QUANTITATIVE ANALYSIS AND COMPUTER AIDED SIMULATION OF MINIMALLY INVASIVE APPROACHES FOR INTRACRANIAL VASCULAR LESIONS

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1. Project Summary

The main goal of this project has been to establish and characterize the minimally invasive surgical procedures, mainly extended endoscopic endonasal (EE) techniques, that could be used for the treatment of intracranial vascular lesions.

We identified three main extended EE routes to access lesions of the cerebral vasculature, comprising the surgical approaches known as: 1) transcribriform, 2) transtuberculum / transplanum, and 3) transclival / craniovertebral junction.

Surgical exposure provided by these three approaches, each related to different vascular territories, has been evaluated and analyzed with image-guided neuronavigation systems, according to preoperative CT-angiography and brain MRI studies. A postoperative CT study has been acquired to reconstruct and quantify each approach. We implemented a very versatile system based on the use of 3D-pdf documents, which allows the preparation of virtual presentations to simulate neurosurgical approaches to the skull base.

2. Results

The project objectives have been accomplished as planned. Our group has characterized the 3 anatomical and surgical corridors that grant access to the anterior and posterior brain arterial circulation, using advanced microdissection techniques guided by neuronavigation, and specific medical visualization and computer simulation systems. The surgical procedures have been thoroughly designed to permit exhaustive quantification.

The main results of the study were as follows:

1- Our group established through anatomical simulation that it is possible to use extended EE approaches to access certain aneurysms located in the anterior and posterior cerebral circulation. A) using a transcribriform route, the surgeon can expose the anterior cerebral (A2 segment), frontopolar, orbital and pericallosal arteries; B) with a transtuberculum-transplanum approach it is possible to access specific lesions

located in the anterior cerebral, ophthalmic, superior and inferior hypophysial, posterior cerebral (P1 segment), posterior communicating and distal segment of the basilar arteries; and C) the transclival/craniovertebral junction approach can be used to establish access to the posterior circulation, and specifically to the basilar, proximal superior cerebellar, anterior inferior cerebellar, posterior inferior cerebellar, vertebral, vertebrobasilar junction and anterior spinal arteries.

2- We established a new classification, on an anatomical, clinical and surgical basis, for the trochlear nerve segments. The new classification permits to accurately describe the anatomical relations of the trochlear nerve, comparing the endoscopic and the conventional microscopic transcranial views.

3- We conducted a retrospective analysis of the treatment of intracranial aneurysms with a ventral approach, comparing the results and complications between the traditional and the most recent extended EE approaches. The latter may represent a surgical procedure of choice in certain cases and in specialized centers, when endovascular techniques are not indicated.

4- Our laboratory developed a new methodology to quantify the working area and surgical freedom in EE approaches, combining neuronavigation and image post-processing. The new methodology established, with quantitative methods, the effect of the progressive resection of nasal structures on the EE suprasellar corridor, achieving the best results with a monolateral turbinectomy.

5- By means of anatomical simulation and 3D modeling techniques, we have found that the transclival expanded EE approach with a previous petrosectomy and medial condylectomy allows access to the anterolateral surface of the brainstem and posterior cranial fossa, through safe corridors around the main neurovascular elements.

6- We have described a new procedure that provides a temporary occlusion of the internal carotid artery with the EE placement of a Fogarty catheter for intraoperative control. This type of control may be useful in the neurosurgical treatment of numerous vascular and tumor diseases.

7- We developed an innovative methodology of brain microdissection guided by neuronavigation, using high field MR imaging (7 Tesla). This allows the neurosurgeons to open new lines for planning safe routes to the core regions of the brain, which are potential locations of vascular malformations and other pathologies, as well to other regions that are difficult to reach, such as the cavernous sinus.

8- Our group described the most advanced neuroimaging techniques currently available for the visualization of the auditory pathways. The use of ex-vivo 7T MR imaging grants greater resolution to analyze this pathways in the brainstem. This study is prior to the description of secure corridors to the brainstem and spinal cord, using minimally invasive procedures.

9- Finally, we have published the procedure for the simulation of the 3 EE approaches analyzed, using virtual reality systems, including planning, quantification and anatomical validation in our laboratory. In this field, we implemented a system based on the creation of 3D-pdf documents allowing for: a) the visualization and interaction with complex anatomical models of the skull base; b) embedding sectional images of any type, including those from DICOM images; c) preparing presentations for the simulation of neurosurgical approaches; and d) easy distribution as the system only requires Adobe Reader® software. The versatility of the system has been proven to generate documents for educational and research purposes in related areas, such as the simulation of anesthetic approaches to the spine.

3. Relevance and implications

The anatomical simulation and computer simulation models developed in this study to analyze different approaches to intracranial vascular lesions using EE techniques may have great potential as translational research:

- In accordance with our results, an extended EE transclival approach was employed for the first time for the treatment of a small aneurysm located at the origin of the posterior inferior cerebellar artery in the Clinic Hospital. The procedure was performed successfully by three members of our research team. Ultimately, approaches of this type represent a real therapeutic alternative for some intracranial vascular lesions.

- It has been established that the placement of a Fogarty catheter through an EE approach, as described in our recent cadaver study, has been easily replicated in two patients, opening up new possibilities for the internal carotid artery control, in interventions that require it.

- The system developed to generate 3D-pdf documents has proved its value to inform patients about the type of treatment they will undergo. Given its open design, the use of such documents in different fields related to teaching and training is expected, the system having already been incorporated into academic courses (graduate, postgraduate and doctoral programs and virtual presentations at conferences).

- Finally, the results achieved by our group open multiple research lines related to planning new safer surgical corridors, through the development of specific procedures for quantifying such procedures, simulation with virtual systems and incorporation of microdissection techniques guided by neuronavigation with high field MRI (7T) in neurosurgical studies.

4. Publications generated by the project

Iaconetta G, de Notaris M, Benet A, Rincon J, Cavallo LM, Prats-Galino A, Samii M, Cappabianca P. The trochlear nerve: microanatomic and endoscopic study. Neurosurg Rev. 2013; 36(2):227-37; discussion 237-8. doi: 10.1007/s10143-012-0426-x.

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Prats-Galino A, Mavar M, Reina MA, Puigdellívol-Sánchez A, San-Molina J, De Andrés JA. Three-dimensional interactive model of lumbar spinal structures. Anaesthesia. 2014;69(5):521 (letter to the editor). doi: 10.1111/anae.12690.

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de Notaris M, Palma K, Serra L, Enseñat J, Alobid I, Poblete J, Gonzalez JB, Solari D, Ferrer E, Prats-Galino A. A three-dimensional computer-based perspective of the skull base. World Neurosurg. 2014;82(6Suppl):S41-8. doi: 10.1016/ j.wneu.2014.07.024.

Ruggeri A, Enseñat J, Prats-Galino A, Lopez-Rueda A, Berenguer J, Cappelletti M, De Notaris M, d'Avella E. Endoscopic endonasal control of the paraclival internal carotid artery by Fogarty balloon catheter inflation. Anatomic study. J Neurosurg [Epub ahead of print].

3D-pdf documents generated for self-learning and continuing education in public repositories

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