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Case Report

Virtual preoperative planning and 3D tumoral reconstruction with Horos open-source software

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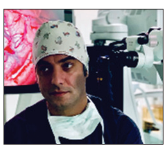

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ABSTRACT

Background: Presurgical three-dimensional (3D) reconstructions allow spatial localization of cerebral lesions and their relationship with adjacent anatomical structures for optimal surgical resolution. The purpose of the present article is to present a method of virtual preoperative planning aiming to enhance 3D comprehension of neurosurgical pathologies using free DICOM image viewers.

Case Description: We describe the virtual presurgical planning of a 61-year-old female presenting a cerebral tumor. 3D reconstructions were created with the "Horos®" Digital Imaging and Communications in Medicine viewer, utilizing images obtained from contrast-enhanced brain magnetic resonance imaging and computed tomography. The tumor and adjacent relevant structures were identified and delimited. A sequential virtual simulation of the surgical stages for the approach was performed with the identification of local gyral and vascular patterns of the cerebral surface for posterior intraoperative recognition. Through virtual simulation, an optimal approach was gained. Accurate localization and complete removal of the lesion were achieved during the surgical procedure. Virtual presurgical planning with open-source software can be utilized for supratentorial pathologies in both urgent and elective cases. Virtual recognition of vascular and cerebral gyral patterns is helpful reference points for intraoperative localization of lesions lacking cortical expression, allowing less invasive corticotomies.

Conclusion: Digital manipulation of cerebral structures can increase anatomical comprehension of neurosurgical lesions to be treated. 3D interpretation of neurosurgical pathologies and adjacent anatomical structures is essential for developing an effective and safe surgical approach. The described technique is a feasible and accessible option for presurgical planning.

Keywords: Neuro-oncology, Simulation, Surgical planning, Three-dimensional reconstruction, Virtual reality

INTRODUCTION

Presurgical planning is an essential process that analyzes individual anatomical features for determining an ideal surgical approach and ensuring therapeutic success. The neurosurgical field is in constant synergy with the latest technological advances, allowing expansion of anatomical insight, pathophysiological bases of diseases, minimization of surgical complications and consequently reducing the morbidity and mortality of treated patients.[2,4,6-8,18,19]

Imaging modalities such as magnetic resonance imaging (MRI) and computed tomography (CT) are our first resources for the identification and examination of lesions of the central nervous system. The basic interpretation of an MRI or CT consists of the sequential review of multiple imaging slices in a two-dimensional (2D) format. The neurosurgeon's workup does not end here, but in turn must extrapolate these images and construct a three-dimensional (3D) mental image for spatial orientation of the lesion at hand, considering relevant anatomical correlations and adjacent noble structures. In this way, the reality *in vivo* of the patient and the pathology is assimilated for optimal surgical resolution.[3,13,15-17,19,20,24]

Although the capability of mental 3D reconstruction is a necessary skill to be acquired by every neurosurgeon, it is not free from errors or individual variability.[6,19]

Virtual reality (VR) can be defined as a 3D environment generated by a computer, providing user interaction in real-time with images obtained from MRI and CT.[7,17] VR ranges from its simplest form as a 3D image obtained through a standard computer to advanced systems linking haptic devices, providing enhanced user interaction. Although international standards for presurgical planning include sophisticated platforms such as neuronavigation, access to these resources is restricted in developing countries due to limited financial resources.[12,14,19,26,27]

To address this obstacle, we describe an alternative unknown to many: virtual preoperative planning and 3D reconstruction utilizing free Digital Imaging and Communications in Medicine (DICOM) image viewers. The objective of this article is to present a method of virtual presurgical planning and enhancement of 3D comprehension of neurosurgical pathologies utilizing free and accessible software.

MATERIALS AND METHODS

We describe the virtual presurgical planning of a 61-year-old female harboring a subcortical cerebral tumor. Images were acquired from a contrast-enhanced brain MRI utilizing T1 weighted volumetric sequences (Philips Ingenia Prodiva 1.5T CX) and a contrast-enhanced brain CT with 1 × 1 mm thickness (Toshiba Aquilion 64). For 3D reconstruction, the DICOM viewer "Horos®" (version 3.3.6; www.horosproject.org) was utilized on a Macintosh operating system (MacBook Pro, 2.9 GHz Dual-Core Intel Core i7; Apple Computer, Inc, Cupertino, California). The tumor and adjacent relevant structures were identified and delimited. A sequential virtual simulation of the surgical stages for the approach was performed.

