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INTERNAL STRUCTURE OF THE CEREBRAL HEMISPHERES

An introduction of fiber dissection technique

Igor de Castro[1], Daniel de Holanda Christoph[2] , Daniel Paes dos Santos[2], José Alberto Landeiro[3]

ABSTRACT - The aim of this study is to introduce the fiber dissection technique and its importance in the comprehension of the three-dimensional intrinsic anatomy of the brain. A total of twenty brain hemispheres were dissected. Using Kingler's technique we demonstrated the intrinsic structures of the brain. The supra lateral aspect of the brain as well as the medial aspect were presented. The most important fiber systems were demonstrated. The use and comprehension of new neuroimaging techniques demand a better understanding of this fascinating anatomy. The knowledge acquired with this technique will improve our understanding of critical pathways of the central nervous system.

KEY WORDS: brain, anatomy, white matter dissection.

Estrutura interna dos hemisférios cerebrais: introdução à técnica de dissecação de fibras

RESUMO - O objetivo é mostrar a técnica de dissecação de fibras e sua importância na compreensão da anatomia tridimensional do cérebro. Um total de 20 hemisférios cerebrais foram dissecados. Usando a técnica de dissecação descrita por Kingler, pudemos demonstrar as estruturas que compõem a anatomia interna do cérebro. A anatomia da face súpero-lateral assim como da face medial foi apresentada. O uso e compreensão de novas técnicas de neuroimagem requerem um melhor conhecimento desta anatomia. O conhecimento adquirido com essa técnica contribuirá para o melhor entendimento de vias essenciais do sistema nervoso central.

PALAVRAS-CHAVE: cérebro, anatomia, dissecação, substância branca.

Traditionally the brain sulci and gyri anatomy of the brain have been studied by anatomists and clinicians but the intrinsic anatomy of the complex fibers of the white matter has been somewhat ignored. Very few books or publications regarding this topic are available when compared to the extensive literature about the external structure of the brain. Recently in Rhoton's masterpiece, "The Supratentorial Cranial Space: Microsurgical Anatomy and Surgical Approaches" - Supplement of Neurosurgery, some beautiful dissections showing the internal fasciculus can be appreciated[1]. With the most recent advances in neuroimaging one can experiences full details pictures of the internal anatomy of the brain[2-7] .Therefore, there is an increasing demand for knowledge of intrinsic brain anatomy. As radiological and surgical techniques become increasingly precise, our knowledge of the superficial anatomy and also the recognition of the internal white matter tracts of the brain is essential. In the last years many studies using diffusion-weighted and diffusion tensor MR imaging were published. The new MRI devices which use high magnetic fields and techniques promoting superior quality images can be used to show the full white matter anatomy in detail[4]. The term so-called tractography is becoming very popular. This analysis of tracts is essential for understanding and explaining the pathophysiologic patterns of certain disease states, especially intrinsic gliomas. In fact, in the studies of the intrinsic brain tumors such as the gliomas, the anatomy of the white matter tracts is more important than the anatomy of the sulci and gyri[3]. Therefore, a complete and in-depth understanding of

[1]Assistente do Serviço de Neurocirurgia do Hospital da Força Aérea do Galeão, Rio de Janeiro RJ, Brasil (HFAG); [2]Graduação em Medicina, Universidade Federal do Rio de Janeiro (UFRJ) Rio de Janeiro RJ, Basil; [3]Chefe de Serviço de Neurocirurgia (HFAG)

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Dr. José Alberto Landeiro - Rua Conde de Bonfim 211/310 - 20520-050 Rio de Janeiro RJ - Brasil. E-mail: jlandeiro@aol.com

the brain's intrinsic anatomy is essential. The knowledge gained from this technique can be applied to microsurgical procedures. Not only the neurosurgeon who can benefit from a detailed description of this anatomy, but also the neurologist, neuropathologist and the neuroradiologist. The precise diagnosis and treatment of central nervous system (CNS) lesions depends upon the comprehension of the whole anatomy itself. Our ability to think in tree-dimensions should be exercised. According with Ture et al.[8] the reestablishment of the fiber dissection of the white matter as a standard study method is recommended. The learning is essential and it should be mandatory in the continuing education of neurosurgeons in training.

