New endoscopic route to the temporal horn of the lateral ventricle: surgical simulation and morphometric assessment

Laboratory investigation

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Object. The temporal horn of the lateral ventricle is a complex structure affected by specific pathological conditions. Current approaches to the temporal horn involve a certain amount of corticotomy and white matter disruption. Surgeons therefore set aside anterior temporal lobectomy as a last resource and avoid it in the dominant hemisphere. The authors propose a minimally invasive endoscopic intraventricular approach to the temporal horn and describe a standardized analysis and technical assessment of the feasibility of this approach.

Methods. To determine the best trajectory, angulation, and entry point to the temporal horn of the lateral ventricle, the authors evaluated 50 cranial MRI studies (100 temporal lobes) from healthy patients. They studied and systematized the neurosurgical endoscopic anatomy. They also simulated the proposed approach in 9 cadaveric specimens (18 approaches).

Results. Mean scalp entry point coordinates (± SD) were 2.7 ± 0.28 cm lateral to the inion and 5.6 ± 0.41 cm superior to the inion. The mean total distance from the uncal recess to the scalp (± SD) was 10.64 ± 0.6 cm. The mean total intraparenchymal distance crossed by the endoscope was 3.76 ± 0.36 cm. The approach was successfully completed in all studied specimens.

Conclusions. In this study, the endoscopic intraventricular approach to the temporal horn is standardized. The morphometric analysis makes this approach anatomically feasible and replicable. This approach provides minimally invasive endoscopic access to the uncal recess, amygdala, hippocampus, fornix, and paraventricular temporal lobe structures. The following essential strategies enabled access to and maneuverability inside the temporal horn: tailored preoperative planning of the trajectory and use of anatomical and radiological references, constant irrigation, and an angled endoscopic lens. Safety assessment and novel instruments and techniques may be proposed to advance this very promising route to pathological changes in the temporal lobe.

Key Words • minimally invasive neurosurgery • ventricular temporal horn • endoscopic anatomy • intraventricular approach • surgical technique

In the field of neurosurgery, endoscopy of the cerebral ventricular system to treat pathological conditions is considered a minimally invasive technique. 5 Endoscopic procedures for the frontal horn of the lateral ventricles and the third ventricle have been widely studied and assessed. 3 However, endoscopic access to the temporal horn has been continuously underestimated and remains undefined.

The temporal horn of the lateral ventricle is a complex neuroanatomical structure affected by several neurosurgical pathological conditions. In past decades, multiple neurosurgical approaches to treat disease in the temporal horn of the lateral ventricle have been described. All these procedures, ranging from extensive temporal lobectomies to less invasive disconnections, share different degrees of cortical and white matter disruption near eloquent areas. 2,4,8,9,11,13,16 This drawback has limited the use of temporal approaches to resistant or late-stage pathological conditions after the function of the temporomesial structures is already impaired. In addition, lateral approaches to the temporal horn to treat pathological conditions affecting the dominant hemisphere are avoided.

Few articles about temporal horn endoscopic procedures have been reported. In 1995, Silbergeld et al. 15 reported a preliminary study about endoscopic navigation along the temporal horn axis. It was not until 2012 that
Bahuleyan et al. resumed temporal horn endoscopic navigation, mainly oriented toward epilepsy resection procedures. However, the literature lacks standardized analyses of the feasibility of this approach and thorough technical assessments of the endoscopic approach to the temporal horn.\(^1\)

The natural corridor offered by the ventricular system determines the optimal endoscopic minimally invasive access to the entire temporal horn. The temporal horn has a longitudinal conformation in its rostrocaudal axis. Thus, we believe that optimal endoscopic access to the temporal horn together with maximal maneuverability could be achieved in a longitudinal axis trajectory.

We studied the features of an optimal endoscopic route for accessing the temporal horn of the lateral ventricle that avoids functional impairment of eloquent areas. To this purpose, we identified the entry point coordinates and the intraparenchymal trajectory distances and angulations that determine an optimal endoscopic trajectory. Moreover, to assess its feasibility and reproducibility, we simulated this procedure in a cadaveric model.

