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Technical Note & Surgical Technique

Three-dimensional, computer simulated navigation in endoscopic neurosurgery

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ABSTRACT

Background: In order to address the pre- and perioperative need for visualization and prediction of patient-specific anatomy for surgical planning, endoscopic neurosurgeons have increasingly relied on computerized navigation devices to guide their surgical approaches.

Objective: This manuscript aims to review: 1) the use of neuronavigation in endoscopic neurosurgery for pre-operative planning, 2) the intraoperative advantages of neuronavigation in endoscopic neurosurgery, and 3) the effects of navigation guidance on operative time, registration accuracy, brain shift, and avoidance of complications. Limitations of the current neuroendoscopic navigation literature will be discussed.

Methods: We conducted a search using PubMed-MEDLINE; the keywords "stereotactic navigation AND endoscopic surgery" and "simulation AND endoscopic neurosurgery." 36 studies were identified that addressed the use of neuronavigation in endoscopic neurosurgery. These studies were then further analyzed for topics relevant to computerized neuroendoscopy and reviewed for the purposes of this article.

Conclusion: Three-dimensional, frameless neuronavigation systems are useful in endoscopic neurosurgery to assist in the pre-operative planning of potential trajectories and to help localize the pathology of interest. Neuronavigation appears to be accurate to <1–2 mm without issues related to brain shift. Further work is necessary in the investigation of the effect of neuronavigation on operative time, cost, and patient-centered outcomes.

1. Introduction

A recurrent problem faced by endoscopic neurosurgeons is the ability to visualize and predict the location of important anatomic structures in a relatively small working environment. In endoscopic trans-sphenoidal surgery of the pituitary gland, the ability to predict the location of the carotid artery behind the sphenoid bone is paramount to prevent accidental vascular injury. In re-operative cases, normal anatomy can be distorted and the risk of iatrogenic complications can significantly increase [1]. To address these potential pitfalls, endoscopic neurosurgeons have increasingly relied on computerized navigation devices to guide their surgical approaches. There are several navigation systems currently available on the market such as the Brainlab Curve (AG, Feldkirchen, Germany) and Medtronic StealthStation S7 (Medtronic, Minneapolis, MN) [2]. This manuscript aims to review the use of three-dimensional (3D) computerized neuronavigation systems in endoscopic neurosurgery for pre-operative planning and several of its key intraoperative advantages through discussion of an illustrative case of odontoidectomy with intraoperative neuronavigation. In addition, the effects of navigation guidance in regards to operative time, registration accuracy, brain shift, and complications will be discussed. Finally, the limitations of the current neuronavigation in neuroendoscopy literature will be discussed.

1.1. Illustrative case: navigation guidance in endoscopic odontoidectomy

Navigation guidance has been utilized in endoscopic odontoidectomy [3–5]. We report the case of a 49-year-old woman who initially presented complaining of severe frontal tussive headaches accompanied by imbalance, dizziness, nausea, and perioral and lingual numbness for the previous seven months. At the time, the patient's exam was normal with the exception of bilateral fine beating nystagmus noted upon sustained horizontal gaze. MRI of the brain and cervical spine revealed a type I Chiari malformation with downward tonsilar displacement of 12 mm, no associated syrinx, and right-sided foraminal stenosis secondary to bulging discs at the cervical level (C) 3/4 and C 4/5 (Fig. 1). Given the unremitting symptomatology with medical therapy, the patient underwent a decompressive suboccipital craniectomy and laminectomy of C1 with an uneventful post-operative course.

Abbreviations: Three-dimensional, 3D; cervical level, C.

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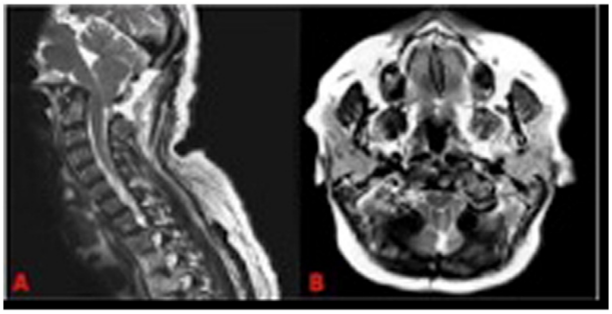

Fig. 1. Pre-operative MRI of the brain and cervical spine. (A) Pre-operative sagittal and axial T2-weighted magnetic resonance imaging scans demonstrating a Type I Chiari Malformation with associated basilar invagination. (B) There is ventral and dorsal medullary compression by the odontoid process and cerebellar tonsils, respectively.

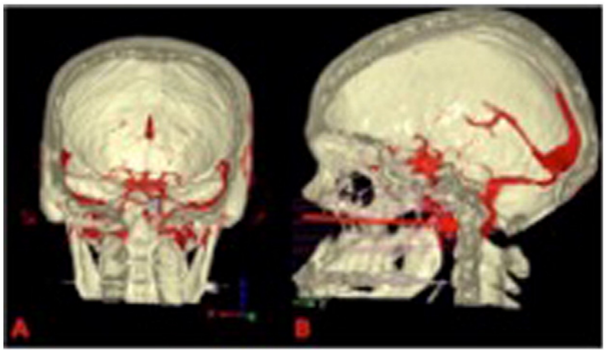

Fig. 3. Pre-operative surgical planning using 3D reconstructions rendered by Surgical Theatre™ (Surgical Theatre, LLC, Mayfield Village, OH). (A) In this coronal view, the vertebrobasilar junction is seen in relation to the clivus (blue asterisk). (B) In this sagittal view, multiple trans-nasal trajectories are projected. The final intraoperative trajectory is displayed (red arrow).