METHOD

The human brains were harvested from autopsy patients that had a non-neurological cause of death. The studies were performed in the microsurgery laboratory of The Brazilian Air Force Hospital, Rio de Janeiro. Each specimens received careful postmortem attention, and those with gross defects were rejected from this study. We used the preservation method of Kingler, with minor adjustments[9,10]. In removing the brain from the skull, every effort was made to minimize damage to the delicate surface. The organ was then suspended, by means of a ligature placed around the basilar artery, in a vessel containing 10% formaldehyde solution. This is an essential maneuver to maintain the brain in its normal contours. This fluid was replaced first after 24 hours and again after an interval of two weeks. After a total period of 4 weeks or longer in the formaldehyde solution, the brain was washed for several hours in fresh cold water. The pia matter, arachnoid membrane, and vessels of the specimens were carefully removed using the operative microscope. Subsequently the specimens were placed in a plastic vessel containing 10% formaldehyde solution and stored for 8 days in a deep freeze at -10º C. At this point the brain was thawed under running cold water for 24 hours. Sometimes, repeating the deep freezing procedure (in 10% formaldehyde solution) two or three times can facilitate the dissection. After the last freezing, the brains were kept in the 10% formaldehyde solution.

For making the dissections, simple anatomic instruments were found to be quite satisfactory. The main instrument utilized was the wooden spatula. To perform the dissections, it was necessary to use different sizes of spatulas tips. A fine forceps was used to execute the delicate fiber bundle preparations. It was also necessary on most occasions to use a dissecting microscope to magnify the specimen and provide better illumination.

RESULTS

The dissection begins at the supero-lateral surface of the cerebral hemispheres.

Supero-lateral aspect – The superolateral surface of each cerebral hemisphere is markedly convex and fits into the corresponding half of the skull vault. In this specimen, we removed the gray matter of the right hemisphere. The gyri and sulci patterns are still the same and can be readily appreciated. The longest sulcus in this aspect is the central sulcus. The so-called "U" fibers connecting on gyri with another under their respective sulcus are revealed (Fig 1).

The insula is a substantial portion of the cerebral cortex that forms the floor of the lateral sulcus that can be opened up by removing the lips bordering the lateral sulcus (Sylvius) and its rami. These lips are known as the frontal, fronto parietal and temporal opercula. After their excision, the insula appears as a triangular eminence that is marked by a number of sulci and gyri. In this specimen, the insular cortex was removed revealing a number of sulci, one of which the central sulcus of the insula is deepend more proeminent than the rest. Again the "U" fibers of the insula gyri can be visualized as well as the circular sulcus of the insula which surrounds the entire lobe. The inferior part of this triangular lobe is known as the limen insula. The entire cortex of the whole hemisphere was removed revealing the "U" fibers of the white matter underneath (Fig 2).

The lentiform nucleus has been removed to expose the lateral aspect of the internal capsule. The corona radiate and its continuity with the internal capsule can be seen in this dissection, since the ends and upper margin of the putamen mark the junction of the internal capsule with the base of the corona. A contrasting appearance is afforded by the long, parallel, closed packed fibers of the sagittal stratum, the fibers of which remain rather discrete as they persue their long and wavy course toward the occipital cortex. The optic nerve, optic chiasma and optic tract can be traced backwards in this specimen. The optic tract terminates in the lateral geniculate body. The fibers of the optic radiation, or geniculostriate projection, emerge from the dorsal surface of the lateral geniculate body and can be traced as part of the sagittal stratum of white fibers that run anterior and inferior into the temporal lobe. Subsequently, they sweep backwards and terminate in the region of the calcarine sulcus (Fig 3).

A close inspection of the internal capsule going down to the brain stem is exposed. Its relations to the optic tract and hippocampus are also visualized. The optic tract going all the way back to the

lateral geniculate nucleus is appreciated in this specimen. The fibers of internal capsule condense to run down through the peduncular part of the midbrain. A line of demarcation can be seen showing the original position of the globo pallidum. The anterior comissure is also despicted. The hippocampus and the choroid plexum above it is also visualized (Fig 4).

