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The heterogeneous space distribution of Superior Longitudinal Fascicle in human telencephalon. Neuronal imaging and forensic implications

Gheorghe S. Dragoi, Petru Razvan Melinte, Liviu Radu*

Abstract: The diversity of neuronal imaging methods especially after the implementation of DT-MRI offers the possibility to represent in space the fascicles inside the white matter of telencephalon. The understanding of the space heterogeneous distribution of the Superior Longitudinal Fascicle becomes possible after admitting the limitations of macro anatomic dissection as a research tool and the topographic variability of the fascicle's segments. The authors consider that a good visualization after the macro dissection of the Superior Longitudinal Fascicle is dependent of the processing of cerebral hemispheres by freezing and de-freezing the water inside neuronal tissue. Connections evaluation inside the neuronal system of Superior Longitudinal Fascicle is really useful for understanding symptoms of psychiatric illnesses or cranial encephalon posttraumatic syndrome.

Key Words: Superior Longitudinal Fascicle (SLF), DT-MRI (Diffusion Tensor Magnetic Resonance Imaging); Encephalon processing after Klingler Method, SLF segments.

The knowledge of nervous fibers fascicles stereo distribution inside the white matter of telencephalon is essential for the imaging evaluation of central neuronal system in ortology and pathology. The connections between cortical areas achieved by the fascicles network present inside the white matter is a marker for neuronal functional specialization. The macro anatomical visualization of neuronal fascicles is difficultly achieved under remarkable technical conditions and generates numerous questions:

- What are the determinant factors of structural heterogeneity and space distribution of nervous fiber fascicles inside the telencephalon white matter;
- When, how and why does it appear during ontogenesis dynamics, the fascicle differentiation inside the white matter;
- What is the functional and pathologic value of knowing the connection networks between cortical areas;
- What are the anatomic and functional evaluation criteria for the nervous fiber fascicles inside telencephalon white matter;
- What is the probative and informational value of knowing the stereo distribution and structural integrity of white matter fascicles in forensic and general pathology;
- What were the chemical basis for intuiting the existence of nervous fiber fascicles inside telencephalon white matter;
- What is the contribution of nervous fiber fascicles in the volume and density asymmetry between the dominant and non-dominant cerebral hemisphere;
- What are the research methods used to study the bi or tri dimensional distribution of the nervous fiber fascicles inside encephalon white matter;
- Is real dissection useful in order to achieve and interpret a virtual in vivo dissection by DT-MRI (Diffusion Tensor Magnetic Resonance Imaging);
- What are the forensic implications of the knowledge of nervous fiber fascicles morphology observed after virtual in vivo dissection.

The purpose of our paper is to try to visualize by macro anatomic dissection the structural segments of Superior Longitudinal Fascicle inside left telencephalon hemisphere. It is considered a three dimensional connection system between the cortical areas specialized in linguistic functions implemented in communication and exteriorization of thinking and feelings.

**) Corresponding author: Prof.Dr. MD, PhD, Member of Academy of Medical Sciences, University of Medicine and Pharmacy of Craiova, E-mail: dragoigs@yahoo.com*

The objectives of the paper are based on our experience in classic anatomic sculptural and layer by layer dissection in order to identify the location and space distribution of the structural elements inside Superior Longitudinal Fascicle of human telencephalon.

MATERIALS AND METHODS

We performed a macro anatomic analysis of the Superior Longitudinal Fascicle stereo distribution on two lots of encephalon. The first lot of five encephalon was harvested 24 hours after death and fixed in 10% formaldehyde solution for a long time (24-36 months).

The second lot of four encephalon harvested in the same conditions were fixed in 10% formaldehyde solution for four weeks. We performed the encephalon dissection differently. In case of the first lot, after washing the anatomic pieces for 24 hours with running water, we did the layer by layer macro anatomic dissection. The encephalon from the second lot were frozen at minus 18 degrees Celsius for four weeks; the dissection was performed after slow de-freezing at minus 5 degrees Celsius for 24 hours.The imagery was shot with a Digital Camera EOS Mark II with Macro Ultrasonic Lens EF 100 mm, f/2,8.

