White Matter Topographic Anatomy Applied to Temporal Lobe Surgery

Ana Flores-Justa[1,2], Matias Baldoncini[2,3], Julio C. Pérez Cruz[4], Federico Sánchez Gonzalez[5,6], Oscar A. Martínez[7], Pablo González-López[8], Álvaro Campero[9]

■ BACKGROUND: **The temporal lobe is an important and complex anatomic region of the brain. Accurate knowledge of anatomic relationships becomes extremely relevant when deciding surgical strategy, such as epilepsy or oncologic surgery, involving this lobe. To our knowledge, there is no strong literature highlighting the relationship between white matter tracts and craniometric landmarks applied to temporal lobe surgery. We aim to describe the topographic relationship between the craniometric points and white matter tracts of the temporal lobe through dissection of cadaveric specimens and describe the potential preoperative usefulness of diffusion tensor imaging in relation to the anatomic features found during the dissections.**

■ METHODS: **Fifteen formalin-fixed whole cadaveric heads were dissected by the Klingler technique in a stepwise manner across the temporal and sphenoid bone windows. The white matter pathways were identified in their different planes and their position was described in relation to craniometric landmarks. Diffusion tensor studies were performed in 2 healthy volunteers to analyze the temporal fasciculi in vivo.**

■ RESULTS: **We identified the topographic relationships between craniometric points and relevant association tracts that lie within the cranial corridors (superior and inferior frontal, parietal, occipital, sphenoidal, and temporal). Important landmarks were defined in correspondence to these different fasciculi.**

■ CONCLUSIONS: **Through this kind of microsurgical anatomic study, a better understanding of the different anatomic layers of the temporal region might be achieved. This factor is essential in planning adequate surgery and strategies to operate in the temporal lobe, improving surgical results and minimizing functional deficits.**

INTRODUCTION

The temporal lobe is considered as an anatomic pearl by some neuroanatomists. It consists of a lateral, basal, opercular, and mesial surface; the mesial surface is related to the hippocampus and the amygdala, which are part of the dorsal limbic system.[1-3] The temporal lobe cortex has a wide variety of functions such as working memory, language comprehension and processing audition, and facial recognition information. Moreover, it is crossed by many cerebral fiber tracts.[4] The intrinsic brain structure, and particularly the temporal lobe, is composed of myelinized fibers, which can be classified into 3 basic types of tract: association fibers, which connect different cortical areas into the same hemisphere; commissural fibers,

Key words
- Epilepsy surgery
- Fiber dissection
- Fiber tracts
- Fiber tracts topography
- Tractography

Abbreviations and Acronyms
3D: Three-dimensional
AH: Amygdalohippocampectomy
DTI: Diffusion tensor imaging
IFOF: Inferior fronto-occipital fasciculus
ILF: Inferior longitudinal fasciculus
ITG: Inferior temporal gyrus
MRI: Magnetic resonance imaging
MTG: Middle temporal gyrus
SLF: Superior longitudinal fasciculus
STG: Superior temporal gyrus
TLE: Temporal lobe epilepsy
UF: Unciform fasciculus

From the [1]Department of Neurological Surgery, University Clinical Hospital of Santiago de Compostela, Santiago de Compostela, Spain; [2]Laboratory of Neuroanatomic Microsurgical -LaNeMic- II Division of Anatomy, Medicine School, University of Buenos Aires; [3]Department of Neurological Surgery, San Fernando Hospital, Buenos Aires, Argentina; [4]Anatomy Academy, Higher School of Medicine, IPN, Mexico and Lic. Neurosciences, Faculty of Medicine, UNAM, City of Mexico, Mexico; [5]Epilespy Surgery Section, Neurosurgical Division, Clinical Hospital, University of Buenos Aires, Buenos Aires, Argentina; [6]Neurosurgical Division, Clinic of Cuyo, Mendoza, Argentina; [7]Epilepsy Section, Neurological Division, Clinical Hospital, University of Buenos Aires, Buenos Aires, Argentina; [8]Department of Neurosurgery Hospital General of Alicante, Alicante, Spain; and [9]Department of Neurological Surgery, Padilla Hospital, TucumÃn, Argentina.

To whom correspondence should be addressed: Ana Flores-Justa, M.D.
[E-mail: annaflores36@gmail.com]

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which link both hemispheres; and projection fibers, which connect different cortical areas to the basal ganglia, thalamus, brainstem, and spinal cord.

When the temporal lobe is studied from a surgical point of view, epilepsy surgery becomes one of the paradigms in which the temporal region has to be thoroughly investigated. The anatomic and physiologic aspects of this region have to be precisely understood to explain the mechanism of the disease and to select the best surgical approach. Because of the prevalence of a temporal source of seizures, the terms temporal and extratemporal epilepsy are commonly used in daily clinical practice to systematize the study and treatment of these patients.[5] Furthermore, temporal lobe epilepsy (TLE) can be divided according to the origin of the seizures: seizures originating in mesial structures, in the temporal lobe neocortex, or in both regions. In epilepsy surgery, the primary epileptogenic area is defined as the region in which seizures originate and comprise the main objective of surgical resection. Surgery can act by removing the epileptogenic focus as well as by disconnecting the pathologic pathways. Therefore, detailed anatomic knowledge of the brain fascicles is essential to achieving optimal surgical results.

Temporal lobe surgery has developed over the years together with microsurgical techniques, neurophysiologic studies, magnetic resonance imaging (MRI), cerebral perfusion and metabolic imaging, neuropsychological studies, and new tools for cortical and subcortical mapping of the cerebral functions, in addition to the study of white matter tracts.

Epilepsy is understood as a disorder of neural networks[6] caused by abnormal brain circuits, so it is mandatory to understand the different structures that could be involved in this network when seizures are generated. When a certain area originates the ictal discharges, these could rapidly propagate through the white matter fasciculi, resulting in different clinical manifestations according to the secondary brain region involved, and this could act as an origin simulator.[7-9]

Surgical treatment is highly effective for patients with TLE[10,11]; however, many patients persist with partial seizure control despite accurate surgical treatment, forcing them to continue taking antiepileptic drugs. This failure could be explained by assuming that hidden epileptogenic foci were not removed during the procedure or, on the other hand, that other areas have become responsible as a result of the propagated ictal discharges through certain white matter tracts. Moreover, understanding the relative location of relevant white matter tracts, such as the Meyer loop, would help us to predict, or even better to avoid, postoperative neurologic deficits. These possible deficits should be discussed with the patient before the procedure.

