers on the perception of XR by selecting the following Likert scale questionnaire: completely disagree, disagree, un-certain, agree, completely agree. These questions were refined taking data from similar studies focused on the efficacy of XR techniques beyond studies focused on these technologies into clinical training.[1-5] The survey remained open for 30 days and two rounds of emails were sent to all initial contacts.

The second part of the study included the analysis of the activity of a small pilot-group experiencing the use of XR in daily clinical activity applied to pre-surgical planning. Five trainees, PGY4 from different Institutions and different academic backgrounds, carried out part of their training period at the Neurosurgery Unit of the Bambino Gesù Children Hospital in Rome between the 1st of January and 31st of March 2024. Having daily access to advanced XR systems for 3D preoperative surgical planning, the trainees created a tailored single-case questionnaire with three standardized categories (anatomical relationships, vascular relationships and surgeon/patient orientation) to compare the impact of this technology on their awareness and understanding of the different surgical cases in which they participated in the analyzed period. These questionnaires consisted of 20 items administered for each case and divided as follows. The first part (1-8) implied a binary yes/no mode on case-tailored questions, regarding standardized anatomical and vascular relationships together with patient orientation and head-position, which were built tailored on the specific characteristics of the single case. The second part (9-20) instead required answering XR perception questions in terms of awareness and overall confidence before and after managing the case by selecting from the following Likert scheme: completely disagree, disagree, uncertain, agree, completely agree. In order to compare the difference of the surgical planning with and without XR, the residents not directly involved in the XR assisted surgical plan, answered the first part of the survey using just standard 2D tools (MRI or other standard 2D neuroimaging). To answer the Likert part of the questionnaire, residents not directly involved in the XR case could retrospectively visualize the 3D model from the Simulation Lab.

Extended reality software

The preoperative 3D modeling was carried out by a multidisciplinary team made up of an Interaction Designer, a Biomedical Engineer (who collaborated with the surgical Staff) and validated by a neuroradiologist. Preoperative planning was developed using the Surgical Theater (Beachwood, OH, USA) extended reality software integrated with the Lenovo (Beijing, China) Oculus headset.

Statistical analysis

The pilot group managed the survey interpretation. All data analysis was performed using Microsoft Excel. Responses were divided comparing junior and senior residents; differences were analyzed between responders who did or did not have XR at their institution. The cases of the pilot group were analyzed with weekly meetings and their trend, answering the standardized questions, was considered overtime.

The manuscript was built following the CROSS guidelines and checklist.[1]

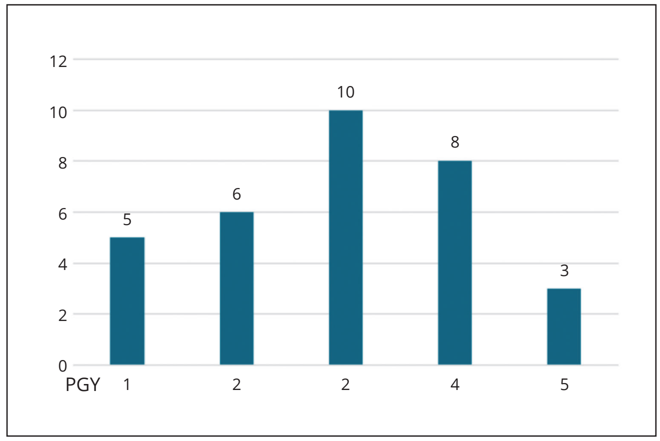

Figure 1.—Number of trainees divided per post-graduate year (PGY).

Results

From the analysis of the first block of the questionnaire study (1-11), thirty-two responses from the various Italian centers were recorded, with all participants completing 100% of the questions; the survey was sent to 49 residents and the response rate was attested around 65.3% calculated by dividing the number of completed surveys by the total number of those surveyed. Residents were divided into junior (PGY 1-3), being the most represented group (65.63%), and senior (PGY 4-5) resulting in 34.37%; a demographic overview of the sample is shown in Figure 1 and the questionnaire (questions 1-11) with respective overall results are reported in Table I.

