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The use of advanced technology for preoperative planning in cranial surgery – A survey by the EANS Young Neurosurgeons Committee

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ABSTRACT

Introduction: Technological advancements provided several preoperative tools allowing for precise preoperative planning in cranial neurosurgery, aiming to increase the efficacy and safety of surgery. However, little data are available regarding if and how young neurosurgeons are trained in using such technologies, how often they use them in clinical practice, and how valuable they consider these technologies.
Research question: How frequently these technologies are used during training and clinical practice as well as to how their perceived value can be qualitatively assessed.
Materials and methods: The Young Neurosurgeons' Committee (YNC) of the European Association of Neurosurgical Societies (EANS) distributed a 14-items survey among young neurosurgeons between June 1st and August 31st, 2022.
Results: A total of 441 responses were collected. Most responders (42.34%) received "formal" training during their residency. Planning techniques were used mainly in neuro-oncology (90.86%), and 3D visualization of patients' DICOM dataset using open-source software was the most frequently used (>20 times/month, 20.34% of responders). Software for 3D visualization of patients' DICOM dataset was the most valuable technology, especially for planning surgical approach (42.03%). Conversely, simulation based on augmented/mixed/virtual reality was considered the less valuable tool, being rated below sufficiency by 39.7% of responders.

Abbreviations: AR, Augmented reality; VR, virtual reality; MR, Mixed reality; EANS, *European Association of Neurosurgical Societies*; fMRI, Functional magnetic resonance Imaging; nTMS, navigated Transcranial Magnetic stimulations; MEG, Magnetoencephalography; EANS, European Association of Neurosurgical Societies; YNC, Young Neurosurgeons' Committee; SD, standard deviation; DICOM, Digital Imaging and Communications in Medicine; OR, operative room.

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Discussion and conclusion: Training for using preoperative planning technologies in cranial neurosurgery is provided by neurosurgical residency programs. Software for 3D visualization of DICOM datasets is the most valuable and used tool, especially in neuro-oncology. Interestingly, simulation tools based on augmented/virtual/mixed reality are considered less valuable and, therefore, less used than other technologies.

1. Introduction

Recent technological advancements in Neurosurgery provided novel tools allowing for accurate preoperative planning in cranial neurosurgery to improve surgery's safety and efficacy. (Kockro et al., 2013, 2016; Low et al., 2010; Stadie and Kockro, 2013; Eliyas et al., 2016; Cabrilo et al., 2014a; Duque et al., 2014; Spiriev et al., 2017; Ferroli et al., 2013; Esposito et al., 2008; Harput et al., 2014; Mert et al., 2012) The possibility to identify and visualize anatomical and functional structures before entering the operating theatre using different technological tools, ranging from 3D rendering up to virtual reality, represents a valuable support to plan the best strategy and achieve the pre-defined goals of surgery in each case (Kockro et al., 2013, 2016; Low et al., 2010; Stadie and Kockro, 2013; Eliyas et al., 2016; Cabrilo et al., 2014a; Duque et al., 2014; Spiriev et al., 2017; Ferroli et al., 2013; Esposito et al., 2008; Harput et al., 2014; Mert et al., 2012). Indeed, the preoperative decision-making process leading to the choice of the definitive surgical strategy and approach may benefit from the possibility to correctly identify brain anatomical and functional structures that will be encountered during surgery. Nowadays, several technological tools are available for preoperative planning in cranial neurosurgery, ranging from advanced software for visualization and 3D rendering of anatomical and functional structures up to novel generation simulators based on virtual reality (Cabrilo et al., 2014a; Spiriev et al., 2017; Raffa et al., 2017, 2019a, 2019b; Stengel et al., 2022; Lee and Lee, 2022; Stadie et al., 2008; Perin et al., 2021)«w. Collectively, they could be divided into three main categories: 1) decision support, open-source or commercial, dedicated software packages for imaging analysis and 3D volumetric rendering and modeling of patient DICOM datasets e.g. Horos (Horos Project™), 3D Slicer (Slicer Community) (Spiriev et al., 2017; Ferroli et al., 2013; Esposito et al., 2008; Harput et al., 2014; Mert et al., 2012; Mandel et al., 2013); 2) tools and dedicated workstations for direct functional and structural preoperative brain mapping, which provides data that can be implemented into the neuronavigation system-e.g. fMRI, nTMS, tractography, MEG etc. (Conti et al., 2014; Raffa et al., 2018; Sollmann et al., 2018; Takahashi et al., 2013; Gasser et al., 2011; Senft et al., 2011; Bisdas et al., 2015) 3) surgical simulators based on augmented or mixed or virtual reality, some of which can be used for preoperative planning (e.g. Dextroscope (Volume Interactions Pte Ltd), Surgical theater (Cleveland, Ohio, USA), etc.) (Kockro et al., 2013, 2016; Eliyas et al., 2016; Ferroli et al., 2013; Stadie et al., 2008; Christopher et al., 2013; Newall et al., 2022; Nicolosi et al., 2018; Ghaednia et al., 2021). Some of these technological tools have been already introduced in routine clinical practice and are used especially by young neurosurgeons who are usually more prone to use technological innovations (Stengel et al., 2022; Zoli et al., 2022). However, to date, little data are available regarding whether and how young neurosurgeons receive training in using such technologies, how often they use them in clinical practice, and how valuable they consider them to be. The Young Neurosurgeons' Committee (YNC) of the European Association of Neurosurgical Societies (EANS) distributed a survey among young neurosurgeons with the aim of providing an overview about how frequently such technologies are currently used during training of neurosurgical residents and their clinical practice, as well as to qualitatively assess the subjectively perceived value by of these preoperative planning techniques in cranial neurosurgery.