The medial aspect – Above the corpus callosum, the cingulum is seen. The cingulum is an association tract that commences below the rostrum of the corpus callosum (cc), in the region of the olfactory cortex, and arches around the entire cc. After curving round the splenium of the cc, the bundle proceeds forward within the parahippocampal gyrus to reach the uncus and nearby cortical areas of the temporal lobe. In this preparation, the corpus callosum was partially remove to show the caudate nucleus (head).

The thalamus is a large nucleus in the depth of the brain. The constituent nuclei on its medial aspect are displaced. The column of the fornix has been divided a short distance above the anterior comissure. The fibers of the mamillothalamic fasciculus (bundle of Vicq d'Azir) arise from the mamillary body and travel upwards and backwards to the anterior, expanded part of the anterior nuclear group of the thalamus (Fig 5).

The cingulum and some fibers of the cc have been removed. The unique composition of the fibers of the cc can be appreciated. Part of the fornix was kept in place. In this specimen, the delicate stria medullaris thalami can be traced backwards between the dorsal and medial surfaces of the thala-

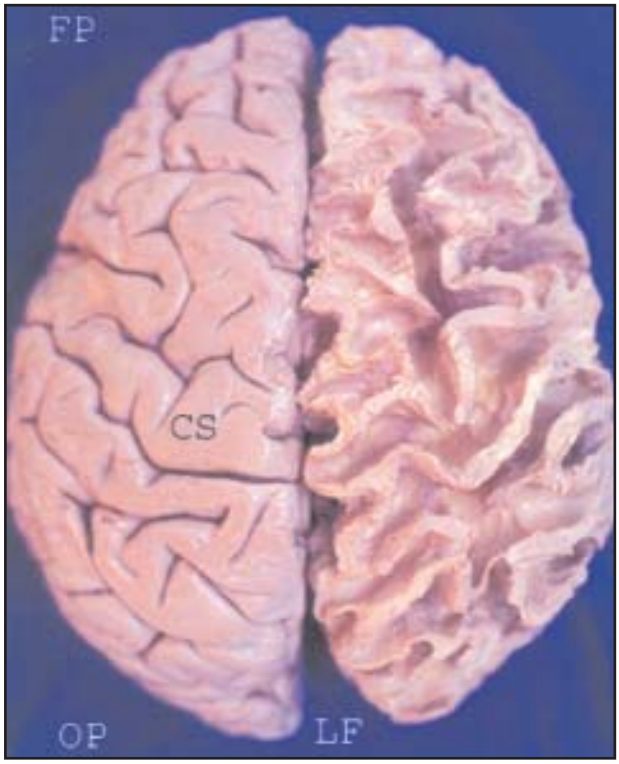

Fig 1. Supero lateral surface of the brain. FP, frontal pole; OP, occipital pole; CS, central sulcus; LF, longitudinal fissure.