Methods

To assess the morphometric features of the approach, we divided the study into 2 parts. First, we analyzed cranial MR images of healthy adults. Then, after we defined the optimal endoscopic trajectory, we simulated the approach in embalmed cadaveric specimens and systematized the endoscopic neuurosurgical anatomy.

Radiological Assessment

We obtained and anonymized 50 cranial MR images (100 temporal lobes) without evidence of intracranial disease from the database of the Department of Radiology at the Hospital Clinic of Barcelona, Spain. T1-weighted 3D gradient-echo sequences were processed by using OsirIX imaging software. These radiological studies were used to characterize the endoscopic surgical trajectory. We measured scalp entry point coordinates, bone entry point coordinates, trajectory angulations, and distances.

Entry Point Coordinates. The scalp entry point was defined as the scalp intersection with the posterior projection of the longitudinal axis of the temporal horn (surgical trajectory). To define the scalp entry point, we identified x-axis and y-axis coordinates. The coordinates were referenced to the external occipital protuberance (inion), which is the most reliable surface landmark of this region. The first coordinate (x) was defined as the horizontal distance between orthogonal projections of the inion and the entry point into the same axial plane. The second coordinate (y) was defined as the vertical distance between orthogonal projections of the inion and the entry point into the same sagittal plane (Figs. 1 and 2A and B).

Trajectory Angulations. To characterize the endoscopic trajectory direction, we measured 2 angulations. We used the middle sagittal plane to define horizontal angulation and the orbitomeatal plane to define vertical angulation of the approach. We chose these orthogonal planes because of the ease of their superficial identification in the operative setting and radiological imaging (Fig. 2C and D).

Trajectory Distances. As primary distances, we measured the distance from the uncus recess to the atrium, the distance from the atrium to the cortex, the bone thickness, and the scalp thickness. As secondary distances, we calculated the distance from the uncus recess to the outer table of the bone and the distance from the uncus recess to the scalp entry point (Fig. 2E).

After the study variables were measured, all data were compiled onto a spreadsheet. Statistical descriptive, calculation, and comparative reports were created by using SPSS version 21.0. (IBM Corp.).

Surgical Simulation and Endoscopic Anatomy

The pilot project was conducted at the Laboratory of Surgical Neuroanatomy, Faculty of Medicine, Universitat de Barcelona. Endoscopic anatomy assessment and surgical simulation were further developed at the Skull Base and Cerebrovascular Laboratory, University of California, San Francisco.

For this study, we used 9 embalmed human cadaveric heads. Of these, 2 heads (4 temporal lobes) were used to study the temporal horn macroscopically, and 7 (14 temporal lobes) were injected with colored silicone to ease visual identification of vessels and used for surgical simulation. A high-resolution CT scan was obtained for each cadaveric head. T1- and T2-weighted 3D gradient-echo MR images were acquired for 2 heads. To aid surgical simulations, we uploaded these images to a neuronavigation system (Stryker NAV 3). Trajectory was planned by using iNtellect Cranial Neuronavigation software version 1.1 (Stryker Leibinger GmbH & Co. KG).

To study the temporal horn morphology and anatomy, we first macroscopically dissected 2 cadaveric heads (4 temporal lobes). The middle temporal gyrus was removed, and the atrium and entire temporal horn were...
Fig. 2. Trajectory assessment. T1-weighted MRI studies processed with a 3D multiplanar rendering module of OsiriX to adjust the image to the temporal horn and to measure endoscopic approach entry point coordinates, trajectory angulations, and distances of the trajectory segments. **A:** Measure of the horizontal entry point coordinate (X). **B:** Measure of the vertical entry point coordinate (Y). **C:** Measure of the trajectory angulation to the middle sagittal plane. **D:** Measure of the trajectory angulation to the orbitomeatal plane. **E:** Length of the trajectory-defined segments. * = trajectory line; *' = middle sagittal plane; AC = trajectory distance from atrium to cortex (intraparenchymal distance); BT = bone thickness; MSPA = middle sagittal plane angle; OMA = orbitomeatal angle; OMP = orbitomeatal plane; p* = projected trajectory; p" = projected middle sagittal plane; plion = projected inion; pSEP = projected scalp entry point; SEP = scalp entry point; ST = scalp thickness; UA = trajectory distance from uncal recess to atrium.
exposed and studied. Preliminary endoscopic navigation was performed through the temporal horn of these specimens by using a 0° rigid endoscope (Stryker Endoscopy high-definition 1488 camera).