Six weeks post-operatively, the patient presented with a recurrence of the tussive frontal headache exacerbated with flexion of the head, neck pain with radiation to the shoulders bilaterally, dizziness, imbalance, dysmetria, ataxia, paresthesias of the upper and lower extremities, and difficulty with ambulation and dexterity. Physical examination revealed a wide-based gait with the inability to toe or heel walk or maintain a tandem gait, diffuse weakness and hyperactive reflexes throughout, and diminished sensation following a stocking glove distribution. As shown in Fig. 1, MRI of the brain and cervical spine revealed a ventral cervicomedullary junction deformity, an acute angle between the dens and the clivus, and stable cerebellar ectopia. Due to the interval development of symptoms suggestive of cervical myelopathy and findings on MRI, the patient underwent a staged endoscopic transnasal odontoidectomy followed by occipitocervical fusion. The interval development of symptomatic atlanto-axial instability was likely exacerbated by the initial decompression. However, it is unclear if the patient had pre-existing instability before surgery. Unfortunately, pre-operative flexion/extension imaging of the cervical spine was not available.

As demonstrated in Figs. 2–4, stereotactic neuronavigation (Brainlab AG, Feldkirchen, Germany and Surgical Theatre, LLC, Mayfield Village, OH) was essential in the determination of the operative approach (transnasal versus transoral), and navigation was used throughout the case with excellent accuracy. Based on the results of imaging, a transnasal entry point was selected instead of a trans-oral approach. The reason was due to a tortuous left carotid artery that was directly anterior to the C2 vertebral body. A trans-oral approach may have increased the risk of accidental carotid injury given the angle of approach; therefore a slightly more superior trajectory angle was selected (trans-nasal). An extradural odontoid, C1 process, and basilar invagination resection was performed using a transclival C1 approach. Following drilling of the inferior clivus, the underlying tectorial membrane and dura were identified. The anterior tubercle of C1 was drilled until the identification of C2, and the angulation of C2 was shaped to an anterior angulation. The odontoid process was drilled using an eggshell technique. A 30-degree endoscope in combination with intraoperative navigation was used to identify decompression of the spinal cord, as pictured in Fig. 5. Occipitocervical fusion occurred 4 days post-operatively, as demonstrated in Fig. 6, and the patient was discharged after an uneventful post-operative course 8 days following the first operation. The patient's post-operative course remained unremarkable and her myelopathic symptoms steadily improved.

In this case study, stereotactic neuronavigation was crucial for pre-operative trajectory planning (transnasal versus transoral) and intraoperative navigation. This patient experienced no adverse events and improved post-operatively. This informative case adds to the growing literature in navigation-assisted endoscopic odontoidectomy, demonstrating the safe and effective use of neuronavigation for pre-operative planning and intraoperative navigation in endoscopic odontoidectomy.

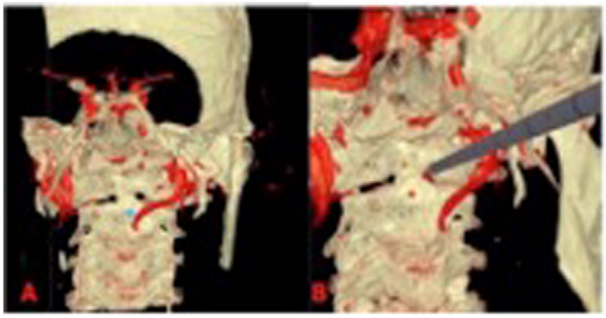

Fig. 2. 3D-reconstructed pre-operative images displayed by the Surgical Theatre™ planning station (Surgical Theatre, LLC, Mayfield Village, OH). (A) (blue asterisk) A tortuous left internal carotid artery is seen directly anterior to the C2 vertebral body and odontoid process. (B) A stereotactic registration wand was used to plan the surgical approach (maroon asterisk). Based on this imaging, a trans-nasal approach was selected given the location of the left internal carotid artery.

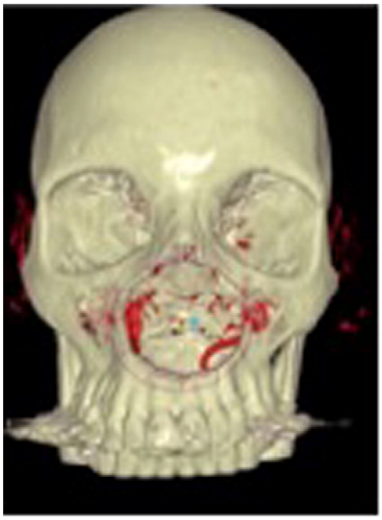

Fig. 4. 3D-reconstructed coronal view demonstrating a "probe's eye" view through the nasal septum. The anterior face of C1-2 is seen in the center of the circle (blue asterisk).