Thus, a complete understanding of the temporal anatomy and connectivity, in addition to the relationships between the craniometric points and the underlying structures, is necessary to select the best surgical approach and strategy. Although a few reports in the literature have correlated cerebral gyri and sulci with craniometric points,[12,13] to the best of our knowledge, there is no strong literature to accurately describe the relationship between temporal lobe tracts and craniometric points applied for TLE surgery.

The main objective of this report is to determine the direct relation of superficial craniometric points with cerebral gyri and sulci, in addition to white matter tracts of the temporal lobe through a sequential cadaveric dissection of the skull and the underlying white fibers. As a secondary objective, we also studied the potential usefulness of diffusion tensor imaging (DTI) in relation to the anatomic features found in cadaveric dissections.

METHODS

The cadaveric dissections were performed at the microsurgical neuroanatomic laboratory of the II Anatomic Department of the University of Buenos Aires and at the Academy of Anatomy of the National Politechnical Institute of Mexico, as well as at the Miguel Hernández University neuroanatomy laboratory in Alicante, Spain. Fifteen adult cadaveric human heads were fixed under 10% formalin by carotid injection and submersion and preserved for 30 days. Once the material was fixed, the scalp was removed as the first step and the bony windows were created with a high-speed drill; sutures and craniometric points were preserved.[12-14] According to the Klingler dissection technique,[15] the specimens were frozen at −15°C for 15 days. With this technique, the water located in the extracellular spaces changes its state from liquid to solid, allowing 10% expansion. This process spreads the fibers and creates a space between axonal groups, which facilitates their dissection. The dissections were performed in a stepwise manner through the temporal and sphenoid bony windows. White matter pathways in different planes were identified and their position described in relation to the craniometric points. Our primary dissection tools for the white matter anatomy were fine wooden spatulas of different sizes, various-sized anatomic forceps, and microscissors.

Dissections were performed under direct visualization through 2 Newton microscopes (Newton microscopía, Buenos Aires, Argentina) with 5 magnification options. Photographs were taken with a Nikon D7200 camera (DSLR) with a Micro Nikon 40-mm F2.8 objective and annular flash (Nikon Corp, Tokyo, Japan). All photographs were performed with a tripod. The camera was set up in the same way for all the images, using a 20 diaphragm, 100 shutter speed, 250 IS (International Organization of Standardization), and 1/128 annular flash.

DTI studies were performed in 2 healthy volunteers to analyze the different temporal fascicles in vivo and their relationship with the cranial and cortical surface. A General Electric HDxt 3.0-T resonator (GE Corporate, Florence, USA) with 40 directions was used. After the images were processed on the workstation, directional maps, anisotropic fraction maps, and tractography were acquired. The following structural sequences were used: sagittal T1 fluid-attenuated inversion recovery, axial T2-weighted fluid-attenuated inversion recovery, T2-weighted and gradient echo coronal T2-weighted, diffusion, and BRAVO sequences. Technical parameters were field of view, 25.6; slice thickness, 3; spacing, 0; repetition time, 12,000; echo time, minimum; phase 2, bandwidth, 250; frequency, 128; and phase, 128). An observational study between the white matter tracts dissected and the results coming from the MRI studies was made.

RESULTS

During the dissections, the cranial corridors were performed as follows: superior and inferior frontal, parietal, occipital, sphenoidal, and temporal; the target for this study was the sphenoidal and temporal corridors. As shown in **Figure 1**, the initial step in

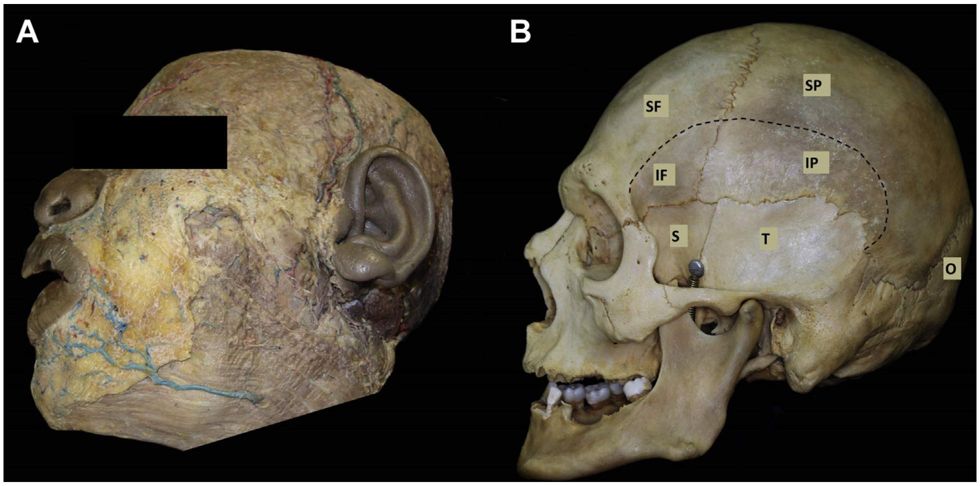
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Figure 1. (**A**) Initial step on the cadaveric specimen, skin was removed and the subcutaneous tissue was exposed with its superficial vessels. (**B**) Exposure of the cranial surface prior to bone drilling. *Dotted line*: superior temporal line; IF, inferior frontal; IP, inferior parietal; O, occipital; S, sphenoid; SF, superior frontal; SP, superior parietal; T, temporal.

the cadaveric dissection was the removal of the scalp in addition to the temporalis muscle to expose the bony cranial surface. We proceeded with the drill to perform the craniotomies preserving the cranial sutures and the anterior superior temporal line, in accordance with previous reports.[12-14]

Once the bony windows were made, the dura and arachnoid membranes were carefully removed to identify the different gyri and sulci of the lateral surface of the temporal lobe (Figure 2A). Exclusively, the most anterior portion of the medial temporal gyrus (MTG) was evident through the sphenoid window.