2. Materials and methods

2.1. Web-based survey and distribution

A 14-questions survey was designed and distributed by the YNC of the EANS between June the 1st and August 31st' 2022. The survey was distributed by email, social networks, and the platform Surveymonkey (https://www.surveymonkey.com) among all registered young EANS members (residents and board-certified neurosurgeons within the first 10 years from certification) and by European national societies: it consisted of 6 demographic questions and 8 specific questions related to the use of novel technologies for preoperative planning in cranial surgery. The entire survey is reported in Supplementary Table 1. Responses were checked for missing and/or duplicate data, and then analyzed.

2.2. Statistical analysis

The results of the survey were expressed using descriptive statistics as percentage (%) and standard deviation (SD). All the graphical illustrations of results were realized using the software Graphpad Prism 9.0.0 for macOS (Graphpad Software LLC, USA).

3. Results

3.1. Demographic data of participants

All the demographic data of responders are reported in Table 1. A total of 441 participants (329 males, 111 females, 1 missing; mean age 37.7 ± 10.6 years old) responded to the survey (Fig. 1A). Most responders were young neurosurgeons within 10 years of their board certification (58.04%, 256 responders). Residents still in their training program accounted for 41.26% (182 responders) (Fig. 1B). The most common area of interest among participants was Neuro-Oncology (74.31%) (Fig. 1C). The majority of responses came from young EANS members working in an European or EANS-affiliated country (90.25%,

Table 1
Demographic data of n. 441 survey responders. Results are expressed as count (percent) or mean (standard deviation). * Missing data from 1 participant (0.23%). ** A detailed list of participating countries is provided in the Supplementary Table 2, but most responses came from Italy (n. 76, 17.23%), Spain (n. 63, 14.28%), Germany (n. 35, 7.93%), Greece (n. 27, 6.12%), Switzerland (n. 26, 5.89%).

No. of responders	441
Age in yrs, mean	37.7 ± 10.6
Gender (%)*	
Male	329 (74.6%)
Female	111 (25.17%)
Missing	1 (0.23%)
Position (%)	
Residents in training	182 (41.26%)
Board-certified (within 10 years)	256 (58.04%)
Continent**	
Europe	398 (90.25%)
North America	2 (0.45%)
Latin America	11 (2.5%)
Africa	9 (2.04%)
Asia	17 (3.85%)
Oceania	3 (0.68%)
Missing*	1 (0.23%)
Total	100%

Fig. 1. Characteristics of the participants: A) Gender, B) Position, C) Area of Interest.

398 responders). The global geographic distribution of responders is reported in Supplementary Table 2.

3.2. Training for the use of preoperative planning technologies

Among responders, 76.25% reported they received specific training for the use of preoperative planning technologies in cranial surgery. However, there were still 23.75% of responders who never received such training. In detail, 59.63% were trained for using tools and dedicated workstations for direct functional and structural preoperative brain mapping providing data that can be implemented into the neuronavigation system (e.g. fMRI, nTMS, tractography, MEG, etc.); 55.15% received training for the use of open-source or commercial, dedicated software packages for imaging analysis and 3D rendering patients' DICOM datasets (e.g. Horos, 3DSlicer, etc.); eventually, only 16.36% were effectively trained for using simulators based on augmented/mixed/virtual reality (e.g. Dextroscope, Surgical Theatre) (Fig. 2A).

When asked about who provided this specific training, most responders reported they received "formal" training during their Residency Program (42.34%). Interestingly, more than one-third of participants received "informal" training on-the-job from their peers (39.64%). Eventually, 10.51% and 7.51% of responders received training from their own Institutions after completion of the Residency program and from industry representatives, respectively (Fig. 2B).

3.3. Use of preoperative planning technologies in clinical practice

When asked how often young neurosurgeons use these technologies in their everyday clinical practice, 47.18% responded "*In most of the cases*", and 27.61% "*Only in complex cases*". Eventually, 14.48% responded "*In all of the cases*", and 10.73 "*Rarely/Not at all*") (Fig. 3A). The use was mainly reported in neuro-oncology cases (90.86%) followed by skull base cases (53.76%) (Fig. 3B).