Reconstructions obtained by CT were utilized for visualization of extracranial structures; MRI was preferred for the recognition of intracranial structures and cerebral surfaces. Virtual planning was carried out in two stages: 3D presurgical planning and surgical simulation. Subsequent steps in each stage are described in Figure 1. We begin with a 3D reconstruction of the lesion and skull for topographic orientation. Superficial marking with craniometric points is followed, to be later utilized for marking over the patient. Posteriorly, the identification of relevant structures along the various cranial layers and localization of the lesion over the cerebral cortex is performed. Based on the information obtained, the surgical approach is determined.

Virtual surgical simulation is carried out with head placement in surgical position, emulation of the skin incision, and examination of extracranial structures, such as scalp vessels and osseous landmarks. Simulating a craniotomy, we arrive at the cerebral surface with the identification of local gyral and vascular patterns for posterior intraoperative recognition.

RESULTS

Clinical case

A 61-year-old female with a history of a pulmonary adenocarcinoma treated with chemo and radiotherapy showed up with a 7-day history of a speech disorder and right upper limb weakness. On physical examination, she presented motor aphasia, moderate right facio-brachio hemiparesis, right hemi-hypoesthesia, and a Karnofsky index of 80. The patient underwent brain CT showing a 2 × 2 cm round subcortical lesion located at the lower extremity of the left pre- and post-central gyrus, presenting annular enhancement after intravenous contrast administration, and accompanied by perilesional edema [Figures 2a-c]. A contrast-enhanced brain MRI displayed greater delimitation of the lesion [Figures 2d-f].

Tumor localization and identification of adjacent structures

We begin 3D reconstruction and digital tumor localization by marking the tumor's approximate dimensions projected onto the cranial surface [Video 1]. The lesion is peripherally delimited from its upper to lower boundaries. Marking of the remaining empty regions is performed and 3D reconstruction of the lesion is generated, obtaining a volume of approximately 2.9 cm^3.

Furthermore, 3D cranial reconstruction and visualization of the lesion from the surface are carried out, allowing 3D spatial orientation of the lesion within the skull.

The following step consists of measuring and locating the tumor for subsequent marking over the patient [Figures 3a and b]. A line is drawn from the lateral edge of the orbit to the upper border of the pinna, allowing

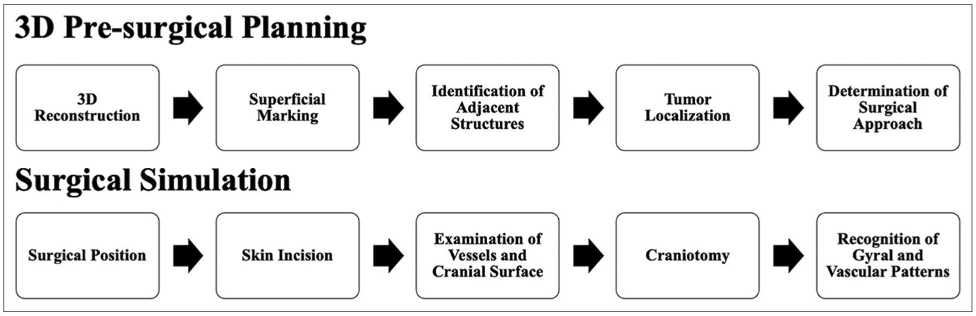


Figure 1: Description of sequential steps for virtual presurgical planning.