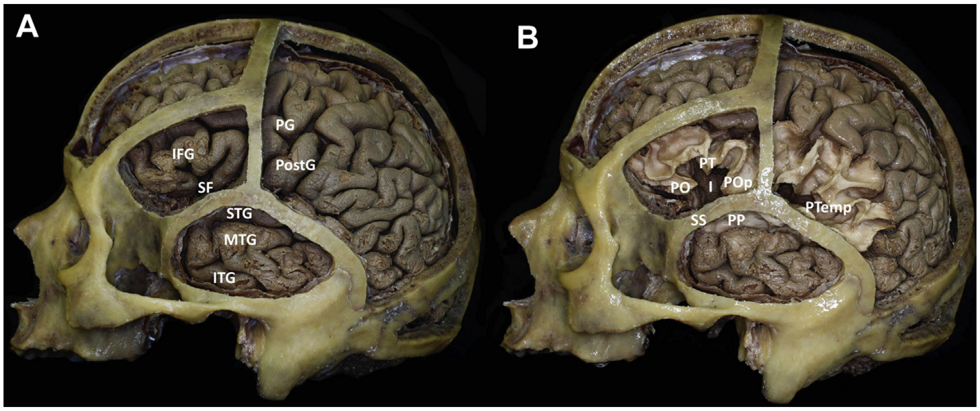

Figure 2. (**A**) Cranial corridors were performed on these left hemispheres of the specimens, preserving the cranial sutures and the anterior superior temporal line. Once the bony windows were made, dura mater and arachnoid membranes were carefully removed. Cerebral gyri and sulci of the lateral surface and their relationship with the cranial bony windows are observed. Exclusively, the most anterior portion of the medial temporal gyrus was evident through the sphenoid window. (**B**) Frontoparietal and temporal opercular cortex was removed, showing the short association fibers or U fibers of Meynert, which interconnect neighboring gyri. These fibers in the superior temporal gyrus (STG) are covered by the squamous suture. The lower third of the insula is topographically below the squamous suture. The sylvian fissure was correlated with the most cephalic and medial margins of the temporal window. I, insula; IFG, inferior frontal gyrus; ITG, inferior temporal gyrus; MTG, middle temporal gyrus; PG, precentral gyrus; PO, pars orbitalis; POp, pars opercularis; PostG, postcentral gyrus; PP, planum polare; PT, pars triangularis; PTemp, planum temporale; SF, sylvian fissure; SS, squamous suture.

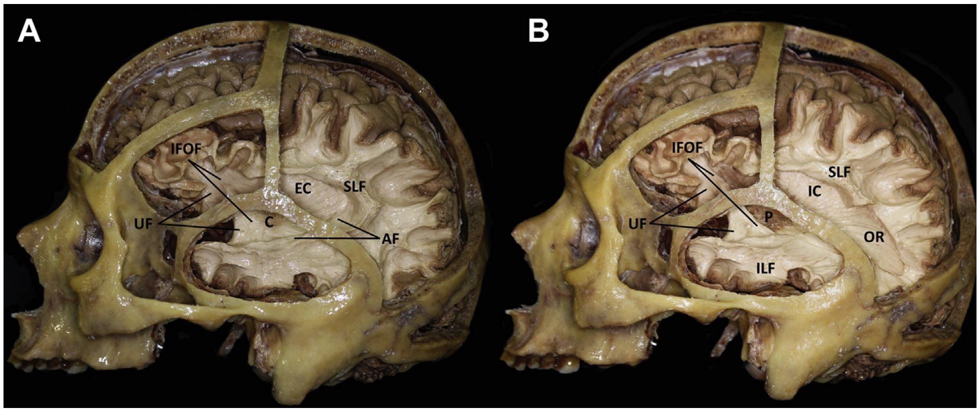

Figure 3. (**A**) The dissection was continued with the Klingler technique, preserving the U fibers of Meynert on the inferior frontal gyrus. The largest association fascicle is highlighted: the superior longitudinal fasciculus (SLF). It projects on the posterior third of the temporal window, where the arcuate fasciculus (AF) is also located. The latter connects the motor and sensory language centers. After the removal of the insular cortex and the fibers of the extreme capsule, the claustrum and the fibers of the external capsule are identified, the latter compact on its ventral portion at the level of the limen insulae in 2 association fasciculi: unciform fasciculus (UF) and inferior fronto-occipital fasciculus (IFOF). The level at which these fascicles converge and they cannot be individualized coincides with the union of the coronal and squamous sutures. (**B**) As dissection was continued at the level of the insula, the lateral surface of the putamen and the internal capsule were reached. The putamen is divided by the squamous suture into superior and inferior segments. Part of the superior longitudinal fasciculus was eliminated and the temporal trajectory of the IFOF and the optic radiations were exposed. The IFOF crossed obliquely the temporal window, whereas the optic radiations were located in the posterosuperior margin of that window. Below the inferior temporal gyrus appears the inferior longitudinal fasciculus (ILF), which can be seen on either the lateral or the basal surfaces. This fasciculus links the temporopolar region with the occipital pole. C, claustrum; EC, external capsule; IC, internal capsule; OR, optic radiations; P, putamen.

Afterward, the cortex of the frontoparietal and temporal operculum was removed (Figure 2B), exposing the short association fibers, the so-called U fibers of Meynert, which interconnect adjacent gyri; the superior temporal gyrus (STG), MTG, and inferior temporal gyrus (ITG). These fibers in the STG are covered by the squamous suture. As the cortex of the temporal lobe and the short association fibers are removed, the sylvian fissure becomes more easily opened for the identification of the