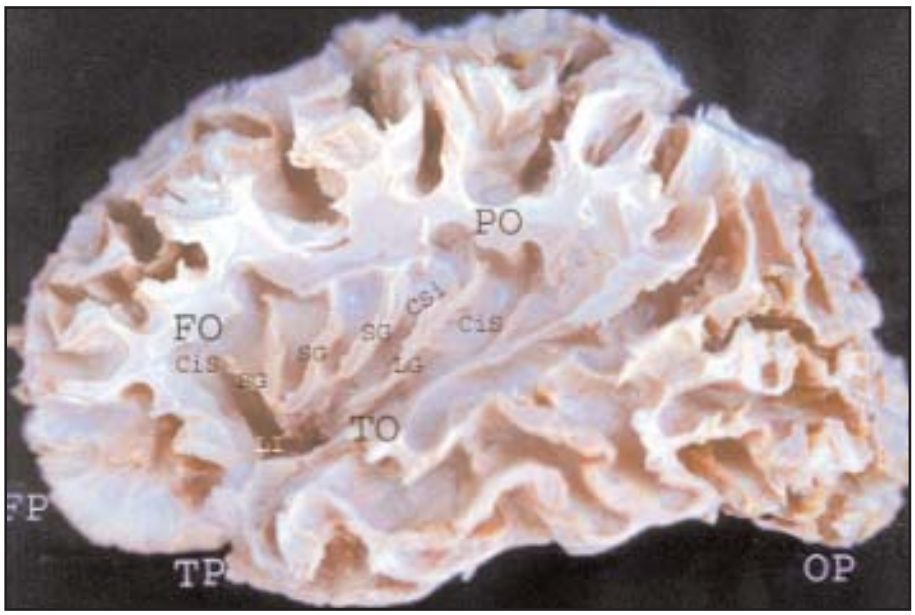

Fig 2. Insula region. FP, frontal pole; OP, occipital pole; TP, temporal pole; FO, frontal operacula; PO, parietal opercula; TO, temporal opercula; CSi, central sulcus of insula; SG, short gyrus of insula; LG, long gyrus of insula; CiS, circular sulcus of insula; LI, limen insula.

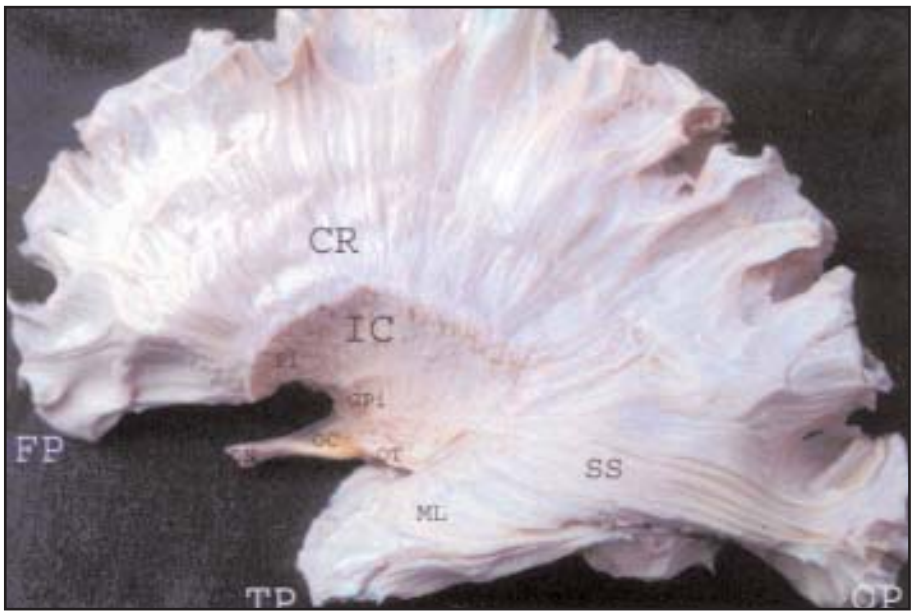

Fig 3. Optic pathway. CR, corona radiate; IC, internal capsule; P, putamen impression; GP, globo pallidum impression; ON, optic nerve; OC, optic chiasm; OT, optic tract; SS, stratum sagittal; ML, meyer loop.