Last, we simulated the defined approach in the 7 injected cadaveric heads. We registered each head for neuronavigation by using a facial mask. After checking accuracy, we marked the external occipital protuberance and scalp entry point coordinates with the neuronavigation probe. We made a 3-cm incision over the scalp entry point. A 10-mm bur hole (core Sumex drill; Stryker) was centered to the bone entry point. A 10-mm bur hole (core Sumex drill; Stryker) was centered to the bone entry point. Meningeal layers were opened to expose the cortical surface. Rigid endoscopes (0° and 30°), equipped with an irrigation sheath and coupled to a Stryker 1488 high-definition camera, were referenced as neuronavigation tools. Endoscopes were introduced through the white matter until they reached the ventricular system at the atrium. During intraventricular navigation, illumination was obtained from a xenon light source. Constant pressure irrigation through the endoscope sheath was produced by a Stryker FloSteady pump. The temporal horn was completely navigated, and the endoscopic ventricular anatomy was explored. Anatomical landmarks were defined and the neurosurgical endoscopic anatomy was systematized. The procedures were recorded with the Stryker SDC Ultra high-definition recording system.

Mean values are presented ± SD.

**Results**

**Trajectory Morphometric Results**

Mean scalp entry point coordinates were 2.74 ± 0.28 cm lateral and 5.65 ± 0.41 cm superior to the inion. From this scalp entry point, the mean trajectory angulations were 5.12 ± 0.68 degrees to the middle sagittal plane and 30.92 ± 2.57 degrees to the orbitomeatal plane.

The intraventricular total mean distance (from the uncal recess to the atrium) was 5.47 ± 0.55 cm. The mean total distance from the uncal recess to the scalp was 10.64 ± 0.6 cm, which defined the maximum endoscope length needed. The mean total intraparenchymal distance (from atrium to cortex) was 3.76 ± 0.36 cm, which represented the possible cortical and white matter transgression segment.

Table 1 summarizes the descriptive statistical information for all variables. A comparison of left and right temporal horn measures revealed no significant differences for all variables (independent samples t-test, *p* < 0.05) (Table 2).

**Endoscopic Anatomy and Surgical Simulation**

Macroscopic dissection of the temporal horn enabled us to identify the longitudinal axis of the temporal horn and to test the preliminary endoscopic navigation inside this cavity (Fig. 3). The approach was successfully completed in all studied specimens. Referencing the endoscope as a neuronavigation tool enabled us to reach the ventricle in all specimens. Specifically, this setting enabled us to accurately and precisely locate the entry points and to maintain trajectory angulations during the cadaveric simulations.

Constant irrigation expanded the ventricles and displaced the choroid plexus medially. These maneuvers enabled us to navigate through the temporal horn and to explore intraventricular anatomical structures. Compared with the 0° endoscope, the 30° endoscope provided a better view of the atrium, the vessels of the choroid fissure, and the medial aspect of the uncal recess.

After several approach simulations, we systematized the endoscopic anatomy into 3 regions that generated critical endoscopic landmarks for safe maneuvering during the surgical procedure. These anatomical landmarks have been described in the literature and were consistently observed and validated during all endoscopic surgical simulations conducted in the laboratory. The following endoscopic segments were defined: the atrium, the body of the temporal horn and the uncal recess.