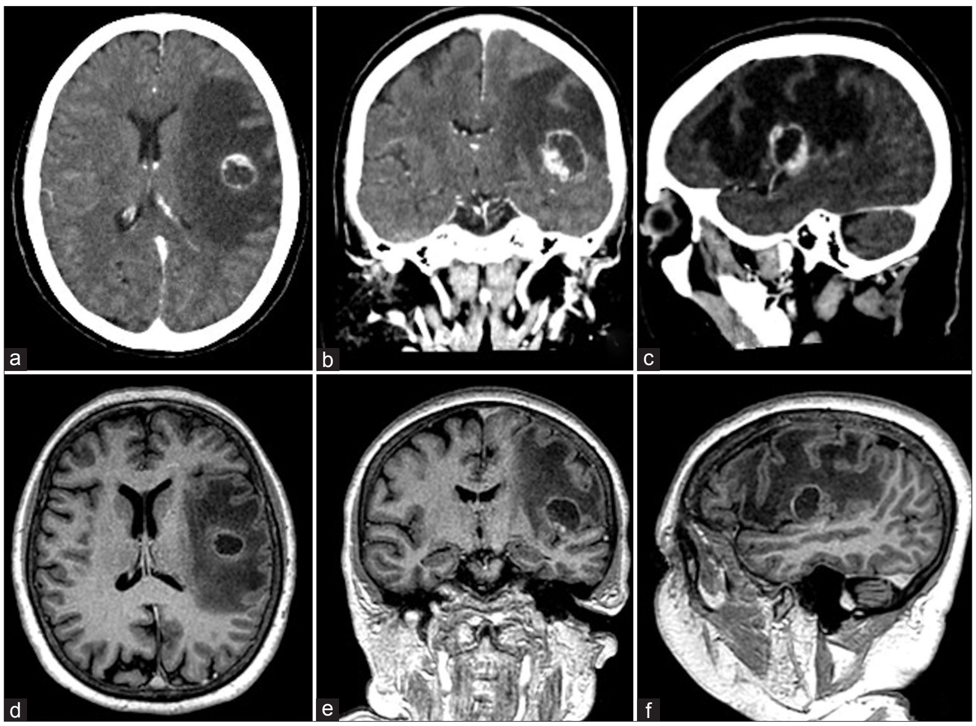
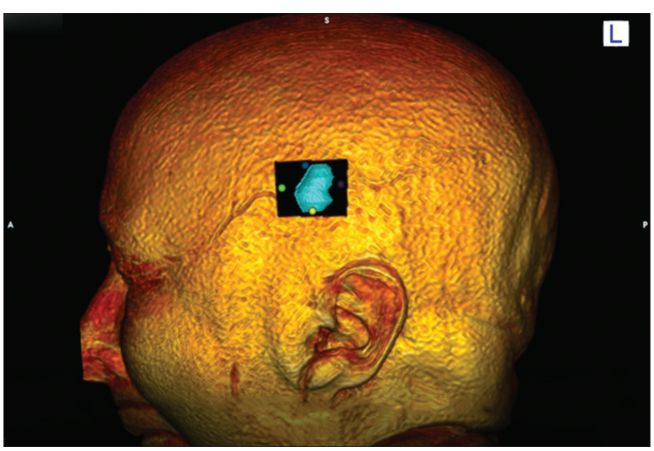


Figure 2: (a-c) Preoperative contrast enhanced brain computed tomography. (d-f) Preoperative contrast enhanced brain magnetic resonance imaging.



Video 1: Three-dimensional reconstruction and tumor localization.

delimitation and measurement of the tumoral boundaries. Virtual measurements are later translocated over the patient for physical marking of the lesion, corroborating its location with craniometric points and topographic expressions of known cerebral structures, such as the central and lateral fissures.

During the extracranial stage, the frontal and parietal branches of the superficial temporal artery were identified as relevant structures, with our lesion located between these and below the superior temporal line [Figure 4a]. Advancing into the cranial cavity, we arrive at the cerebral surface, locating the tumor within the lower extremity of the postcentral gyrus [Figures 4b and c]. Potential structures to be recognized during the surgical procedure are identified, such as the central fissure, precentral gyrus, and vein of Trolard anteriorly and the lateral fissure, Sylvian vessels, and vein of Labbé along with the superior temporal gyrus inferiorly.