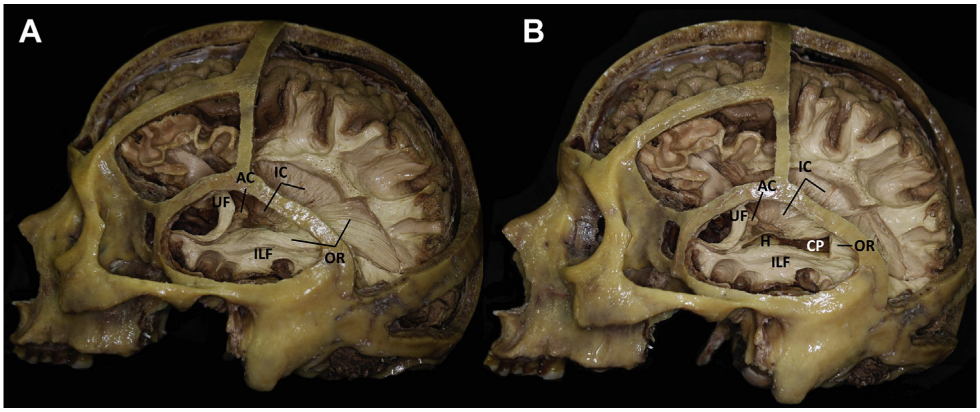

Figure 4. (**A**) The inferior fronto-occipital fasciculus (IFOF) and the lentiform nucleus (putamen and globus pallidus) were removed, showing the internal capsule on the medial edge of the globus pallidus. The anterior commissure is seen behind the unciform fasciculus, which interconnects both temporal lobes. On the temporal window is also exposed the anterior bundle of the optic radiation or Meyer loop, which projects below the middle temporal gyrus and forms the superior wall of the temporal horn of the lateral ventricle. (**B**) Part of the optic radiations and the dorsal fibers of the inferior longitudinal fasciculus (ILF) were removed to expose the lateral ventricle, and the hippocampal formation is emphasized inside. AC, anterior commissure; CP, choroid plexus; H, hippocampus; IC, internal capsule; OR, optic radiations; UF, uncinate fasciculus.

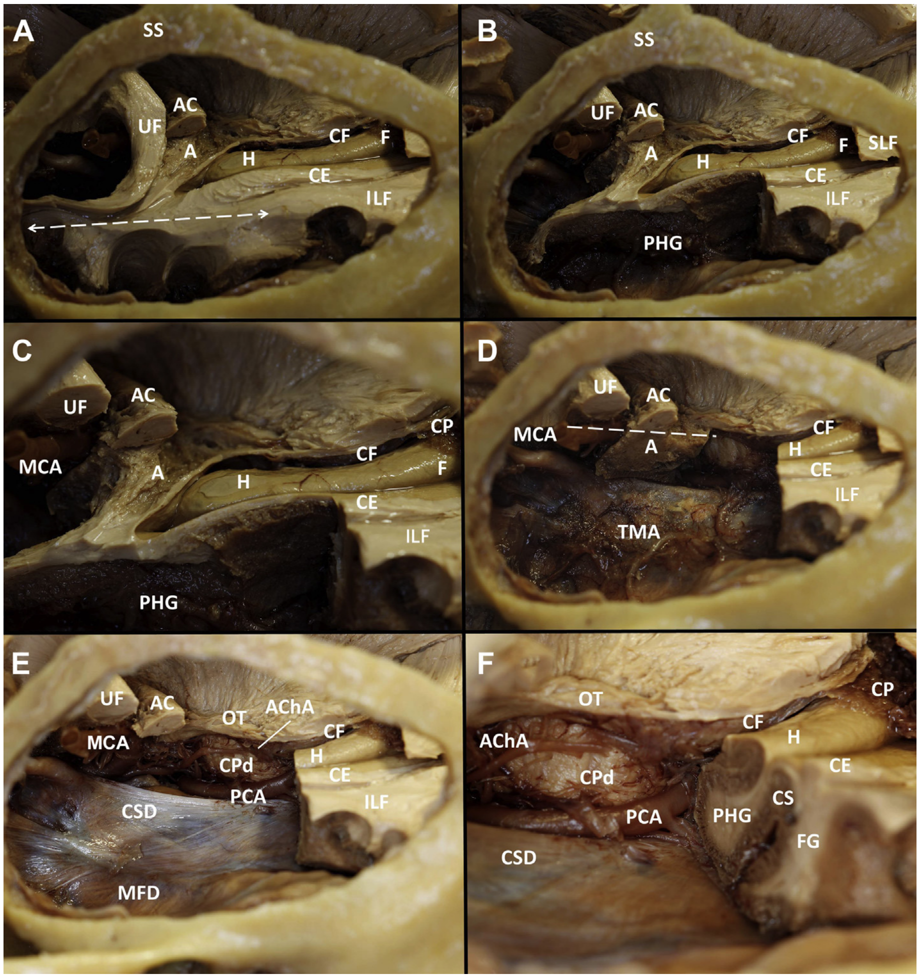

Figure 5. (**A**) Through the temporal window, dissection is continued. The hippocampal formation is situated in the center of this bony window. A white line is drawn delineating the 5 cm of the neocorticectomy used in temporal lobectomies. The following structures are highlighted: uncinate fasciculus (UF) on the anterior margin; posterior to it, the anterior commissure (AC) has been divided, with exposure of the amygdala below. The lateral ventricle has been opened to visualize the hippocampus, which continues with the fimbria of the fornix ventral to the choroidal fissure. Lateral to the hippocampus, the collateral eminence is detected. (**B**) View after the removal of the neocortex and section of the temporal areas of the uncinate fasciculus, inferior fronto-occipital fasciculus, AC, and inferior longitudinal fasciculus (ILF). The lateral surface of the parahippocampal gyrus is observed as the lobectomy is performed through the collateral eminence. Only the archicortex remains; amygdala and hippocampus formation. (**C**) Magnification of the important temporomesial structures in temporal lobe epilepsy surgery. Next to the cortex of the limen insulae is located the medial cerebral artery (MCA) on its transition from M1 to M2. Dorsally to the fornix, the choroid fissure is shown, which is an important landmark and indicates the medial limit of the temporal resection. (**D**) Once subarachnoidal resection of 25 mm of hippocampus, fimbria of the fornix, and the parahippocampal gyrus is performed, the arachnoid of the temporomesial region is exposed together with the anterior and medial temporobasal arteries and veins. A dotted line is drawn between the bifurcation of the MCA and the inferior choroidal point to represent the superior limit used in surgery to complete an adequate resection of the amygdala. (**E**) Amygdalectomy through the temporal bony window is performed, dividing it from the AC. The dura mater of the middle cranial fossa which continues with the dura mater of the cavernous sinus and the free edge of the tentorium, is observed. Cranial nerve III is related to the free edge of the tentorium. The optic tract indicates the limit between the brainstem and diencephalon. (**F**) Greater magnification of the anterior view after anterior temporal lobe resection and amygdalohippocampectomy. The collateral eminence continues with the collateral trigone in the atrium, where the glomus of the choroid plexus is shown. The collateral eminence is the lateral limit of the hippocampectomy. Cerebral peduncle is exposed as well as the posterior cerebral artery (PCA) and the anterior choroidal artery (AChA). A, amygdala; CE, collateral eminence; CF, choroidal fissure; CP, choroid plexus; CPd, cerebral peduncle; CS, collateral sulcus; CSD, cavernous sinus dura mater; F, fornix; FG, fusiform gyrus; H, hippocampus, MFD, middle fossa dura mater; OT, optic tract; PHG, parahippocampal gyrus; SLF, superior longitudinal fasciculus; SS, squamous suture; TMA, temporomesial arachnoid; *Dotted line* in (**A**) delineates the 5-cm neocorticectomy used in temporal lobectomies. *Dotted line* in (**D**) shows line between the bifurcation of the MCA and the inferior choroidal point defines the superior limit used in surgery to complete an adequate resection of the amygdala.

insular lobe in the depth. Its lower third is topographically evident below the squamous suture. The sylvian fissure was correlated with the most cephalic and medial margins of the temporal window.