A generic radiological software, not strictly related to XR, for imaging visualization and 3D rendering is used by all the interviewees in their respective belonging Institutions. 78.13% were trained in this regard during the first PGY year with prevalent use in neoplastic pathology (62.50%). All participants use neuronavigation systems and the most used 3D reconstruction software is 3D slicer (Brigham and Women's Hospital, Harvard University, NIH), in 21.88% of the cases; the vast majority do not combine preoperative 3D rendering with XR and in fact only approximately one-third of participants (34.38%) reported having had at least once an access to XR technologies, although its use is not yet systematic and standardized. The neurosurgeon has an active role in presurgical planning in all institutions and 3D models are used (independently of XR) in more than 75% of surgical cases, although only 18.75% of residents constantly actively take part in the development of pre-operative virtual models.

The second block of the questionnaire study (12-23) revealed that the majority (87.50%) of the interviewed perceived XR as effective in terms of anatomy and global

Table I.—*Questions from 1 to 11 and overall results are described.*

Questions 1-11	Results
1. Do you use 3D pre-surgical virtual planning systems?	Generic PACS radiological software, not strictly related to XR, for 3D rendering is used by ALL the interviewees
2. Do you use 3D Printing Systems?	3.1% of responders
3. When did you start using 3D pre-surgical planning?	78.13% during the first PGY year
4. On which pathologies do you mainly use it?	Prevalent use in neoplastic pathology (62.50%)
5. Which programs do you use in 3D reconstruction?	21.88% of responders use 3D slicer (Brigham and Women's Hospital, Harvard University, NIH)
6. Do you use 3D pre-surgical XR virtual planning systems?	Only approximately one-third of participants (34.38%)
7. If you use 3D imaging, do you associate it with virtual or augmented reality systems?	One-third of participants (34.38%) with at least once an access to XR technologies
8. If you answered yes to the previous question, which one?	Surgical Theater (Beachwood, OH, USA) extended reality software integrated with the Lenovo (Beijing, China) Oculus headset
9. Who are the professional figures involved in the planning phase?	43.75% Neurosurgeon + Neuroradiologist; only 6.25% of Neurosurgeons are supported by dedicated Technician
10. How often do you use it in complex surgical procedures?	Responders who have XR use this technology for 75% of surgical cases
11. Please indicate your type of involvement	18.75% of residents constantly actively take part in the development of pre-operative virtual models

case awareness; the questionnaire (questions 12-23) with respective synthetic overall results is reported in Table II and the results of the Likert scale evaluation are summarized in Figure 2. Uncertainty remains for more than half (56%) of the interviewees regarding the real ability of XR to simulate stress and the real circumstances experienced in OR, although 61% believe that XR will be the standard in resident training in the near future. At this regard, al-

TABLE II.—*Questions from 12 to 23 and overall results are described.*

Questions 12-23	Results
12. The quality of the current pre-surgical planning is adequate for my needs	45% neither disagree or agree (see Figure 2 for complete results)
13. The use of 3D models is useful for communication with family members	40% neither disagree or agree (see Figure 2 for complete results)
14. XR is effective in simulating the circumstances and stress that occur in the operating room	56% neither disagree or agree (see Figure 2 for complete results)
15. XR will be the standard in trainee training in the near future	56% agree (see Figure 2 for complete results)
16. XR is cost-effective	46% agree (see Figure 2 for complete results)
17. Presurgical planning using XR is a simple method to learn	45% neither disagree or agree (see Figure 2 for complete results)
18. XR improves the effectiveness and safety of surgical interventions	40% agree (see Figure 2 for complete results)
19. XR reduces surgeon's fatigue	51% agree (see Figure 2 for complete results)
20. The 3D model, compared to 2D imaging, is useful in pre-operative planning of the clinical case	56% agree (see Figure 2 for complete results)
21. The 3D model, compared to 2D imaging, is useful in identifying the boundaries and anatomical relationships of the lesion	70% agree (see Figure 2 for complete results)
22. The 3D model, compared to 2D imaging, is useful in identifying critical neurovascular structures	70% agree (see Figure 2 for complete results)
23. The 3D model, compared to 2D imaging, is useful for learning the anatomy of the clinical case	60% agree (see Figure 2 for complete results)