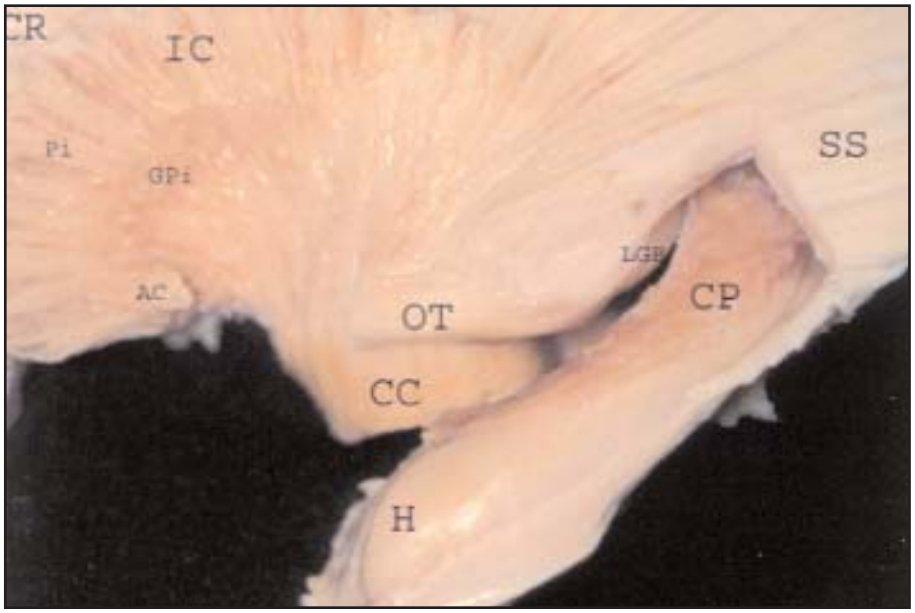

Fig 4. Internal capsule. P, putamen impression; GP, globo palidum impression; AC, anterior comissure; CC, crus cerebri; OT, optic tract; H, hippocampus; CP, choroids plexus.

mus towards the habenular trigone. In addition to the habenular trigone, the following components of the epithalamus can be distinguished: the habenular comissure, the pineal body and the posterior comissure. The posterior thalamic nucleus, known as pulvinar is demonstrated (Fig 6).

In this preparation the corpus callosum, caudatenucleus, and most of the brain stem structures have been removed. The thalamus is shown in the center of the picture. The thalamus is an important integrating center which receives sensory signals of various modalities, and transmits impressions to appropriate areas of the cerebral cortex. An extensive accumulation of the axons connecting various thalamic nuclei to practically all cortical areas is seen in a fan-like array and this, in three dimensions, re-

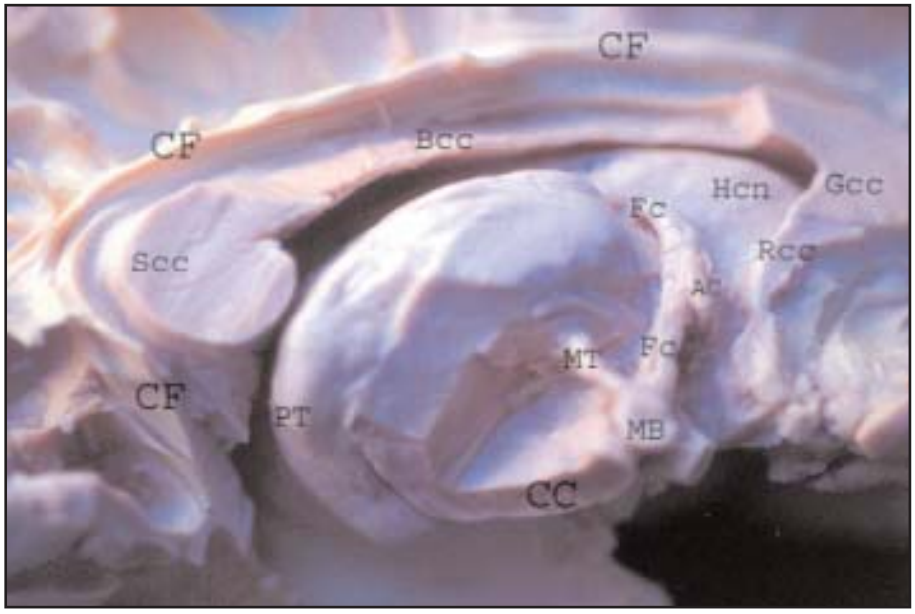

Fig 5. Medial aspect. CF, cingulate fascicullum; Rcc, rostrum of corpus callosum; Gcc, genu of cc; Bcc, body of cc; Scc, splenium of corpus callosum; PT, pulvinar thalamus; CC, crus cerebri; MT, mamilothalamic fascicullum; MB, mamilar body; Fc, fornix (columm); AC, anterior comissure.