With the use of wooden spatulas and under the microscopic view, the dissection continued through the supramarginal and angular gyri. The most superficial long association fibers were identified; the superior longitudinal fasciculus (SLF) and the arcuate fasciculus. The SLF consists of the frontoparietal connection fibers. It curves and provides fibers to the lateral surface of the temporal lobe, especially to the superior and middle gyri. The SLF projects on the posterior third of the temporal window. Another tract identified is the inferior longitudinal fasciculus (ILF), which connects the temporal pole to the dorsolateral occipital cortex without reaching the calcarine cortex. It lies within the ITG.

After removal of the insular cortex and the fibers of the extreme capsule, the claustrum and the fibers of the external capsule are identified and divided into dorsal and ventral sectors, below the squamous suture and inside the temporal window, as shown in **Figure 3**. At the level of the limen insulae, the fibers of the ventral part of the external capsule compact in the region where 2 association fascicle run together; the inferior fronto-occipital fasciculus (IFOF) above, and the uncinate fasciculus (UF) below[16] (**Figure 3A**). The IFOF connects the middle and inferior frontal gyri to the posterior part of the parietal and occipital lobes; it covers the optic radiation fibers as they pass deep to the STG, MTG, and occipital lobe and lateral to the temporal horn, atrium, and occipital horn of the lateral ventricle. Avoiding entering the depth of the IFOF during surgery helps prevent injury to the optic radiations. The UF courses just anterior to the anterior perforated substance. It covers the inferior and medial sides of the nucleus accumbens to reach the area below the genu of the corpus callosum. At the level at which these fasciculi converge, it is impossible to individualize them and this landmark coincides with the junction of the coronal and squamous sutures. As the dissection went further, the claustrum and external capsule are removed (**Figure 3B**). The lateral surface of the putamen is exposed, showing its characteristic gray color; it is divided by the squamous suture into superior and inferior segments of similar size.

Over the surface of the temporal lobe, the different tracts overlap in a stratigraphic way. For that reason, the temporal fibers of the SLF were removed with a wooden spatula and number 11 blade to allow continuation of the dissection. This maneuver permits following through the temporal window those fibers of the IFOF that are directed backward and cross that window obliquely. Another tract exposed at this level is composed of the geniculocalcarine fibers. They arise from the lateral geniculate body and are projected to reach area 17 of Brodmann. These fibers are located in the posterosuperior margin of the temporal window and must be respected during temporal lobe surgery to avoid visual deterioration. Each optic radiation comprises part of the posterior thalamic peduncle, passing below the lentiform nucleus as an important component of the sublenticular component of the internal capsule, and dorsal to the tail of the caudate nucleus to join and integrate into the sagittal stratum, which forms the lateral ventricular wall. The so-called sagittal stratum consists of the IFOF, the posterior thalamic peduncle (which contains the optic radiations), and the fibers that compose the anterior commissure. It is located on the most posterior margin of the temporal window. The optic radiation fibers are traditionally divided into 3 portions according to their origin[5]: anterior, central, and posterior bundles. In our specimens, we found the anterior bundle of the optic radiation in relation to the temporal window (**Figure 4**), also called the Meyer loop, which forms the superior wall of the temporal horn of the lateral ventricle. These anterior fibers of the optic radiation arise in the inferior aspect of the lateral geniculate body and are related on its surface with the STG and MTG, without exceeding the basal limit of the inferior temporal sulcus, and end up at the inferior lip of the calcarine fissure. In the specimens, we found fibers intermingling between the optic radiations and the parietal and occipital fibers of the anterior commissure. Some of the optic radiations, the dorsal fibers of the ILF, and the ependyma of the temporal horn of the lateral ventricle are removed during the dissection. The presence of the hippocampal formation is emphasized and the nuclear complex of the amygdala is observed above it and slightly dorsal.

The inferior choroidal point represents the entrance site of the inferior choroidal artery to the ventricular cavity and also the beginning of the choroidal fissure and the choroid plexus. Some investigators consider this landmark as the hippocampal neck, because it represents the limit between the head and the body. The hippocampal formation is situated in the center of the temporal window and does not exceed the anterior limit of the junction between the coronal and squamous sutures.

The limits of an en bloc 5-cm resection of the neocortical aspect of the temporal lobe are shown in **Figure 5**. At this surgical step, the most anterior fibers of the ILF, SLF, temporal segment of the UF, and ventral arcuate fibers of the anterior commissure are divided. As we continue with the medial dissection, the hippocampectomy is performed at a distance of 25 mm from its most anterior segment, using the choroidal fissure as the medial limit of the resection. Then, the hippocampus is divided together with the fibers of the fimbria of the fornix, which is a long association fasciculus of the limbic system. Once the hippocampal formation is separated from the temporal lobe, the arachnoid of the temporomesial region is subpially uncovered. It is through this anatomic element that the P2 segment of the posterior cerebral artery, the surface of the homolateral cerebral peduncle, and cranial nerve III are observed (**Figure 5D**). To complete the amygdalectomy, some anatomic landmarks have been established and can be resorted intraoperatively. These are also observed in the figures. An imaginary line between the bifurcation of the middle cerebral artery, exposed after the resection of the planum polare, and the inferior choroidal point is taken into account to define the superior limit of an adequate resection of the amygdale. As the amygdalectomy is completed, the dura mater of the middle cranial fossa that continues with the dura mater of the cavernous sinus and the free edge of the tentorium are observed. The latter related to the cranial nerve III, and both mark the medial limit of the surgical resection. An anterior view after the amygdalohippocampectomy (AH) is shown with greater magnification in **Figure 5F**, showing the optic tract, which marks the limit between the diencephalon and the brainstem, anterior choroidal artery, and posterior