Determination of surgical approach and simulation

One of the potential advantages of virtual planning is an examination of the selected approach in surgical position, possible alternatives, and the identification of adjacent structures to be recognized during the procedure. In our case, we positioned the patient supine with the head lateralized to the right. A left frontal-parietal linear incision in a cephalo-caudal direction of approximately 6 cm was determined. The frontal branch of the superficial temporal artery was in close proximity to the caudal end of the incision in the subcutaneous and muscular planes; attention to this detail will help ensure its preservation and thus achieve optimal healing. Subsequently, we performed a left temporoparietal craniotomy measuring approximately 3 × 4 cm, immediately inferior to the superior temporal line. Posterior to the dural opening, the vein of Labbé and Sylvian vessels was utilized as the caudal limit of the lesion, establishing a corticotomy over the postcentral gyrus 1 cm rostral to these vessels [Video 2].

The surgical procedure was performed with accurate localization of the lesion by identification of the previously described cortical structures and achieving total removal of the lesion [Figures 5a and b]. On postoperative day 9, the patient presented full recovery of her facial paralysis, hemi-hypoesthesia, muscle strength, and slight improvement of motor aphasia.

DISCUSSION

3D reconstructions for presurgical planning are obtained from volumetric sequences of MRI, CT, and their sub-modalities (angio-MR and angio-CT, etc.). Numerous free DICOM viewers with 3D reconstruction capacity currently exist, however, the most widely used are Horos® and Radiant viewer®. These provide several tools with neurosurgical applicability, allocating spatial orientation of lesions and their anatomical relationship with adjacent neurovascular and osseous structures.[1,2,9-11,13,19,24,25,27] In this sense, surgical simulation can be carried out with a comparison of surgical approaches (including the type of incision, craniotomy, and corticotomy) for the preservation of noble structures and anticipation of possible complications.

3D anatomical orientation and comprehension of cerebral structures in unusual surgical positions can be challenging for the neurosurgeon in training. Through virtual reconstructions, manipulation of anatomical viewpoints and acceleration of the learning curve for spatial orientation can be achieved.[23,24,27] The authors have utilized virtual planning for

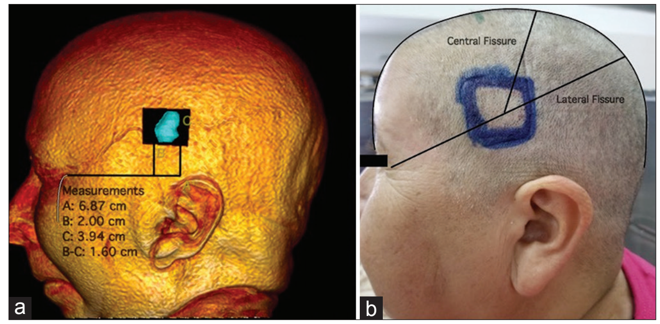


Figure 3: (a) Virtual marking and localization of the cerebral tumor. (b) Tumoral marking over the patient.

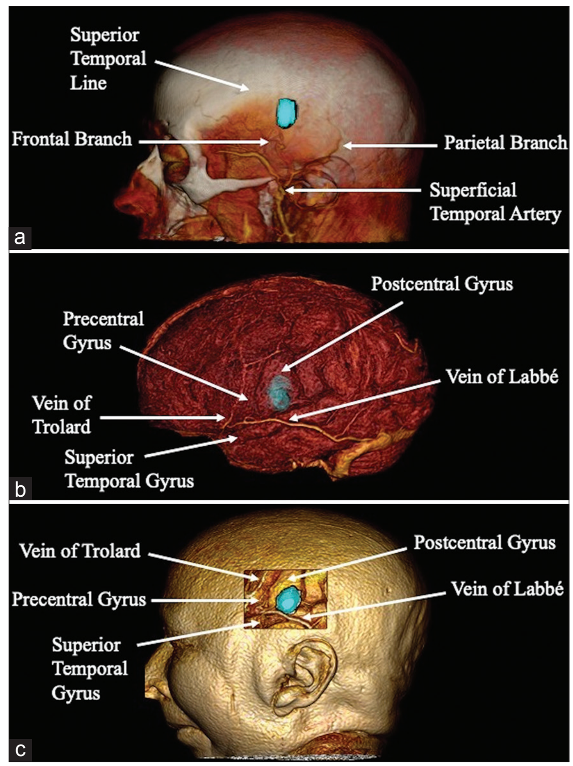
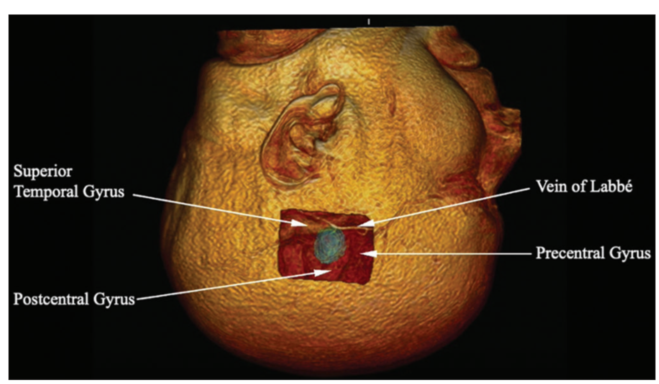