Among the three main categories of preoperative planning technologies, the most commonly used one was represented by tools and dedicated workstations for direct functional and structural preoperative brain mapping (e.g. fMRI, nTMS, tractography, MEG, etc.), followed by decision support open-source or commercial dedicated software packages for imaging analysis and 3D rendering and modeling of patient DICOM datasets (e.g. Horos (Horos Project™), 3D Slicer (Slicer Community). Since this specific question allowed for multiple choices, the percentages were 73.57% and 69.07%, respectively. The use of simulators based on augmented/mixed/virtual reality (AR/MR/VR) was reported only by 13.51% of responders (Fig. 4A).

When asked to describe how often they use these technologies according to specific frequency ranges, responders reported the most frequently used was *"open-sources software for 3D rendering and modeling of patients' DICOM datasets"*. Indeed, 20.24% of survey participants reported they use this technology >20 times per month. In the same frequency range (>20 times per month), *"Dedicated workstation for preoperative simulation based on augmented/mixed/virtual reality"* was reported only by 2.06% of responders, thus representing the less frequently used tool. Similarly, when considering the less frequent range (1–3 times per month), "Dedicated workstation for preoperative simulation based on augmented/mixed/virtual reality" simulation technology was the most common response, being reported by 77.32% of responders (Fig. 4B).

3.4. Subjective value of different preoperative planning technologies

When asked to rate (from 0 to 10) the value of different preoperative planning technologies, responders reported the most valuable tools were *"commercial" and "open source" software for 3D rendering and modeling of patients' DICOM datasets,* being rated with a 10 by 37.43% and 31.81%, respectively. Unexpectedly, *"Simulation based on augmented/mixed/virtual reality"* was considered the less valuable tool, being rated with a 0 by 9.27% of responders. Surprisingly, 39.7% of responders rated this technology below sufficiency (rate 0–5) (Fig. 5).

Eventually, after rating (from 0 to 10) the value of different technological features, the most appreciated was "*Planning of the surgical approach (measuring the exact location of the lesion, the size and location of the craniotomy/burr hole/craniectomy, the relationship with surrounding structures)",* which received a 10 rate from 42.03% of responders. The second most valuable technological feature was *"Planning the intradural part of the operation (3D visualization of cortical brain surface and vessels, planning of the surgical corridor/trajectory and target, identification of functional brain areas, visualization of subcortical white matter tracts etc.)"*, being rated with a 10 rate by 35.38% of participants (Fig. 6).

Conversely, the less valuable features were "*Using augmented/mixed reality in the OR before skin incision to plan surgical strategy*" and "*Simulating the surgical procedure before entering the OR*" which were rated 0 by 6.73% and 5.10% of responders, respectively.