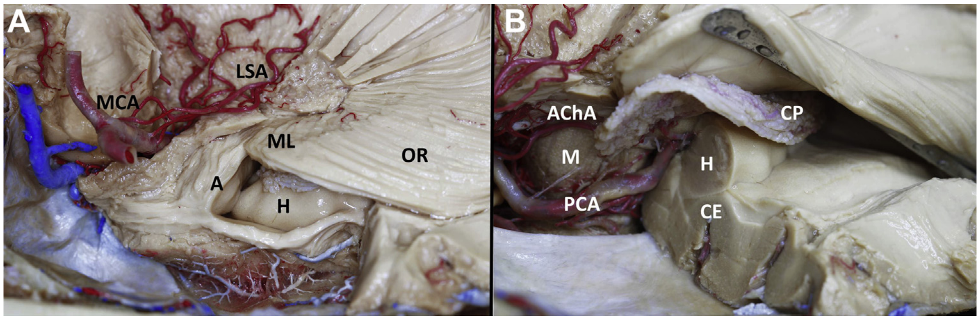

Figure 6. Dissection of another specimen. (**A**) Temporal horn of the lateral ventricle has been opened to expose the vascular relationships of the amygdala; M1 bifurcation is at the same level as the amygdala and also the Meyer loop is just superior to the posterior margin of the amygdala. (**B**) Anterolateral view after anterior temporal lobe resection and amygdalohippocampectomy. The collateral eminence shows the lateral limit of the hippocampectomy. Cerebral peduncle is exposed as well as the posterior cerebral artery and the anterior choroidal artery (AChA). A, amygdala; BV, basal vein of Rosenthal; CE, collateral eminence; CP, choroid plexus; H, hippocampus; LSA, lenticulostriate arteries; M, midbrain; MCA, middle cerebral artery; ML, Meyer loop; OR, optic radiations; PCA, posterior cerebral artery.

cerebral artery (Figures 6 and 7). The collateral eminence marks the lateral limit of the hippocampectomy.

In addition to the anatomic study, magnetic resonance diffusion tensor tractography was performed with the aim of studying the trajectory of the different tracts of the temporal lobe and correlating them to the cranial and skin surface through a three-dimensional (3D) reconstruction of the MRIs. Figure 8 shows images of 2 healthy volunteers virtually superimposed onto one of our dissected specimens, for iconographic purposes. After obtaining the colorimetric maps in the sagittal, coronal, and axial sections, we individualized voxels of each fasciculus for final acquisition of the complete trajectory of each. It was possible to isolate the SLF, ILF, UF, IFOF, anterior commissure, optic radiations, cingulum, and fornix. Initially, each was configured 3D independently and afterward all were merged into the T1-weighted MRIs of the 3 sections. The relationships between fasciculus with gyri and sulci of the surface of the temporal lobe were carefully analyzed. The direction, shape, and relationships between the different studied tracts matched accurately among the DTI reconstructions and the brain white matter dissections.

Results found in the cadaveric dissections and in vivo tractography enabled the individualization of the main 8 tracts of the temporal lobe; all projected on to the temporal and sphenoidal windows.

Through the temporal window the following tracts are projected: the SLF projects on the posterior third; the ILF crosses it horizontally and slightly upward from the ITG to the occipital lobe; the fornix crosses it on the inferior margin of the superior third to end above

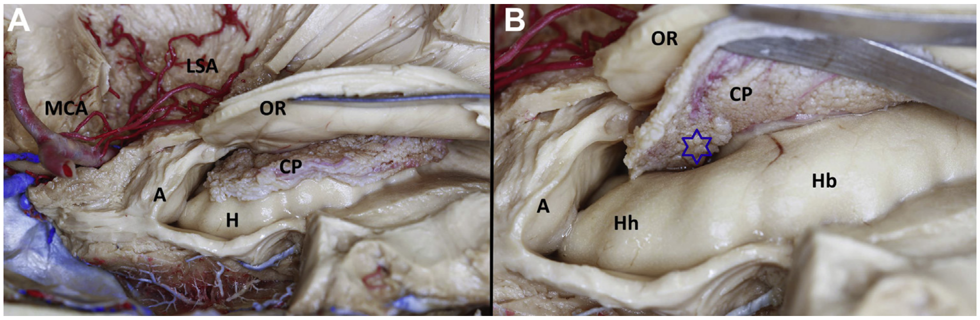

Figure 7. (**A**) Elevation of the optic radiations that form the superior wall of the temporal horn showing the body of the hippocampus (H) and the choroid plexus. (**B**) Elevation of the choroid plexus showing the inferior choroidal point (*blue star*), which represents the entrance site of the anterior choroidal artery to the ventricular cavity, the beginning of the choroidal fissure and the choroid plexus, and also the hippocampal neck. Also, at that point, the inferior choroidal vein exits the lateral ventricle. A, amygdala; Hb, hippocampus body; Hh, hippocampus head; LSA, lenticulostriate arteries; MCA, middle cerebral artery; ML, Meyer loop; OR, optic radiations; CP, choroid plexus. Blue star, inferior choroidal point.