### Table 1: Descriptive statistics of the study sample*

<table>
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<th>Variable</th>
<th>No. of Lobes</th>
<th>Range</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>SD</th>
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<td>0.683677</td>
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<tr>
<td>OMA (°)</td>
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<td>25.180</td>
<td>36.261</td>
<td>30.92060</td>
<td>2.572017</td>
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<td>ST (cm)</td>
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</table>

* AC = trajectory distance from the atrium to the cortex (intraparenchymal distance); BT = bone thickness; MSPA = trajectory angle to the middle sagittal plane; OMA = trajectory angle to the orbitomeatal plane; SD = standard deviation; ST = scalp thickness; TotalD = total distance from the atrium to the scalp entry point; UA = trajectory distance from the uncal recess to the atrium; X = coordinate of the scalp entry point lateral distance to the inion; Y = coordinate of the scalp entry point superior to the inion.
In the atrium, we recognized its medial wall with the corpus callosum impression superiorly and calcar avis inferiorly. In the anterior wall of the atrium, we identified the entrance to the body of the lateral ventricle superiorly (we defined this endoscopic landmark as the frontal ostium), the temporal ostium inferiorly, and the choroid plexus between them. During this step, retraction of the choroid plexus provided access to the fornix, the fimbrial-plexus, the fornical joint, and the hippocampus tail. In the floor of the atrium, we observed the collateral trigonus, which becomes the collateral emience beyond the temporal ostium (Fig. 4A and B).

In the body of the temporal horn, we identified the collateral emience as its floor. Medially, the hippocampus sulcus was the natural boundary between the floor and the medial wall. In the medial wall, we observed the choroid fissure and plexus, the fimbria, and the hippocampus body. In the lateral wall and the roof, we identified a smooth layer of ependyma (Fig. 4C and D).

In the uncal recess, we identified the anterior aspect of the collateral emience inferiorly and the amygdaline nucleus impression anteriorly. Medially, we recognized the hippocampal head with its digitations. The lateral wall and the roof were also a layer of ependyma (Fig. 4E and F).

**Discussion**

This study shows that our proposed approach is feasible and reliable for minimally invasive access to the temporal horn. In all surgical simulation experiments, we successfully navigated the temporal horn. The morphometric data of the trajectory obtained in this study enabled us to standardize the approach, thereby making it replicable. Furthermore, we found that there is only one unique valid endoscopic approach to navigate the entire temporal horn.

Despite previous cadaveric studies of intraventricular temporal horn endoscopic procedures, to our knowledge, a full assessment of the approach to the temporal horn is lacking in the literature. In 1995, Silbergeld et al. reported temporal horn navigation by use of a flexible endoscope from undefined parietal and occipital entry points. Seventeen years after this publication, Bahuleyan et al. reported a cadaveric endoscopic study of an occipital approach to the ventricular temporal horn. They defined this technique as an endoscopic intraventricular amygdalohippocampectomy. This resective technique is conducted through nitrogen-powered microshavers (NICO Myriad). We found several drawbacks in this technique...
that would need further revision. First, Kocher’s point (precoronal frontal entry point) is used to access the temporal horn. This is not congruent with the description of the well-known ventricular access points. Kocher’s point provides access to the frontal horn of the lateral ventricles; in our experience, the temporal horn is not safely accessible from this surface landmark.\(^7,10\) Second, Bahu-leyan et al. do not define the features of the approach, which makes it not reproducible in the laboratory setting. Last, we consider that big resective procedures, such as amygdalohippocampectomy, are technically challenging in such a narrow cavity as the temporal horn. The delivery of those resected structures outside the ventricle can be challenging and can cause uncontrolled bleeding and field obstruction. Therefore, new minimally invasive techniques should be studied and novel instruments developed to advance the very promising route to temporal lobe pathology that we assessed.