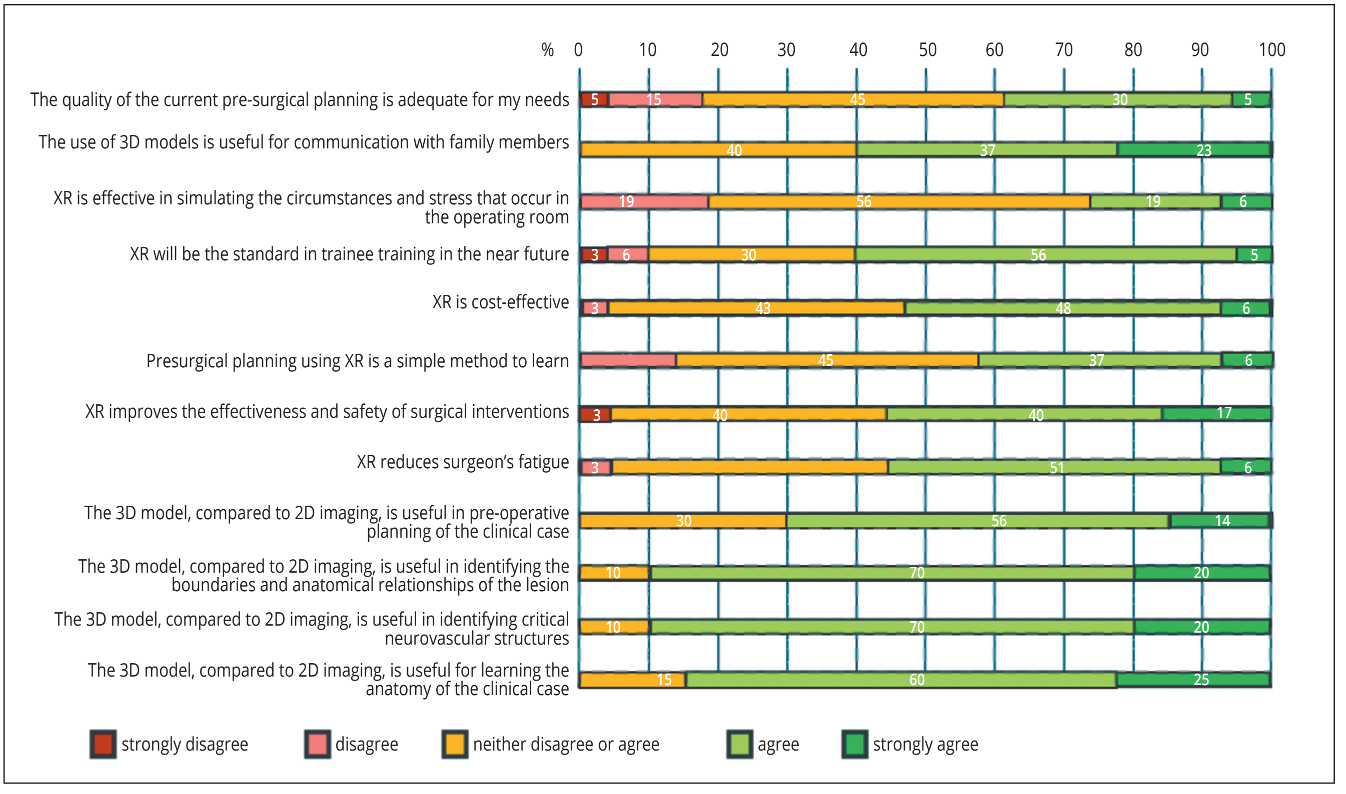

Figure 2.—Results of the Likert scale evaluation from the first section of the study administered to a sample of Italian neurological surgery trainees from different Institutions.

though the perception of the use and possible impact on neurosurgery of XR is substantially overlapping between the junior and senior cohorts with a homogeneous distribution of all responses between the two groups, concerning that very question at number 15 of questionnaire 1, differences were noted: among the 30% of participants who were skeptical about the possibility that XR will become the training standard 77% come from the senior resident court. From the analysis of the pilot group study, 12 cranial surgery cases for each resident were collected: the preliminary experience of the small sample has revealed a positive impact on the residents' learning curve and overall confidence in managing a surgical case. The report of the first part (1-8) of the questions regarding anatomical and vascular relationships together with capacity in predicting patient head-position during surgery reveal a tendency overtime to improve the number of correct answers given by the resident preparing the case with XR; the questionnaire (questions 1-8) with respective synthetic overall results is reported in Table III. In addition, results of the subjective perception (questions from 9 to 20 in Likert scheme) (Table IV) arising from the 5-trainee cohort reflect the above-mentioned belief that XR will be the standard in education; on the contrary, it testifies that trainees who have access to XR technologies hold a more positive feedback regarding the benefits of XR in their training and perceive a reduction in stress when involved in the case (results of the respective Likert Scale evaluation are summarized in Figure 3).