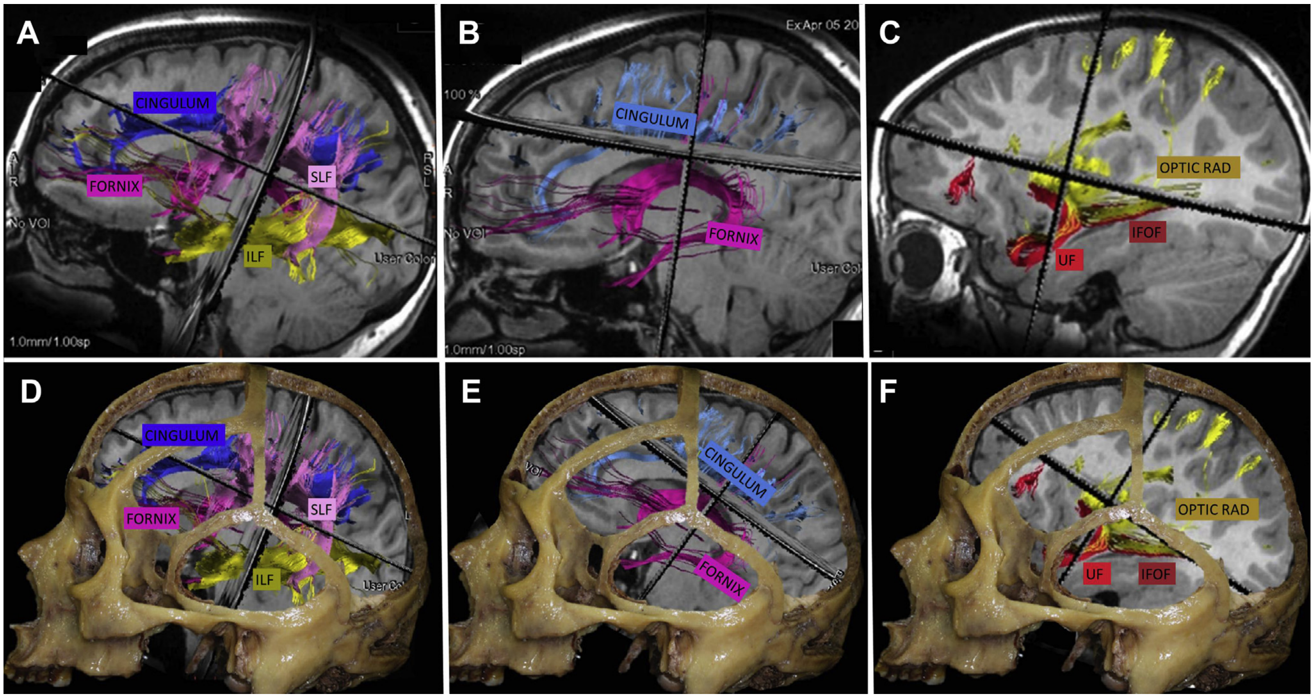

Figure 8. (**A**—**C**) Diffusion tensor imaging (DTI) in a lateral view of the left cerebral hemisphere. In pink is marked the fornix with its temporal fibers ending above the hippocampus, in blue the cingulum fasciculus. In light pink, the superior longitudinal fasciculus (SLF) where the fibers travel over the cingulum fasciculus in an arciform shape behind the insula to end over the temporal lobe. The inferior longitudinal fasciculus (ILF) is represented in yellow and its trajectory from the inferior temporal gyrus to the occipital lobe is observed. In red, the external capsule; the unciform fasciculus with its trajectory from to the temporal pole to the orbitofrontal area and the inferior fronto-occipital fasciculus (IFOF) connecting the middle and frontal gyri to the posterior part of the parietal and occipital lobes. Behind is represented in gold the optic radiation. (**D**—**F**) DTI fused with the skull of the cadaveric dissection to show the relationships between the white matter tracts obtained by DTI and the cranial corridors used in the dissections. The superior longitudinal fasciculus projects on the posterior third of the temporal bony window, which is crossed horizontally and slightly upward by the ILF. The fornix is represented below the ILF ending above the hippocampus on the temporal window. The cingulum fasciculus is shown on the inferior frontal and parietal bony windows. Through the temporal window are projected the temporal part of the uncinate fasciculus (UF) on its anterior and superior margin, the fibers from the inferior fronto-occipital fasciculus and the anterior bundle of the optic radiations on its posterosuperior margin. Imaging studies and dissections are merged mainly for iconographic purposes. OPTIC RAD, optic radiations.

the hippocampus; the UF descends and courses forward on its anterior and superior margin, whereas its most anterior fibers directed to the temporal pole reach the sphenoidal window; the IFOF fibers cross backward through the inferior aspect of the superior third; and the anterior bundle of the optic radiations projects onto the posterosuperior margin of the temporal window. The cingulum fasciculus projects on the inferior frontal and parietal bony windows. Its posterior fibers are directed to the parahippocampal gyrus and project on the temporal window.

DISCUSSION

Extensive knowledge of the anatomic structures of the temporal lobe is important for planning safe and accurate surgical procedures for lesions within the lobe, including tumors such as gliomas or cavernomas, and especially for epilepsy surgery. According to TLE surgery, the most challenging technique, which requires solid anatomic knowledge, is AH, which has its precise indication in mesial temporal sclerosis. AH can be performed by selective AH surgery, in which the anterior temporal cortex and structures of the deep white matter are respected, and resective surgery (standard anterior temporal lobectomy), which also includes other structures such as the neocortex (STG, MTG, and ITG) and the temporal pole.[17] Spencer et al.[18] modified this technique, leaving the STG and using the superior temporal sulcus as the entry zone, then directing the dissection to the temporal horn without damaging the superior wall of the ventricular cavity or the temporal stem. This technique includes the MTG, ITG, fusiform gyrus, amygdala, hippocampus, and parahippocampal gyrus[19] and is the main approach for AH.[17,20,21] In standard anterior temporal lobectomy and Spencer type lobectomy, a regulated resection is performed and the UF, IFOF, temporal segment of the anterior commissure, ILF, cingulum, and fornix must be divided, according to our anatomic study. There are also other types of approaches for AH: the transsylvian, subtemporal, and transcortical approaches.

If epilepsy is considered as a network disease, the disconnection of the afferent and efferent pathways of the temporal lobe are probably part of the success of the surgery but could also generate a functional deficit.

This study tried to show the complex connections of the temporal lobe and correlate these tracts to the craniometric points that we use to perform temporal basal craniotomy in epilepsy surgery. We performed dissections following the so-called Klingler technique[15] on brains through cranial corridors in their normal location in the skull. This anatomic study allowed us to achieve a better understanding of the relationships between the white matter structures within the temporal lobe and their projection to the craniometric points. Ribas et al.[22] and Gusmao et al.[13] described the craniometric points and their relationship with gyri and sulci; in previous studies,[16,23] the dissection of the white matter tracts of the lateral surface of the brain was reported but there is no literature about the relationship that correlates those fiber tracts with the classic bony landmarks. We propose a novel approach of the subject in which 3D understanding of the mesial structures and the surrounding brain and skull configuration is possible. In addition, in the laboratory, it is possible to simulate surgical positioning with the 3-pin Mayfield headholder, increasing flexion, deflection, or angulation for the 3 different approaches; subtemporal, which requires a temporal basal craniotomy, or transsylvian and transcortical, which require a pterional craniotomy. With every change in positioning, the anatomic view is modified, increasing the difficulty in terms of orientation during the surgical procedure. This difficulty can be overcome by studying the relationships of the fiber tracts with the skull, only possible by dissecting the whole cadaveric human head. We tried to show that through the temporal bony window, a complete AH can be performed, guaranteeing correct access to the main implicated structures for resection. The main limitation of our cadaveric study is that it is a descriptive analysis and it must be considered that there are individual variations in the skull joint structure and brain fiber bundles. Moreover, the measurement based on cadaver specimens does not accurately represent the observations of living organisms.