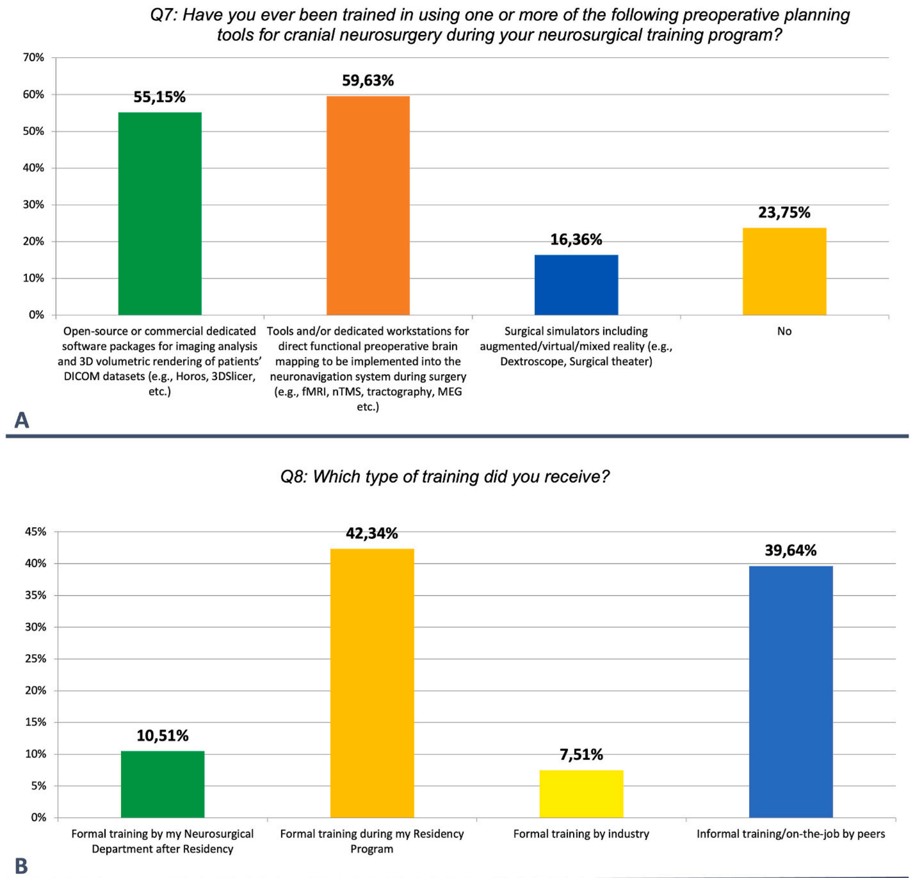

Fig. 2. Training for using preoperative planning technologies: A) responses regarding whether participants have ever been trained for using different preoperative planning tool in cranial surgery; B) responses regarding which type of training participants received.

4. Discussion

The survey examines the application of advanced technological tools (open-source or commercial software for imaging analysis and 3D volumetric rendering, workstations for direct functional and structural preoperative brain mapping, and AR/VR/MR simulators) for preoperative planning predominantly among EANS members and participants from other non-European countries. We chose an online survey format as this provides relatively fast data collections including representative answers from neurosurgeons coming from different training programs, with variable availability of modalities for preoperative planning. Therefore, such broader collection of data and diversity in answers would possibly provide more valuable information about the researched questions and possibly would allow recommendations. Most responders were young neurosurgeons within 10 years of their board certification, residents accounted for 41.55% of the responders, with the mean age of the participants of the survey was 37 years old. This demographic data for survey participants would provide a more precise image of the current technological methods for preoperative planning. However, despite our best efforts, the low response rate would not allow the generalization of the data.

Young neurosurgeons are usually considered more prone than seniors in acquiring the technological skills needed to use such novel technologies during their everyday practice. However, to date, there is no evidence or proof that young neurosurgeons are effectively exposed to appropriate training allowing them to properly learn how to use these technologies. (Stengel et al., 2022; Lippa et al., 2022; Zoia et al., 2022) Moreover, it's not clear how often young neurosurgeons concretely use them and which is the consideration about the real usefulness of these novel tools. The aim of this survey was to assess, for the first time, among the EANS young neurosurgeons community, the modalities of training for the use of these modern techniques, how often they are used in everyday practice, and how valuable they are perceived by young neurosurgeons.

The first, probably unexpected, result of the survey is that young neurosurgeons receive proper formal training for the use of these preoperative planning technologies during their Residency program. Since senior neurosurgeons faced the introduction of these technologies in the clinical practice after completion of their residency training, it could be speculated they would not be able to provide proper training to young residents and fellows. Conversely, a strong impact of medtech industry in the education and training of both senior and young neurosurgeons could be expected. As a matter of fact, our survey documented that most responders learned how to use these technologies mainly during their official neurosurgical training. The most common source is the official training from senior neurosurgeons, while the role of industry representatives was very limited. This indicated that neurosurgical residency programs across the EANS countries can rapidly adapt to technological changes and implement novel tools in the clinical settings (Stienen et al., 2016, 2020). The second learning source is the informal training by peers on the job. However, more than 23% of responders report that they did not receive any specific training on the use of these technologies. These last findings suggest that the training in using advanced technologies during the formal Residency program may still be improved.

Another important finding from our survey is that advanced technologies are diffusely used in clinical practice for preoperative planning in cranial neurosurgery. More than 96% of responders confirmed the use of such technologies, and almost 1 out of 2 responders declared they use them in almost all cases. These responses outline how technology changes our everyday practice (Fig. 3A). In particular, preoperative