Illustrative case

A 16-year-old male presented to Bambino Gesù Children's Hospital with a clinical onset characterized by episodes of loss of balance, nausea, and vomiting. Fundus examination revealed disc edema and venous stasis. The patient underwent brain MRI which showed a solid-cystic vermian lesion with a right cerebellar hemispheric extension suspicious for pilocytic astrocytoma (Figure 4). During January 2024 a first surgery was performed to empty the cystic component through a stereotaxic pathway; consequently, a sitting position was chosen to obtain a gross total removal through a supracerebellar infratentorial approach.

The Surgical Theater extended reality software integrated with the Lenovo Oculus headset made it possible

TABLE III.—*Overall results from the pilot group show a tendency overtime to increase the number of correct answers given by the residents preparing the case with XR.*

Anatomical relationships (question 1 to question 4)	70.66% 83.33% 91.66%	January February March
Vascular relationships (question 5 to question 6)	66.66% 74.99% 87.49%	January February March
Head-positioning and surgical orientation (question 7 to question 8)	62.5% 75% 87.5%	January February March

TABLE IV.—*Questions from 9 to 20 and overall results are described.*

Questions 9-20	Results
9. The quality of the current pre-surgical planning is adequate for my needs	60% agree (see Figure 3 for complete results)
10. The use of 3D models is usegul for communication with family members	60% agree (see Figure 3 for complete results)
11. XR is effective in simulating the circumstances and stress that occur in the operating room	60% agree (see Figure 3 for complete results)
12. XR will be the standard in trainee training in the near future	60% agree (see Figure 3 for complete results)
13. XR is cost-effective	60% agree (see Figure 3 for complete results)
14. Presurgical planning using XR is a simple method to learn	80% agree (see Figure 3 for complete results)
15. XR improves the effectiveness and safety of surgical interventions	60% agree (see Figure 3 for complete results)
16. XR reduces surgeon's fatigue	60% agree (see Figure 3 for complete results)
17. The 3D model, compared to 2D imaging, is useful in pre-operative planning of the clinical case	80% agree (see Figure 3 for complete results)
18. The 3D model, compared to 2D imaging, is useful in identifying the boundaries and anatomical relationships of the lesion	80% agree (see Figure 3 for complete results)
19. The 3D model, compared to 2D imaging, is useful in identifying critical neurovascular structures	80% agree (see Figure 3 for complete results)
20. The 3D model, compared to 2D imaging, is useful for learning the anatomy of the clinical case	80% agree (see Figure 3 for complete results)