The Klingler technique allows identification of the main fiber tracts and has been shown to have a good correlation with other methods of fiber identification, such as DTI.[5,24,25]

In our study, we checked the direction, shape, and relationships between the different studied tracts, achieving an acceptable match between both techniques. Preoperative DTI studies can be helpful for optimal surgical planning. For instance, the Meyer loop can be individualized and measured from the temporal pole in each specific candidate for TLE to provide a safe and accurate procedure, considering the individual anatomic differences. Furthermore, intraoperative neuronavigation with DTI studies, with previous individualization of the important fiber tracts such as optic radiations, can also be useful for achieving the best surgical outcomes for our patients. Future studies comparing preoperative and postoperative DTI should show the fiber tracts that are damaged according to the different surgical approaches for temporal lobe disconnection.

CONCLUSIONS

Extensive knowledge of the anatomic structures of the temporal lobe is important in planning safe and accurate surgery for lesions within this area (e.g. tumors) and especially in epilepsy surgery. Through the temporal bony window, a complete AH can be performed, guaranteeing correct access to the main implicated structures for resection. We consider that through this type of microsurgical anatomic study, 3D understanding of the mesial structures and the surrounding brain and skull configuration is possible. This knowledge is essential to plan accurate brain surgery and improve neurosurgical strategies to achieve better surgical and functional outcomes in our patients, minimizing deficits. The Klingler technique has shown good correlation with DTI and, therefore, preoperative DTI studies can help in surgical planning.

REFERENCES

1. Federal International Committee on Anatomical Terminology and International Federation of Associations of Anatomists. *Terminología Anatómica internacional*. Madrid: Panamericana; 2001.

2. Rhoton AL. The cerebrum. *Neurosurg*. 2002;51:375-410.

3. Testut L, Latarjet A, Latarjet M. *Tratado de anatomía humana*. Barcelona: Salvat; 1988.

4. Niewenhuys R, Voogd J, Van Huijzen C. *The Human Central Nervous System*. Heidelberg: Springer; 2008.

5. Parraga RG, Ribas GC, Welling LC, Alves RV, de Oliveira E. Microsurgical Anatomy of the optic radiation and related fibers in 3-dimensional Images. *Neurosurgery*. 2012;71:160-171.

6. Spencer SS. Neural networks in human epilepsy: evidence of and implications for treatment. *Epilepsia*. 2002;43:219-227.

7. Liu M, Bernhardt BC, Hong SJ, Caldairou B, Bernasconi A, Bernasconi N. The superficial white matter in temporal lobe epilepsy: a key link between structural and functional network disruptions. *Brain*. 2016;139:2431-2440.

8. Cataldi M, Avoli M, de Villers-Sidani E. Resting state networks in temporal lobe epilepsy. *Epilepsia*. 2013;54:2048-2059.

9. Bertram EH, Williamson JM, Scott C, Mangan PS, Zhang DX. The midline thalamus: alterations and a potential role in limbic epilepsy. *Epilepsia*. 2001;42:967-978.

10. Engel J, Wiebe S, French J, et al. Practice parameter: temporal lobe and localized neocortical resections for epilepsy: report of the Quality Standards Subcommittee of the American Academy of Neurology, in association with the American Epilepsy Society and the American Association of Neurological Surgeons. *Neurology*. 2003;60:538-547.

11. Wiebe S, Blume WT, Girvin JP, Eliasziw M. A randomized, controlled trial of surgery for temporal-lobe epilepsy. *N Engl J Med*. 2001;345:311-318.

12. Ribas GC. The cerebral sulci and gyri. *Neurosurg Focus*. 2010;28:E2.

13. Gusmao S, Silveira RL, Arantes A. Pontos referenciais nos acessos cranianos. *Arq Neuropsiquiatr*. 2003;61:305-308 [in Portuguese].

14. Kendir S, Acar HI, Comert A, et al. Window anatomy for neurosurgical approaches, Laboratory investigation. *J Neurosurg*. 2009;111:365-370.

15. Klingler J, Ludwig E. *Atlas cerebri humani*. Basel: Karger; 1956.

16. Yagmurlu K, Vlasak AL, Rhoton AL. Three-dimensional topographic fiber tract anatomy of the cerebrum. *Neurosurgery*. 2015;11:274-303.

17. Penfield W, Flanigin H. Surgical therapy of temporal lobe seizures. *AMA Arch Neurol Psychiatry*. 1950;64:491-500.

18. Spencer SS, Spencer DD. Entorhinal-hippocampal interaction in medial temporal epilepsy. *Epilepsia*. 1994;35:721-727.

19. Spencer DD, Spencer SS, Mattson RH, Williamson PD, Novelly RA. Access to the posterior medial temporal lobe structures in the surgical treatment of temporal lobe epilepsy. *Neurosurgery*. 1984;15:667-671.

20. Falconer MA, Taylor DC. Surgical treatment of drug-resistant epilepsy due to mesial temporal sclerosis. Etiology and significance. *Arch Neurol*. 1968;19:353-361.

21. Ebeling U, Von Cramon D. Topography of the uncinate fascicle and adjacent temporal fiber tracts. *Acta Neurochir (Wien)*. 1992;115:143-148.

22. Ribas GC, Yasuda A, Ribas EC, Nishikuni K, Rodrigues AJ. Surgical anatomy of microsurgical sulcal key points. *Neurosurg*. 2006;59:177-211.

23. Ribas EC, Yagmurlu K, Wen HT, Rhoton AL Jr. Microsurgical anatomy of the inferior limiting insular sulcus and the temporal stem. *J Neurosurg*. 2015;122:1263-1273.

24. Martino J, da Silva-Freitas R, Caballero H, Marco de Lucas E, García-Porrero JA, Vázquez-Barquero A. Fiber dissection and diffusion tensor imaging tractography study of the temporoparietal fiber intersection area. *Neurosurgery*. 2013;71:87-89.

25. Ture U, Yasargil MG, Friedman AH, Al-Mefty O. Fiber dissection technique: lateral aspect of the brain. *Neurosurgery*. 2000;47:417-427.

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