Figure 4: (a) Three-dimensional (3D) reconstruction of extracranial structures. (b and c) 3D reconstruction of the cerebral surface and tumor.



Video 2: Surgical simulation.

various intracranial pathologies, particularly supratentorial lesions in the setting of both urgent and elective cases [Figure 6]. The literature describes its widespread use for intraoperative localization of lesions such as neurovascular conflicts, intracranial tumors and hematomas, extra-axial hematomas (epi and subdural), cerebral aneurysms,[15] and for measurement of the distance between the asterion and the transverse-sigmoid sinus junction during retrosigmoid approaches.[1,5,6,10,14,21,24,25,27]

Several authors have reported successful utilization of "virtual surgeries" for various cerebral pathologies, simulating incisions and craniotomies along with identification of relevant adjacent structures within the layers of the head.[6,10,13,14,24,27]

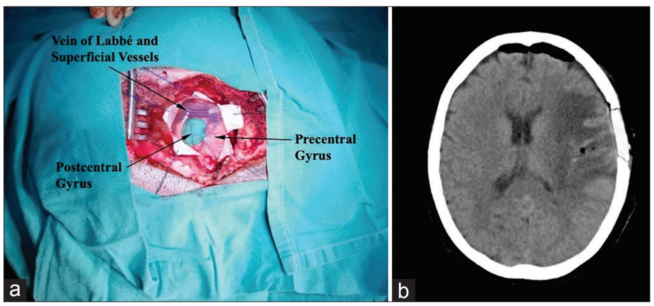


Figure 5: (a) An intraoperative photo is demonstrated along with tumoral reconstruction in the expected topography. (b) Postoperative brain computed tomography displaying complete tumoral resection.

Intraoperative recognition of vascular and gyral patterns of the cerebral surface are useful for both intra and extra-axial tumoral pathology, allowing the determination of its boundaries, relationship with neighboring structures, and localization of those without cortical expression for less invasive corticotomies. Piece of literature evidence reported similar results with an emphasis on superficial cerebral vascularization as intraoperative reference points.[7,9]

In the emergency setting, correct interpretation of the lesion, subsequent surgical approach selection, and prompt action can define the prognosis of a patient. Virtual planning by these means generally requires <30 min, supporting its use in urgent situations.[6,10,14,19,22] Virtual delineation of the extent or dimensions of extra-axial traumatic pathologies (hematomas and fractures) over the skull surface allows determination of the size and location of the pertinent craniotomy/craniectomy. Similarly, Mandel *et al.* highlighted the practicality of 3D reconstructions in the acute setting and determined the relationship of traumatic extra-axial hematomas with overlying bone structures for endoscopic evacuation.[19]

Limitations

Although many advantages of this resource have been documented, certain disadvantages must be considered. Infratentorial reconstructions were found to be of little use by the authors for topographic location. In addition, precise surface marking and measurement of certain injuries can