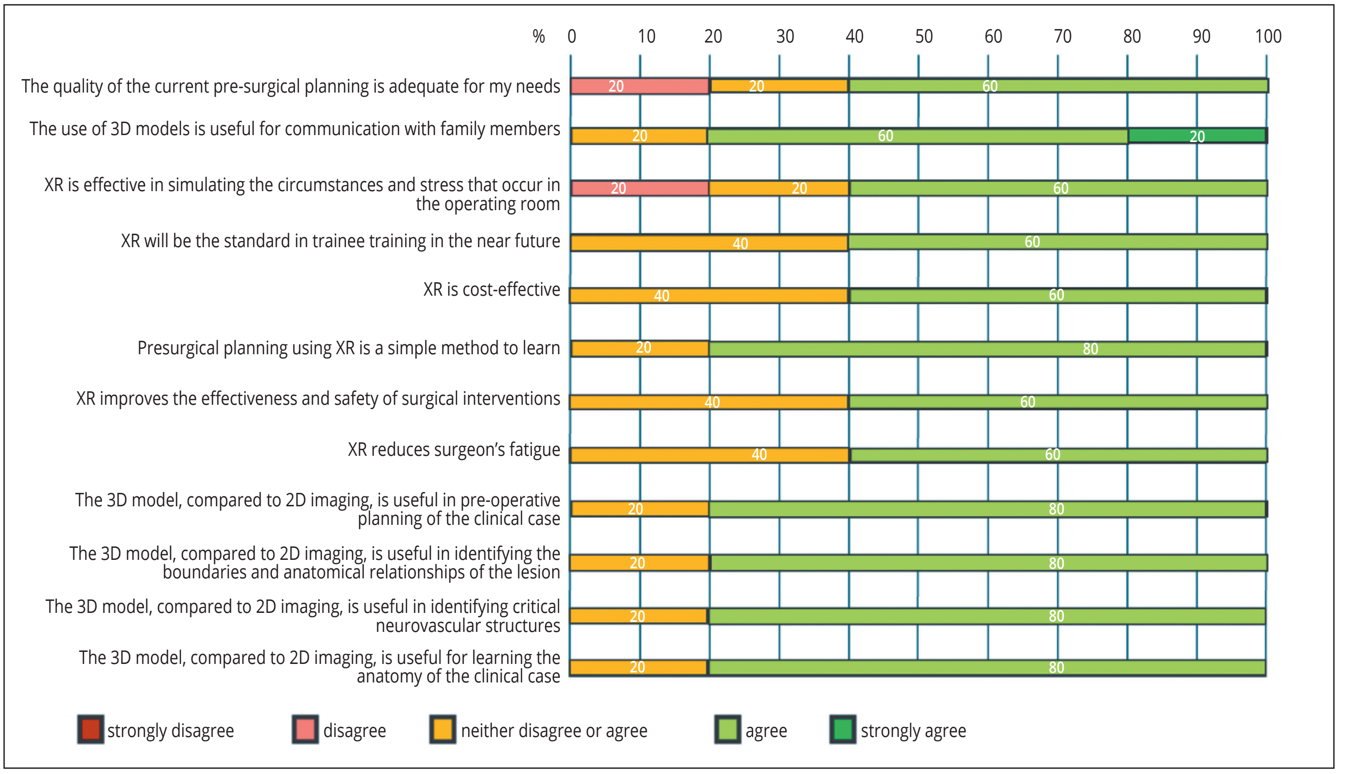

Figure 3.—Results of the Likert scale evaluation from the pilot group section of the study administered to a sample of five PGY-4 trainees from different Institutions.

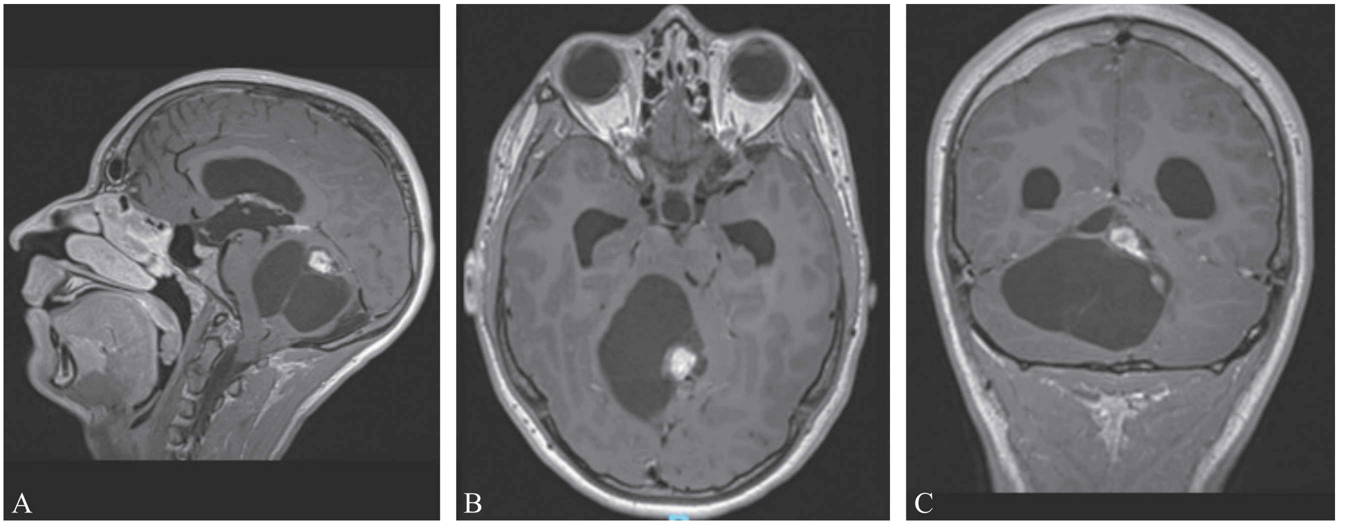

Figure 4.—Sagittal (A), axial (B), coronal (C) MRI demonstrated a solid-cystic vermian lesion with a right cerebellar hemispheric extension suspicious for pilocytic astrocytoma.

for the pilot group to create a realistic simulation (Figure 5): it included the initial phase of incision (Figure 5A) and craniotomy (Figure 5B, C) up to the highlighting of the anatomical and vascular relationships (Figure 5D-F). This technology made it possible for the trainees to rotate the head and imagine its position in the operating room along