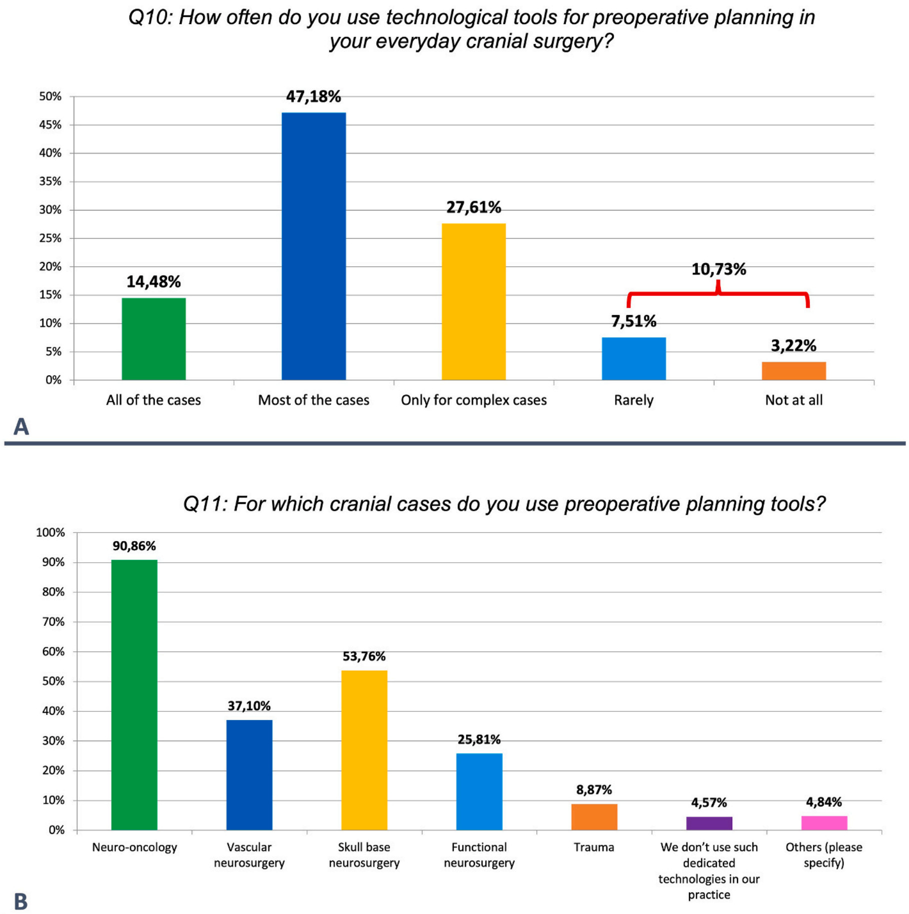

Fig. 3. Reponses regarding A) how often participant use preoperative planning technologies in their clinical practice and B) and for which cranial case they use them.

planning tools are mainly used in neuro-oncology and skull base cases: in these patients, the use of such technological tools helps the surgeon in visualizing preoperative models based on imaging rendering that allows him/her to be mentally prepared for the patient-specific anatomy, which is usually distorted by the pathological process. Such advanced tools improve surgeons' intraoperative orientation and are useful also for teaching residents (Ferroli et al., 2013; Harput et al., 2014; Mert et al., 2012; Cabrilo et al., 2014b). Neurosurgery is a highly technology-driven branch of surgery: advanced technological support is required by the need to preserve the normal brain functioning and to achieve a good functional outcome which is possible only through minimal brain tissue manipulation during the operation. Therefore, technologies such as fMRI, nTMS, tractography-guided neuronavigation, 3D rendering of patients DICOM's datasets are becoming an indispensable part of our everyday practice.

In particular, responders to our survey reported that the most commonly used tool for preoperative planning is represented by workstations for direct functional and structural preoperative brain mapping (e.g. fMRI, nTMS, tractography, MEG, etc.). That is probably due to the ability of these tools to improve the functional outcome and safety of surgery. The implementation of data provided by these workstations in contemporary neuronavigation systems does not require deep knowledge of computer graphics and has acceptable workflow in terms of learning curve (Spiriev et al., 2017; Ferroli et al., 2013; Harput et al., 2014; Mandel et al., 2013; Conti et al., 2014; Raffa et al., 2018; Gerard et al., 2016; Valeri et al., 2015). The second most-used technology is open-source or commercial dedicated software for imaging analysis and 3D volumetric rendering of patient DICOM datasets. In particular, the easy availability of open-source software for preoperative modeling of patient DICOM datasets makes these tools always more popular among residents during their training and practice. (Ferroli et al., 2013; Harput et al., 2014; Mandel et al., 2013; Guigou et al., 2015; Miller et al., 2008; Bendok et al., 2014; Rotariu et al., 2016) This is a confirmation of a well-known trend of the rising use of open-source platforms in the medical field (Spiriev et al., 2017; Ferroli et al., 2013; Esposito et al., 2008; Harput et al., 2014; Mert et al., 2012; Mandel et al., 2013). In recent years there have been many reports presenting results and associated algorithms for the use of DICOM imaging visualization software packages with 3D rendering and modeling features such as Horos (Horos Project™), 3D Slicer (Slicer Community) applied as preoperative planning tools. (Spiriev et al., 2017; Ferroli et al., 2013; Esposito et al., 2008; Harput et al., 2014; Mert et al., 2012; Mandel et al., 2013) The advantages of 3D rendering include the preoperative visualization of cortical gyri, vessels, subcortical tracts, and potentially every single anatomical structure that can be segmented to create 3D models (Spiriev et al., 2017; Ferroli et al., 2013; Harput et al., 2014; Mandel et al., 2013; Conti et al., 2014; Raffa et al., 2018; Gerard et al., 2016; Valeri et al., 2015). These can be rotated in every possible direction, zoomed, panned, etc. (Spiriev et al., 2017; Ferroli et al., 2013; Harput et al., 2014; Mandel et al., 2013; Conti et al., 2014; Raffa et al., 2018; Gerard et al., 2016; Valeri et al., 2015). Such a control over the patient specific 3D model provides a greater understanding of patients' anatomy preoperatively through the analysis of the relationships between normal and pathological structures, thus increasing the safety of surgery. This is of great adjunct to the standard neuronavigation, which due to the phenomenon of brain shift, is mostly used to correctly locate the pathological entity and define the craniotomy boundaries (Mandel et al., 2013; Spivak and Pirouzmand, 2005). Indeed, among responders to our survey, the most appreciated feature of such software was the planning of the surgical approach. This included measuring the exact location of the lesion, the