Fig 6. Medial aspect. CCS, splenium of the corpus callosum; Fc, fornix (columm); AC, anterior comissure; MB, mamilar body; MI, massa intermedia (thalamus); SM, stria medullaris thalami; PC, posterior comissure; P, pineal gland; IF, intraventricu.

flects the profusion of the thalamic radiations. For descriptive purposes, different parts of the thalamic radiations are grouped into four thalamic peduncles. The anterior, superior, posterior and inferior peduncles are displayed (Fig 7).

The internal capsule and corona radiate have been exposed by removal of the corpus callosum, caudate nucleus and diencephalon. The most striking figure of this preparation is the convergence of the great masses of corticofugal fibers from extensive areas of cerebral cortex into the relativily narrow, but thick, basis pedunculi. Some torn fibers of the thalamic peduncles can still be identified. The stratum sagittal is also visualized (Fig 8).

Fig 7. Thalamic peduncles. A, anterior thalamic peduncles; S, superior; P, posterior; I, inferior; T, thalamus.

Fig 8. Medial aspect of the internal capsule. C, caudate nucleus; IC, internal capsule; CC, crus cerebri; SS, sagittal stratum.

DISCUSSION

Using fiber dissection techniques some early anatomists such as Vieussens, Willis, Steno, Bell, Reil and Foville could demonstrate many tracts and fasciculi of the brain[8,11-14]. In fact, the fiber dissection technique was one of the first methods used to demonstrate the internal structures of the brain[8]. An extensive historical review is beyond the scope of this paper and was made in an outstanding manner by Ture et al.[8], although we can not forget to mention the work of Joseph Kingler (1888-1963). He was an anatomist in Basel that made the greatest contribution to the fiber dissection technique. In 1935, he developed an improved method of brain fixation and a technique that now bears his name[9,10] (Kingler's technique). Like others, he dissected formalin-fixed brains with wooden spatulas. However, he froze and thawed the brains be-

fore dissection. Freezing helps to separate the fibers. His superb atlas containing detailed anatomic studies of the brain was published in 1956. Although his studies were impressive, this technique never became widely used[8-10].

While the freezing method is an aid to dissection and generally increases the distinction between the grey and white matter of the brain, it does not produce absolutely consistent results, as Kingler himself acknowledged[9]. As a rule, however, the technique makes it easier to prepare dissections of the both fiber tracts and nuclei.

Illustrations of the internal structures of the brain in current textbooks are usually pictures of sections or schematic drawings. Only few fiber dissections from earlier textbooks are still reproduced[8]. In Rhoton's masterpiece published in 2002 we can appreciate some superb pictures of white matter anatomy exposed. In this publication he described the white matter anatomy in detail. With the learning gained from the above mentioned dissections, the younger generation is stimulated to perform dissections on their own.

The evolution of neuroimaging techniques has imposed a greater demand of knowledge. Without the understanding of the three-dimensional intrinsic anatomy of the brain one can not interpret precisely the new neuroimaging studies such as "tractography". Diffusion-tensor MR imaging is a promising tool to evaluate white matter anatomy. The first attempt to visualize the white matter tract was made by Kinosada et al in 1993[2]. With best MRI devices using higher magnetic field such as 3.0 Tesla, better images are now available[4,5,7]. In the literature, one can find reports about the correlation of AVMs[6] or tumors[3] with the white matter tracts. We project that in a few years, these images will be essential for the precise diagnosis or treatment planning of many diseases of the central nervous system. According with Ture et al.[8] the fiber dissection technique is a demanding and time-consuming technique. The technique was somehow abandoned after the introduction of the microtome and histological preparations. The histological sections are very important to the interpretation of biplanar MRI films, but our ability to think in three dimensions should be stimulated. Therefore, the knowledge of intrinsic white matter anatomy is of great importance. The combination of histological techniques with fiber dissection technique improves the understanding and prevents misinterpretation of the complex anatomic features of structures. The first surgeon that gave attention to this technique was Yasargil[17].

After he gained knowledge with this technique, he applied it to all of his routine microsurgical procedures[15-17]. The goal of this manuscript is to stimulate the younger generation of neurosurgeons to acquire proficiency in fiber dissection technique and become experts in surgical neuroanatomic features.

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