RESULTS

The macro anatomic dissection of telencephalon imposes the knowledge of the fiability limits of neuronal tissue. The visualization of the nervous fiber fascicles is dependent of the encephalon gradual fixation that depends on the concentration of formaldehyde solutions and the fixation time. An essential condition for the dissection of Superior Longitudinal Fascicle is the removal of cerebral cortex by freezing and de-freezing method initiated by Klingler (1935). Dissection was achieved on two lots: a lot with encephalon fixed for a long time in 10% formaldehyde solution (minimum 24 hours) a lot that undergone the freezing and de-freezing of the water inside the neuronal system after an initial fixation in 10% formaldehyde solution (minimum 4 weeks).

A. Macro anatomic dissection of cerebral hemispheres fixed for a long time in 10% formaldehyde solution.

The study was performed on encephalon fixed in 10% formaldehyde solution for 24-48 months. In a first stage, we separated the cerebral hemisphere by a mediosagital section. We used the left cerebral hemisphere that is more frequently implemented in linguistic functions. The leptomeninges together with the cerebral blood vessels were extracted from the grooves in between gyri (Fig.1 A, E). After sectioning the operculum adjacent to the lateral groove (Sylvius) we entered a cleavage subcortical space where we visualize the lateral face of capsula extrema (Fig. 1 B, F). At that level we noticed the presence of two structures that protrude under capsula extrema: an arched one with its convexity cranially orientated that is determined by the Superior Longitudinal Fascicle and another one situated inferiorly, convex laterally that correspond to claustrum (Fig. 1 B and H). The fiber fascicles from the structure of capsula extrema have a fan shaped radial distribution (Fig. 1 B). We created a “window” in the inferior third of capsula extrema in order to visualize claustrum and lentiform nucleus (Fig. 1 C and D).

B. Macro and mesoscopic dissection of cerebral hemispheres fixed in 10% formaldehyde solution and processed by Klingler technique.

1. Preparation of cerebral hemispheres for freezing the tissue water and the analyze of de-freezing effects.

We used encephalon fixed in 10% formaldehyde solution for minimum four weeks and then washed in running water for 24 hours. After removing leptomeninges afferent blood vessels we identified the gyri and grooves on the surface of frontal, parietal, temporal and occipital lobes. We froze a left cerebral hemisphere for four weeks at minus 18 degrees Celsius (Fig. 2 B, D, E). At the end of the freezing period the cerebral hemispheres were slowly de-frozen for five days at 5 degrees Celsius.

When examining the surface of gyri we easily noticed the depreciation of grey substance layer (cortex cerebri) that became spongy and friable (Fig. 2 F). Equally we used another 3 cerebral hemispheres without removing the leptomeninges and we processed them following the same freezing and de-freezing method.

2. Visualization of white matter after cerebral cortex removal.

The removal of grey substance from the de-frozen cerebral hemispheres was carried out gently using plastic spatulas and small metallic curettes. We performed de-cortication from the gyri surface towards the bottom of cerebral grooves. Afterwards we clearly saw the subcortical area of the white matter. The entirely decorticated surface is crossed by deep grooves delimited by walls formed of white matter. In some areas we identified prominences that created compartments inside the grooves (Fig. 3 A and B). We must emphasize that the removal of the grey matter is easy but requires patience, rigor and attention in order to maintain the integrity of the white matter structures (Fig. 4 A, B).

3. The analysis of the visualization stages of capsula extrema and the location of Superior Longitudinal Fascicle.

We identified two types of nervous fibers in the subcortical area: a) short fibers, “U” shaped, known as inter-gyri, arcuate or U fibers that connect two neighboring gyri; b) vertical fibers or long association fibers. The first group of fibers was visible at the surface of white matter and the second one in its deep area (Fig . 4).

The Superior Longitudinal Fascicle appears after seeing the capsula extrema; underneath, protrude the sectors of that association system (Fig . 4 B).

4. The analysis of location, shape and structural segments of Superior Longitudinal Fascicle.

After visualizing the Superior Longitudinal Fascicle we continued with the removal of grey matter and of short fibers adjacent to the frontal, temporal and parietal operculum, middle and superior frontal, middle temporal and inferior parietal gyri. The removal of short fibers revealed the long association fibers with variable trajectories: horizontal, vertical or arcuate. We observed and followed the trajectory of the frontal fibers from Superior Longitudinal Fascicle until they reached the inferior parietal pole. That group of fibers forms the frontal-parietal segment or “horizontal” segment of Superior Longitudinal Fascicle (Fig . 5 A).