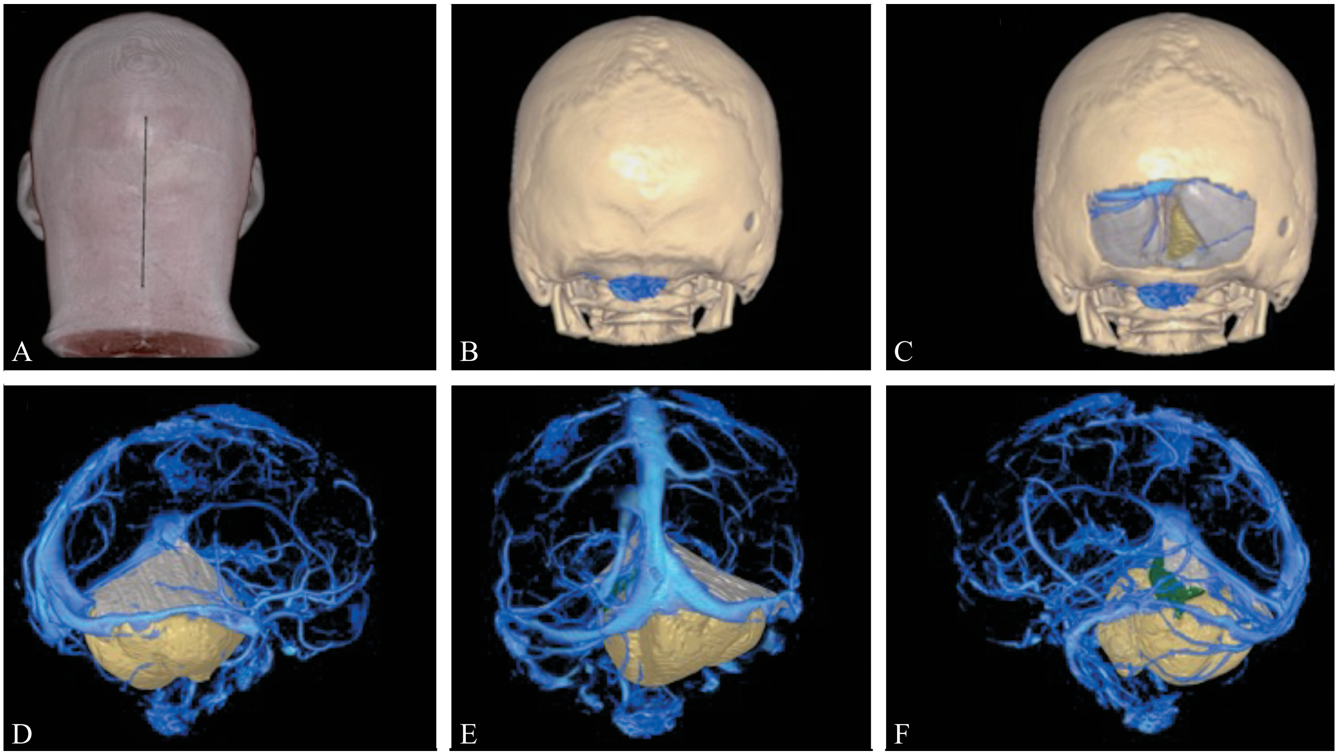

Figure 5.—Example of a virtual model used by the pilot group at Bambino Gesù Children's Hospital.

with the various inclinations and angles of work used by the surgeon in the microscopic phase. The three-dimensional model was exploited to develop the questionnaire and used by the pilot group to answer questions on a case-by-case basis during the study period.

Discussion

The use of extended reality can change the way in which residents, as well as young neurosurgeons, face neurosurgical pathologies and learn surgical anatomy; in addition, research and trainees demand regarding the use of XR in neurosurgery increased significantly in the last few years.[2-13] It brings many educational perspectives to the trainees, ranging from a better understanding of surgical anatomy to a deeper consciousness of possible intraoperative complications. As lately demonstrated by Wang *et al.*,[14] a mixed-reality neurosurgical educational system is effective to help neurosurgeons in training, offering a valuable alternative to cadaveric dissections; particularly, they enrolled 40 patients who underwent surgery for micro-vascular decompression (MVD) or resection of intracranial tumors and demonstrated the clinical efficacy of the system, leading to changes in surgical posture, degree of head rotation, craniotomy size and location. As expected, these changes were more common among respondents with less experience in brain tumor resection and a change in craniotomy's size and location was significantly correlated with the neurosurgeon's experience ($P<0.05$).