Although there are different surface points for intraventricular access, none is appropriate for the endoscopic temporal horn approach. The entry point for the proposed approach is similar to the classic occipital-parietal point. The occipital-parietal point, which is typically placed 6 cm superior to the inion and 4 cm lateral to the sagittal plane, is slightly more superior and lateral than our defined entry point. Although both points are used to enter the atrium, the occipital-parietal point is used to access the frontal ostium, whereas the point we describe is used to access the temporal ostium. Furthermore, the longitudinal axis of the temporal horn conditioned an inferior-lateral trajectory, which required different angulations than those proposed for the classic technique.\(^7\)

The distances obtained in the radiological assessment enabled us to characterize different features in association with the specific devices used. The total distance of the trajectory provided references to determine the minimum length of the instruments needed to reach any structure inside the temporal horn. Considering the maximum value of the total length of the trajectory in our sample, an endoscope 12 cm or longer would achieve this objective. The intraparenchymal segment (distance from the cortex to the atrium) determined the safety margin when introducing the endoscope through the brain parenchyma. Our studies showed that the atrium should be reached in fewer than 5 cm from the cortex and that failure to do so should indicate a wrong trajectory. Minimal deviations could result in transgression of the surrounding white matter.

With this anatomical study, we standardized 3 seg-
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**Fig. 4.** Endoscopic anatomy. Views (0° and 30° are the green and red avatars, respectively) of endoscopic intraventricular navigation procedure in the left temporal horn.  
A: Atrium view with 0° endoscopic device.  
B: Atrium view with 30° endoscopic device.  
C: Body of the temporal horn view with 0° endoscopic device.  
D: Body of the temporal horn view with 30° endoscopic device.  
E: Uncal recess view with 0° endoscopic device.  
F: Uncal recess view with 30° endoscopic device.  
Amgi = amygdaline nucleus impression; B = bottom; bHi = body of the hippocampus; cav = calcar avis; cci = corpus callosum impression; ce = collateral eminence; chf = choroidal fissure; clt = collateral trigonus; cplv = choroid plexus of the lateral ventricle; fi = fimbria; FO = frontal ostium; hHi = head of the hippocampus; His = hippocampus sulcus; L = left; LW = lateral wall; OLV = occipital horn of the lateral ventricle; plcha = posterior–lateral choroidal arteries; R = right; Rf = roof of the ventricle; T = top; TH = temporal horn; tHi = tail of the hippocampus; TO = temporal ostium; UR = uncal recess.
ments encountered during the endoscopic intraventricular navigation. Most of the defined anatomical landmarks have neurophysiological functions that will be useful for designing future applications of the technique and for avoiding possible neurological injuries. The different intraventricular parts of the hippocampus, the fimbria, and the amygdaline nucleus are highly functioning structures of the limbic system. They play critical roles in the consolidation of information and human behavior, but the main physiopathological application of the described approach is probably their relation with temporal mesial lobe epilepsy. The collateral eminence and the collateral trigonus are the intraventricular impressions of the collateral sulcus. These anatomical landmarks are also relevant to epilepsy applications of the approach because the connections of the mesial temporal lobe cortical structures (parahippocampal and entorhinal cortex) with the neocortex of the temporal lobe run below them. Connections between the hippocampus and the amygdaline nucleus run below the anterior aspect of the collateral eminence at the region of the uncal recess. The calcar avis is the intraventricular impression of the calcaneous sulcus and should be respected to prevent injury to connections of the primary visual cortex. Last, the choroidal fissure and plexus must be taken into account to avoid vascular injury.

Through the surgical simulation we were able to standardize the main surgical steps of the technique. However, as Shimizu et al. reported in 2004, occipital ventricular catheterization without guidance leads to a high rate of error. In addition, Lind et al. reported in 2008 that occipital ventricular catheterization has a lower margin of error than the frontal and parietal trajectories. These findings are in accordance with our experience. Therefore, we recommend tailored preoperative planning of the trajectory and use of anatomical and radiological references and external surgical helpers during the procedure.

In our experiments, neuronavigation was critical for defining the optimal trajectory for each specimen and for entering the ventricle after the predefined trajectory in all cases. When using the endoscope as a navigation-calibrated tool, we could move the tip of the endoscope through the planned trajectory. Doing so provided a very precise and accurate method for entering the ventricle and prevented trajectory deviation that could result in unnecessary white matter transgression or missing of the target. Other external helpers (for example, stereotactic frames or external endoscope holders) should be considered to improve surgical success.