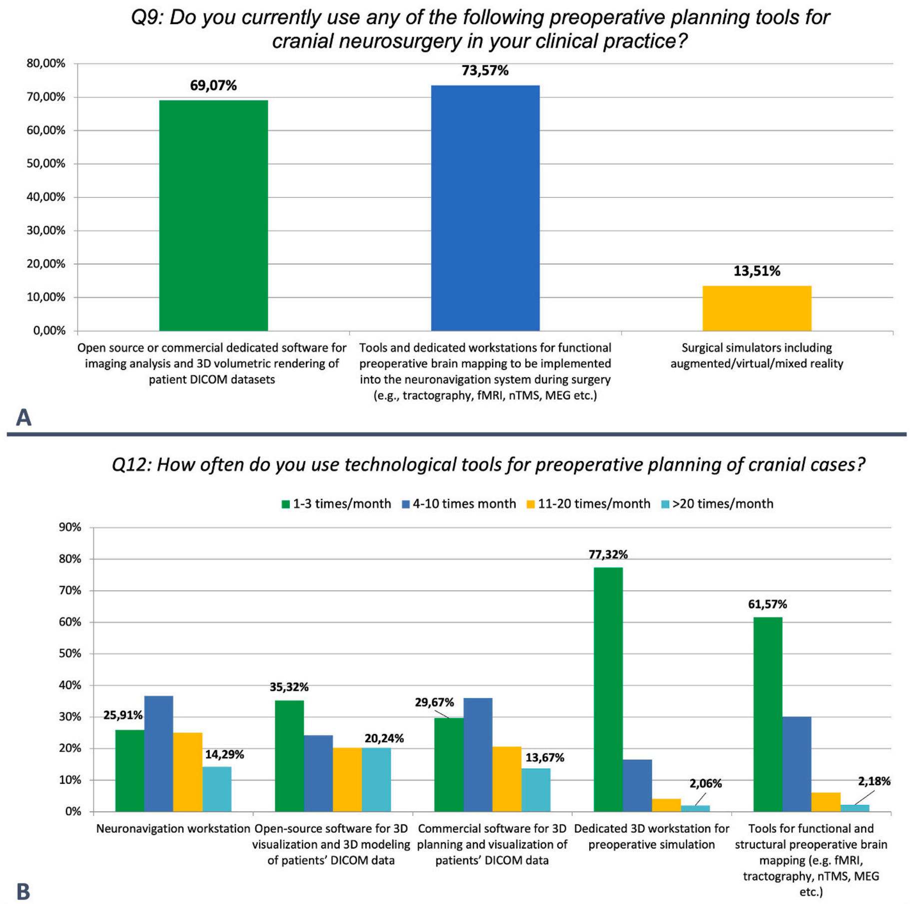

Fig. 4. Frequency of the use of advanced technologies for preoperative planning in cranial surgery: A) responses regarding the use of the three main categories of technologies; B) frequency of the use of different tools according to specific ranges.

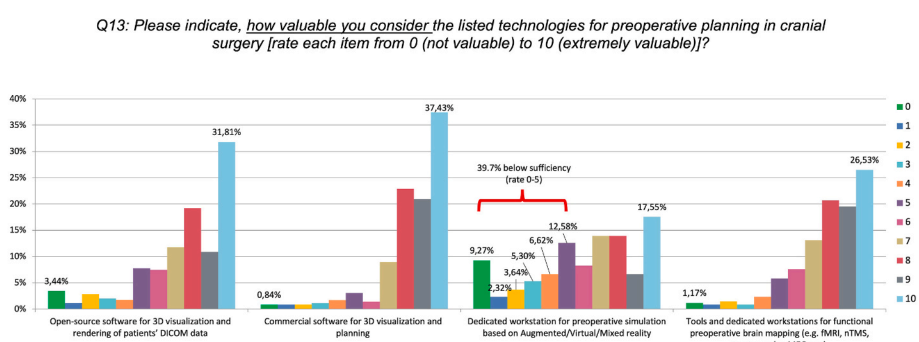

Fig. 5. Subjective value of different preoperative planning technologies as perceived by responders.

size, and location of the craniotomy/burr hole/craniectomy, etc. (Fig. 6). Considering the results of our study regarding the implementation of open-source software for visualization of the normal and pathological anatomy, preoperative planning and the ease of access of high-quality open-source software packages, such solutions can be very useful in residents' education, especially in the early years of training. These software packages can be implemented in the morning conferences to visualize the preoperative patient data in 3D or as a self-study training by residents for lesion localization, planning the positioning, skin incision and simulation of the craniotomy (Spiriev et al., 2017; Ferroli et al., 2013; Esposito et al., 2008; Harput et al., 2014; Mert et al., 2012; Mandel et al., 2013).