At the temporal-parietal junction area we identified a group of vertically oriented fibers located between the posterior part of superior and middle temporal gyri and the inferior part of parietal lobe. It forms the temporal- parietal or “vertical” segment of Superior Longitudinal Fascicle (Fig . 5 A). In the deep part of temporal-parietal area, there is a group of arcuate fibers situated on the posterior and superior border of isle lobe; they pass between the posterior temporal region and prefrontal area. Those form the frontal-temporal or “arcuate” segment of superior longitudinal fascicle (Fig . 5 A). Another group of fibers was identified in the depth of temporal-parietal segment and it passes posteriorly starting from the anterior part of temporal lobe. That group of fibers form “the Inferior Longitudinal Fascicle” or the temporal-occipital fascicle located laterally from optic radiation (Fig . 5 B; Fig . 6B).

DISCUSSIONS

The encephalon elements are organized in differentiated neuronal structures that include specialized “cerebral areas” towards which converge white matter fascicles that ensures the inter-connectivity. Nowadays it is accepted that Superior Longitudinal Fascicle is a major association path between parietal temporal to frontal areas and vice versa.

A. Consideration on architecture and relations of the association fiber system from the structure of Superior Longitudinal Fascicle.

The Superior Longitudinal Fascicle was largely debated in the history of medical sciences regarding: name, terminology, segments, structure, connectivity and last but not least regarding the techniques for visualization.

Reil and Autenerieth (1809) were the first to identify a group of nervous fibers in the white matter of temporal, parietal and frontal regions that was distributed along the Sylvius groove.

Later, Burdach (1822) described in detail this fascicle of fibers and named it “Fasciculus Arcuatus”. Dejerine (1895) confirmed the presence of arcuate fascicle and recognize it belonging to Burdach. Equally, Dejerine thought that the arcuate fascicle is made mainly of short association fibers that connect the cortex around Sylvius groove. Wernicke (1874) launched the hypothesis according to which the language is bound to the integrity of a “psychic reflex arc” between the temporal and frontal regions.

Nevertheless, the arcuate fascicle was not include in Wernicke’s original anatomic model as a connection between Broca and Wernicke areas. The role of the arcuate fascicle as a connector between Broca and Wernicke areas was not accepted by Wernicke until late 1908. Although the superior longitudinal fascicle was recognized to contribute to language related processes, there still remained many terminology problems. Nieuwenhuys *et al.* (1988), Wakana *et al.* (2004) considered as Dejerine (1895) that there is a single structural unit named as the superior longitudinal fascicle that is synonym to arcuate fascicle described by Burdach (1822). This concept was accepted by the Committee of the International Anatomic Terminology (1988). There is also another group of researchers that consider the existence of two independent fascicles: Superior Longitudinal Fascicle and Arcuate Fascicle (Carpenter, 1991; Mori *et al.*, 2002; Rhoton, 2002; Catani *et al.*, 2002, 2005). This last statement is unanimously accepted in comparative anatomy.

A. Observations on the importance of knowing the morphology of Superior Longitudinal Fascicle in neuroimaging, neurosurgery and forensic medicine.

Anatomic information about the location and trajectory of the Superior Longitudinal Fascicle structural elements came from postmortem dissection. Lately the Superior Longitudinal Fascicle was described using DT-MRI technique (Diffusion Tensor Magnetic Resonance Imaging) (Catani *et al.*, 2002; Mamata *et al.*, 2002). By means of this technology, Makris *et al.* (2005) identified in huma some component segments that included the arcuate fascicle.

Geschwind (1965) revolutionized neurosciences by introducing the concept of disconnection and states the “disconnections syndrome” determined by lesions of white substance or cortical areas. It is mentioned in schizophrenia (Bullmore *et al.*, 1997), autism (Frith, 2000) and dyslexia (Demonet *et al.*, 2004).

The knowledge of the location of major tracts and of the interconnected cortical areas is important for the understanding of symptoms in the context of encephalon traumatic lesions. In case of lesions involving the Superior Longitudinal Fascicle of left cerebral hemisphere, one might encounter: conduction aphasia, depression and ideational apraxia (Taber *et al.*, 2007).