Therefore, residents can perform preoperative planning and surgery with greater confidence, potentially shortening their learning curve. This could indeed help skill progression as demonstrated in 2023 by Guha *et al.* in a single-blind randomized study on a cohort of medical students.[15]

In addition, a systematic review by Suresh *et al.* evaluating the impact of AR on performance and educational measures of trainees during surgical training (not necessarily neurosurgical), reviewed several studies supporting the role of AR simulation in surgical training.[16] Another review, by Kos *et al.*, focusing on the role of AR in neurosurgery highlighted the lack of standardized evaluation metrics and the need of validated questionnaires.[17]

Even though there is growing evidence about the role of extended reality in neurosurgery, these tools are far from being widely spread. Our study confirms this, showing that only one-third of the preliminary Italian sample has sporadic institutional access (at least once) to XR technologies; nevertheless, there is a broad perception of its beneficial impact even in contexts where XR is not available and this is underscored by the majority (87.50%) of the interviewed who perceived XR as effective in terms of anatomy and global case awareness and by the 61% of all responders who believe that XR will be the standard in resident training in the near future. The different perception of junior and senior in relation to the training standard in the near future may be due to the fact that senior people at the end of the course may not believe in sudden changes in training having recent experience of how much the academic training path in Italy is bureaucratically complex to change in a short time; this is in fact a suggestion of the authors and further studies should be conducted to deepen the subject. Furthermore, even if responders who have access to this technology use XR for 75% of surgical cases, at the moment residents' role seems to be limited since only 18.75% of them constantly and actively take part in the development of virtual models. Some degree of skepticism reported by Gupta *et al.* was representative even by of our cohort of study participants:[18] uncertainty remains for more than half (56%) of the interviewees regarding the real ability of XR to simulate stress and the real circumstances experienced in OR, but, in contrast with the abovementioned authors, our sample did not include a substantial difference between residents with or without prior XR experience. At the same time, residents with access to XR in their home institutions, underscored the transformative potential of XR in neurosurgical education confirming the previous results described in literature and the interest towards this technology gained among several Authors over the years.[19-23]

The possibility to discuss the case with patients and relatives using XR to improve medical communication is an important issue: in this regard, Hou *et al.* highlighted how the utilization of AR can also improve patients' understanding of surgical approach as well as risk and complications related to surgery, addressing the growing need for patients to understand their care route.[24]

In our preliminary experience this aspect was not focused, but we believe that XR potentially provides useful work patterns in daily clinical practice that can be insights for other colleagues to develop further studies. Our analysis reported a prevalent application of 3D presurgical planning in neo-plastic diseases: 62.50% of responders use three-dimensional surgical planning before brain tumor resection. In this field, the use of XR is often combined with 3D printed physical hands-on model: Jeising *et al.* combined mixed reality visualization with the corresponding 3D model demonstrating an improvement in brain tumor resection skills among their sample of trainees;[25] same results were obtained by Sandralegar *et al.* who compared mixed reality associated to 3D models to the standard ex cathedra format showing that students acquired a better knowledge of the anatomy and that these modern solutions are promising in improving education especially with the production of a precise and reproducible models.[26] In our sample, only 3.1% of responders used 3D printing systems: this could depend by both cultural and economic reasons: financial resources could represent an important limitation to the dissemination of these technologies. On the other hand, we believe that XR potentially leads to improved surgical skills in trainees justifying investments. From a sustainability of costs point of view, it can be argued that developing XR could reach a long-term cost-saving effect since it reduces, in our view and preliminary experience, the learning curve and hypothetically the need of many years of training and educational courses.

Limitations of the study

Our study is not exempt from flaws, ranging from a small sample size to a lack of randomization to a short-term outcome.

Nevertheless, despite the growing role that extended reality is gaining, this technology could still be considered as in its infancy and our study highlights how there is a widespread tendency to believe that XR will be the standard in education, that there is a need for it, but that it is currently only available in the minority of centers that participated in the study.

Conclusions

This preliminary study suggests that XR can positively influence trainees' education and that there is a broad perception of this beneficial impact even in contexts where XR is not available. Further and larger studies are necessary in our country to better understand and standardize these results.

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Conflicts of interest

The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

Authors' contributions

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