Also, newer devices in the form of surgical simulators based on augmented or mixed or virtual reality are being gradually introduced in neurosurgical everyday practice and can be used for preoperative planning in cranial neurosurgery (e.g. Dextroscope (Volume Interactions Pte Ltd), Surgical Theater (Cleveland, Ohio, USA). (Kockro et al., 2013, 2016; Eliyas et al., 2016; Ferroli et al., 2013; Stadie et al., 2008; Christopher et al., 2013; Newall et al., 2022; Nicolosi et al., 2018; Ghaednia et al., 2021) Another unexpected finding from our survey is that, despite being used by young neurosurgeons during their formal training (Stengel et al., 2022), simulators based on augmented/virtual/mixed reality resulted to be the less used tools in clinical practice. Surprisingly, simulators are also considered the less valuable tools in comparison to other advanced technologies for preoperative planning in cranial neurosurgery. More than 39% of responders reported the value

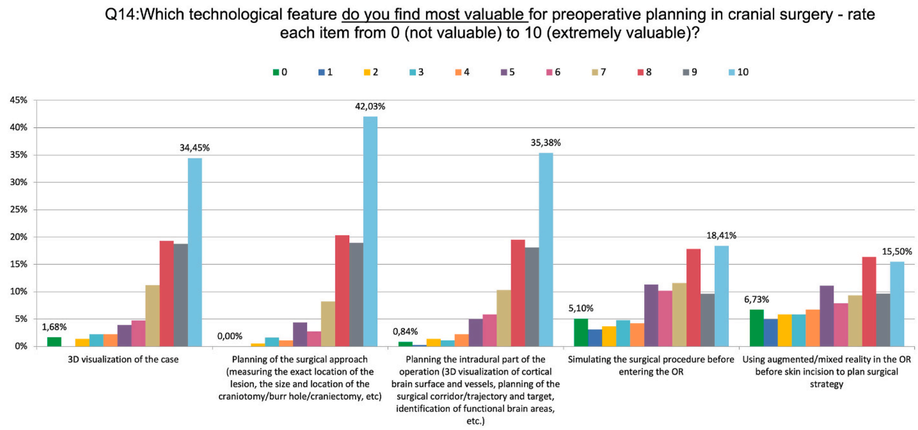

Fig. 6. Subjective value of specific features of preoperative planning technologies as perceived by responders.

of simulators based on augmented/virtual/mixed reality to be below sufficiency. This is probably because simulators' technology is still new, not well widespread, and still not commonly used in clinical practice. This finding confirms the results of our previous study (Stengel et al., 2022) despite the obvious advantages of the new augmented/virtual/mixed reality devices such as interactivity, immersion, better visualization, preoperative simulation, the use of such technology currently remains low. In our opinion, at present this might be due to the higher price of these devices, limited software solutions for VR and MR for preoperative planning and the fact that currently not

Table 2
Comparative analysis of different technologies for advanced preoperative planning in cranial surgery.

Technology	Availability (Free vs. at cost)	Features	Application in different scenarios	Ease to use	Accessibility for training	Pros	Cons
Neuronavigation workstations	High cost	• Preoperative 3D rendering of patients DICOM data • Possibility to import other preoperative functional data • Intraoperative precise localization of the lesions	• Before surgery for planning • During surgery	Minor training required	Easily accessible	• Useful before and during surgery • Minor training required • Easily accessible	• High cost
***Open-Source software** for 3D visualization and rendering of patients DICOM data*	Free	• Preoperative 3D rendering of patients DICOM data • Possibility to export data into neuronavigation systems to be used intraoperatively • Simulation of surgical steps	• Before surgery for planning • During surgery (after data export into the neuronavigation workstation)	Moderate/ High training required	Easily accessible	• Free • Useful before and during surgery • Easily accessible	• Moderate/ High training required
***Commercial software** for 3D visualization and rendering of patients DICOM data*	Moderate/ High cost	• Preoperative 3D rendering of patients DICOM data • Possibility to export data into neuronavigation systems • Simulation of surgical steps	• Before surgery for planning • During surgery (after data export into the neuronavigation workstation)	Moderate training required	Not always accessible	• Useful before and during surgery	• Moderate/ High cost • Moderate training required • Not always accessible
***Tools for functional and structural preoperative brain mapping** (e.g. tractography, fMRI, nTMS; MEG)*	High cost	• 3D visualization of brain functional areas and structures • Possibility to export data into neuronavigation systems	• Before surgery for planning • During surgery (after data export into the neuronavigation workstation)	Moderate/ High training required	Not always accessible	• Useful before and during surgery	• High cost • Moderate/ High training required • Not always accessible
Dedicated tools and workstations for preoperative simulation based on Augmented/ Mixed/Virtual reality	Moderate/ High cost	• Immersive 3D rendering of patients DICOM data • Immersive simulation of surgical steps	• Before surgery for planning • Inside the OR before skin incision	Moderate/ High training required	Rarely accessible	• Useful before and in the OR (before skin incision)	• Moderate/ High cost • Moderate/ High training required • Rarely accessible