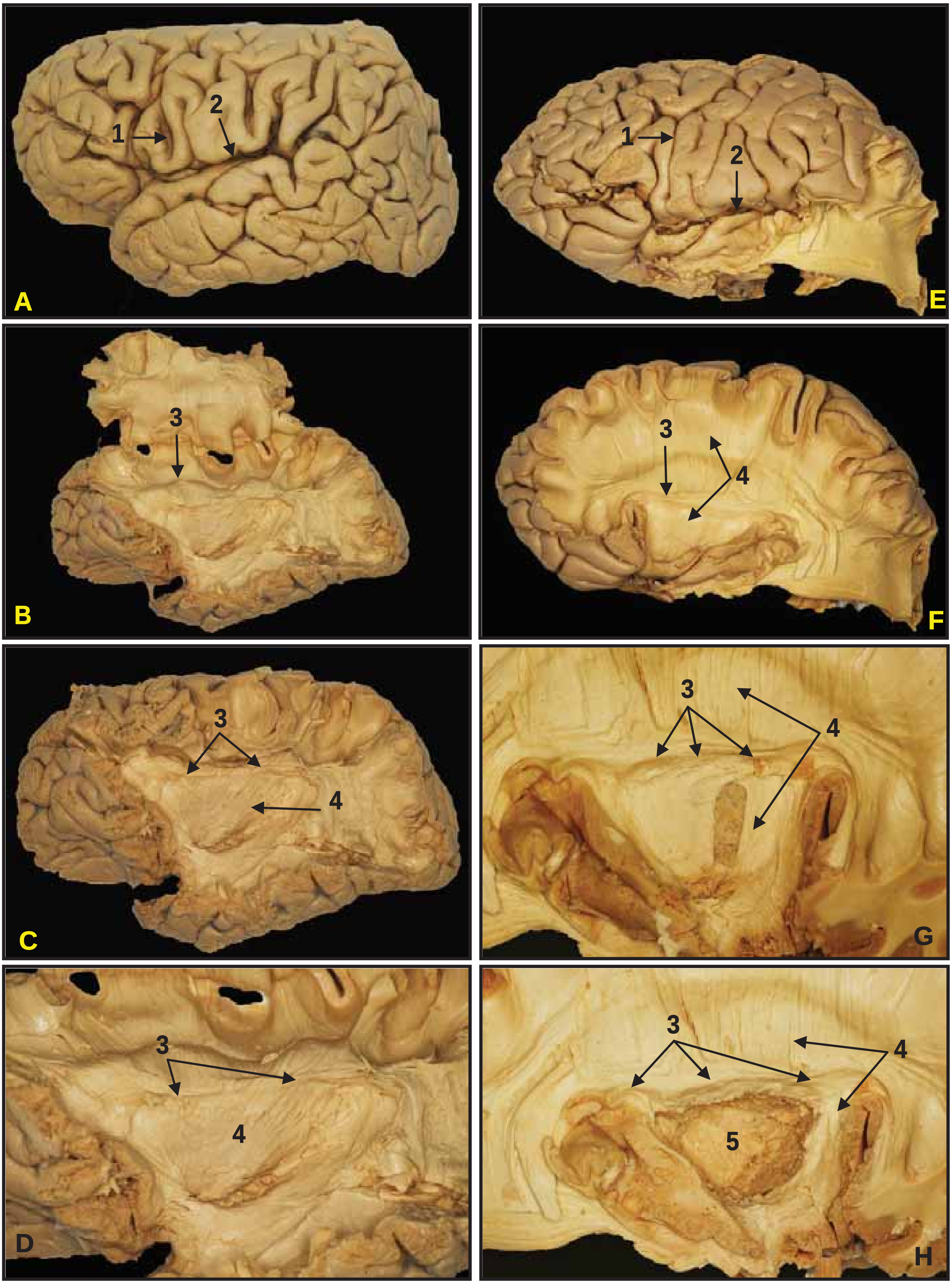

Figure 1. Visualization of the Superior Longitudinal Fascicle on a left cerebral hemisphere that was fixed in 10% formaldehyde solution for 2 years. 1. Sulcus centralis; 2. Sulcus lateralis; 3. Fasciculus Longitudinalis Superior; 4. Capsula extrema; 5. Claustrum. Macro photos by Canon EOS Mark II Digital Camera. Macro Ultrasonic Lens EF 100mm, F/2.8.