Irrigation was crucial for success during the procedure simulation. The constant-pressure pump enabled us to achieve displacement of the choroid plexus and to maintain the expansion of the ventricular temporal horn. Irrigation was also useful for maintaining a clean surgical field. We considered irrigation to be an essential part of the surgical technique.

During the procedure simulation, a 30° endoscopic lens contributed to better exploration of the temporal horn. Endoscopic anatomy explored with the 0° endoscope did not differ from that reported by Bahuleyan et al. However, the 30° endoscope enabled us to see behind the corners, which exposed anatomical structures not visible with the 0° scope. The specific structures that were better assessed with this angulated lens were the uncal recess and the superior region of the atrium, including the frontal ostium.

As a limitation of the study, the differences between cadaveric specimens and living humans should be considered. Above all, bleeding is the most challenging condition because it could completely block the endoscopic view, which would necessitate ending the procedure prematurely. Moreover, high rates of morbidity or mortality could result from uncontrollable intraventricular bleeding. However, those limitations have been widely studied and overcome in the classical endoscopic intraventricular approaches. Hence, further studies are needed to assess the effects of unexpected bleeding and its prevention during the intraventricular approach to the temporal horn.

We propose a wide range of potential applications of this technique. The main pathological conditions that could be treated by this endoscopic approach are mesial temporal lobe epilepsy, intraventricular tumors, and CSF disorders affecting the temporal horn. Endoscopic surgical anatomy applied to these different endoscopic procedures will need to be addressed by future studies. In addition, design and development of customized instruments, in association with different temporal ventricular-associated pathological conditions, will be needed.

We consider that dissection and resection instruments that avoid inadvertent vascular injury will be essential. Also, to avoid injuries to the neural tissue surrounding the area of coagulation, we will need adapted high-precision bipolar coagulators with minimal heat diffusion. In addition, flexible or angulated endoscopic lenses could probably make the procedure easier to perform and also permit a better field of view during the procedure. Flexible endoscopes are fiberscopes that can adjust their curvature to the ventricular anatomy, but they have limitations; they have low resolution and brightness, and they are difficult to clean because they cannot be autoclaved. Probably new chip-in-the-tip flexible endoscopes can overcome these limitations. Moreover, most pathological substrates within the temporal horn are non-linearly oriented with the endoscopic trajectory defined in this article. Therefore, flexible or angulated endoscopes alone will not be enough for performing precise surgical maneuvers within spaces lateral to the trajectory main axis. For this reason, to increase surgical precision when performing this procedure, we consider it crucial to combine the use of angulated scopes and flexible working channels and instrumentation.

Safety and eloquence in relation to the neural tissues transgressed by the approach will require further study. In 2003, Song et al. described endoscope-assisted temporal intraventricular placement of an electrode as a preoperative study of 8 patients with temporal mesial epilepsy. Although the trajectory used was not defined, they reported no complications during the procedure and no postoperative neurological injury. In our study, we aimed to describe the trajectory with precision to set the standard for future studies of safety with regard to potential production of cortical and subcortical damage during the parenchymal segment of the approach. Therefore, de-
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spite our good results, further studies are needed before implementation of this technique in the neurosurgical clinical setting.

Conclusions

We consider that the endoscopic intraventricular temporal horn approach that we assessed is feasible and reliable. Different pathological conditions that affect the temporal mesial lobe could be treated by using this surgical route. For successful application to the treatment of neurosurgical pathological conditions of the temporal horn, technological support and development are mandatory. However, different studies, including a thorough assessment of eloquence, surgical applications, and experimental trials should be conducted before this technique is applied in the clinical setting.

Disclosure

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Author contributions to the study and manuscript preparation include the following. Conception and design: González Sánchez, Benet. Acquisition of data: González Sánchez, Rincon-Torrellas, Benet. Analysis and interpretation of data: González Sánchez, Rincon-Torrellas, Benet. Drafting the article: González Sánchez, Rincon-Torrellas, Benet. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: González Sánchez. Statistical analysis: González Sánchez. Administrative/technical/material support: González Sánchez, Rincon-Torrellas, Prats-Galino, Berenguer, Benet. Study supervision: González Sánchez, Prats-Galino, Benet.

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