many neurosurgeons, especially from middle- or lower-income countries, have been exposed to these technologies as modality for preoperative planning. Therefore, the perceived value of simulators by young neurosurgeons is currently still low. However, there is a growing number of studies suggesting the potential benefits of these tools for residents' training, image visualization, and intraoperative orientation. (Stadie and Kockro, 2013; Eliyas et al., 2016; Ferroli et al., 2013; Christopher et al., 2013; Stadie et al., 2011) Probably, in the next few years, the evolution of these technologies and the identification of specific neurosurgical fields in which their use is concretely helpful. This would increase their application in everyday practice, especially among the next generation of neurosurgeons who will be surely more confident with using augmented/virtual/mixed reality.

Finally, according to the results of our survey it's not easy to define which technological tool for advanced preoperative cranial planning is the most frequently used, most accessible during training and considered most valuable (Table 2) by young neurosurgeons. Each different technology has pros and cons that influence its use in the clinical practice and its perceived value. Based on a rough comparative analysis (Table 1), all the different tools analyzed showed to be useful before surgery but also in the operating theatre, thanks to the possibility to import the preoperative planning data into the neuronavigation system. Open-source software solutions for 3D rendering are free and easily accessible both during training and during practice: therefore their perceived value is very high. However, these software often require moderate or high training; commercial software are usually more user-friendly, thus requiring only a moderate training, but have a variable cost (usually moderate/high) and are not always available during training and practice; tools for preoperative brain mapping (nTMS) are considered very useful because providing functional and structural data otherwise not available using other common technologies. However these tools have a usually high cost, are not always available during training and practice and requires a specific training (usually moderate/high). Finally, modern simulation platform based on AR/MR/VR have been recently introduced in the market and many of these are still being developed or prototypes. Therefore, they are rarely available during training and practice, have a variable cost (moderate/high) and are perceived as less useful than other more available technologies by young neurosurgeons. Since the survey was designed just to collect opinions from EANS young members, no firm recommendations can be done to improve residents' and young neurosurgeons' education in using different advanced preoperative planning tools. However, our survey demonstrated that the cost and the "perceived value" of these technologies is probably the most important factor influencing their availability and their use during training and practice. We strongly suggest increasing the exposure of young neurosurgeons to these technologies, even if expensive or considered "less valuable". Residency programs and companies should play an important role by promoting courses and frequent on-site training. That could increase the confidence of young neurosurgeons with these technologies, their awareness about the real usefulness of these novel tools, and may influence their use in the current practice to pursue the final aim of improving our patients' care by using the most effective and up-to-date available technologies.

5. Strengths and limitations of the study

This survey provides data on the use of advanced technology for preoperative planning in cranial surgery among the European neurosurgical community and an evaluation of the different planning modalities serving as a foundation for future more focused studies. The main limitation is the relatively low response rate (441 responses) and the risk of bias as this is a voluntary and subjective evaluation. Another limitation is the lack of demographic data for public or private practice of the participants which might have given insight of the different types of preoperative modalities in different practices. Finally, responses were not equally distributed among different Europeans countries (with some countries who showed a good response rate and some with a very low response rate). Moreover, we received responses also from young EANS members working in non-European countries which together with the low response rate do not allow generalization of the results.

6. Conclusions

Young neurosurgeons receive formal training in the use of advanced technologies for preoperative planning in cranial neurosurgery during their Residency programs. The training is mainly provided by senior neurosurgeons and by peers on the job, while the role of industry is limited. However, there is still a minority of young colleagues who never receive proper training. Preoperative planning technologies are commonly used in everyday clinical practice, especially in neuro-oncology and skull base cases. The most commonly used and appreciated tools are open-source software for 3D visualization and modeling of patients' DICOM datasets and workstations for direct functional and structural preoperative brain mapping (e.g. fMRI, tractography, nTMS, etc.), especially to plan the surgical approach. Surprisingly, simulators based on AR/VR/MR are still not widely used, and their value as a tool for preoperative planning needs to be better determined in the next future.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Jiri Bartek Jr reports a relationship with Medtronic Inc that includes: consulting or advisory.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.bas.2023.102665.

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