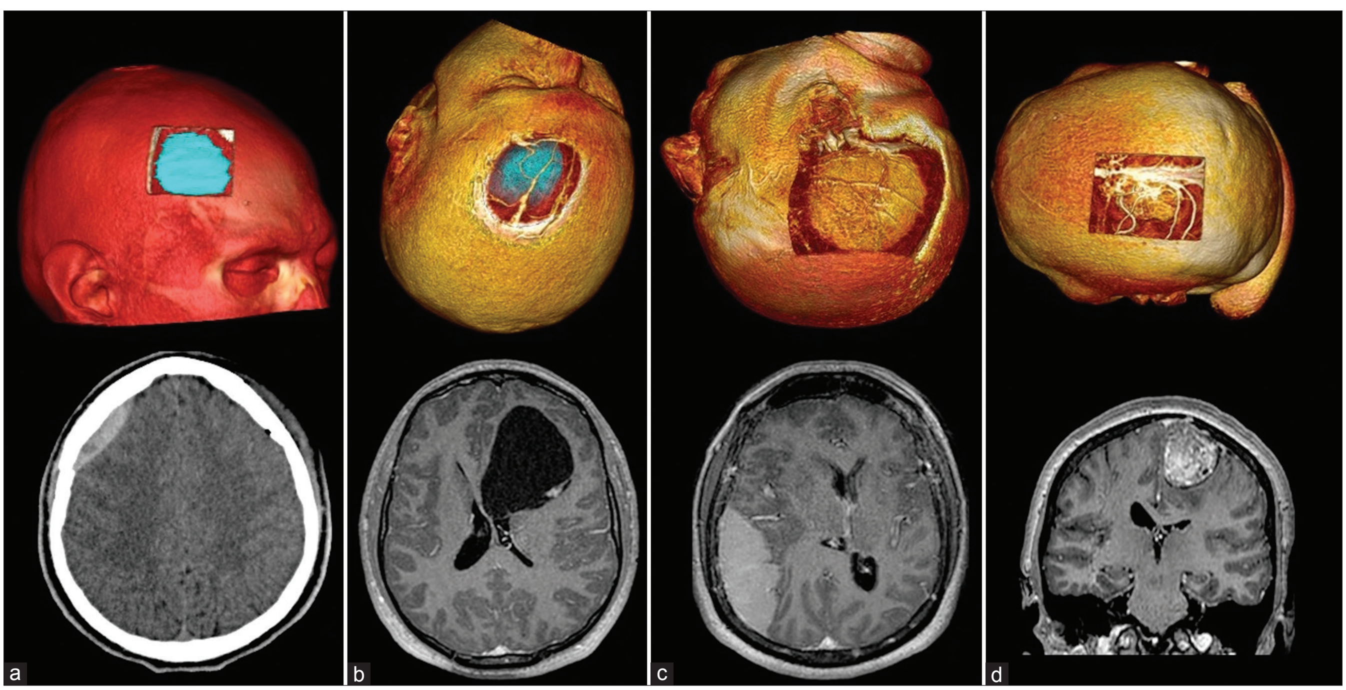


Figure 6: Examples of three-dimensional reconstructions of supratentorial lesions. (a) Epidural hematoma. (b) Hemangioblastoma. (c and d) Meningioma.

be difficult due to the cranial curvatures and lack of tools for correction; the exact distances between the lesions and multiple reference points may require corroboration by means of traditional measurement with 2D images. Furthermore, despite simple and intuitive user interfaces, utilization of these programs requires a basic notion of informatics.

CONCLUSION

The neurosurgical field is found within a digital paradigm aimed at a greater interaction between medical personnel and digital programming for the treatment of pathologies. Despite a large number of freely accessible technological resources worldwide, the educational and illustrative potential of 3D reconstruction with open-sourced software is not fully exploited in our field, either due to access to more sophisticated devices or unawareness of their existence. 3D interpretation of cranial structures is essential for developing an effective and safe surgical approach. Digital manipulation of the various cerebral structures and visualization through multiple angles favors the anatomical comprehension of each individual patient. The described technique is a viable and accessible option for presurgical planning, useful for both the resident in training and experienced neurosurgeon.

Institutional review board statement

The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Institutional Review Board.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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