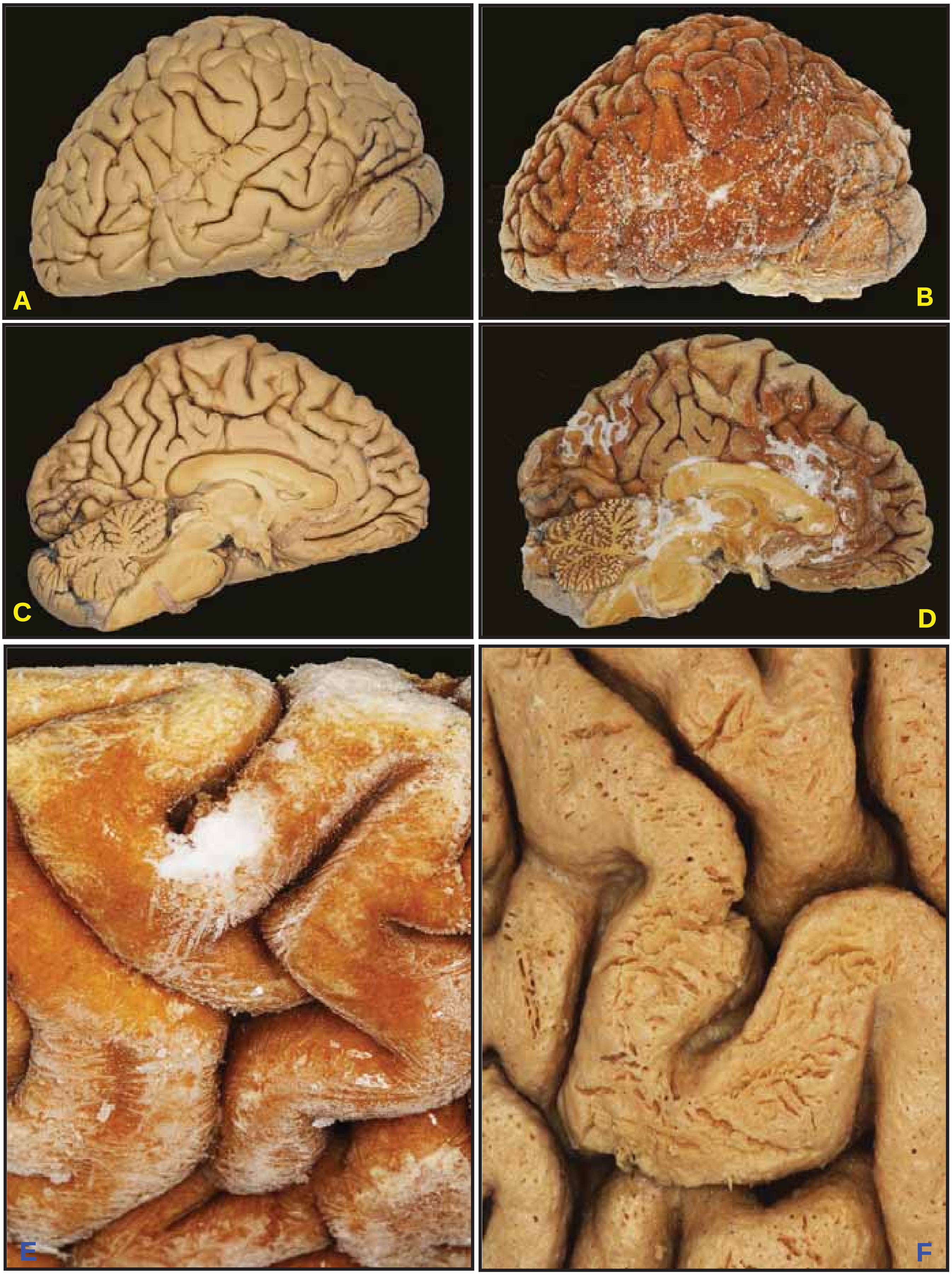

Figure 2. The effects of water freezing and de-freezing inside the structures of the neuronal system. A, C: Before freezing; B, D, E: After freezing; F: Cortical gyri become spongy after de-freezing. Macro photos by Canon EOS Mark II Digital Camera. Macro Ultrasonic Lens EF 100mm, F/2.8.

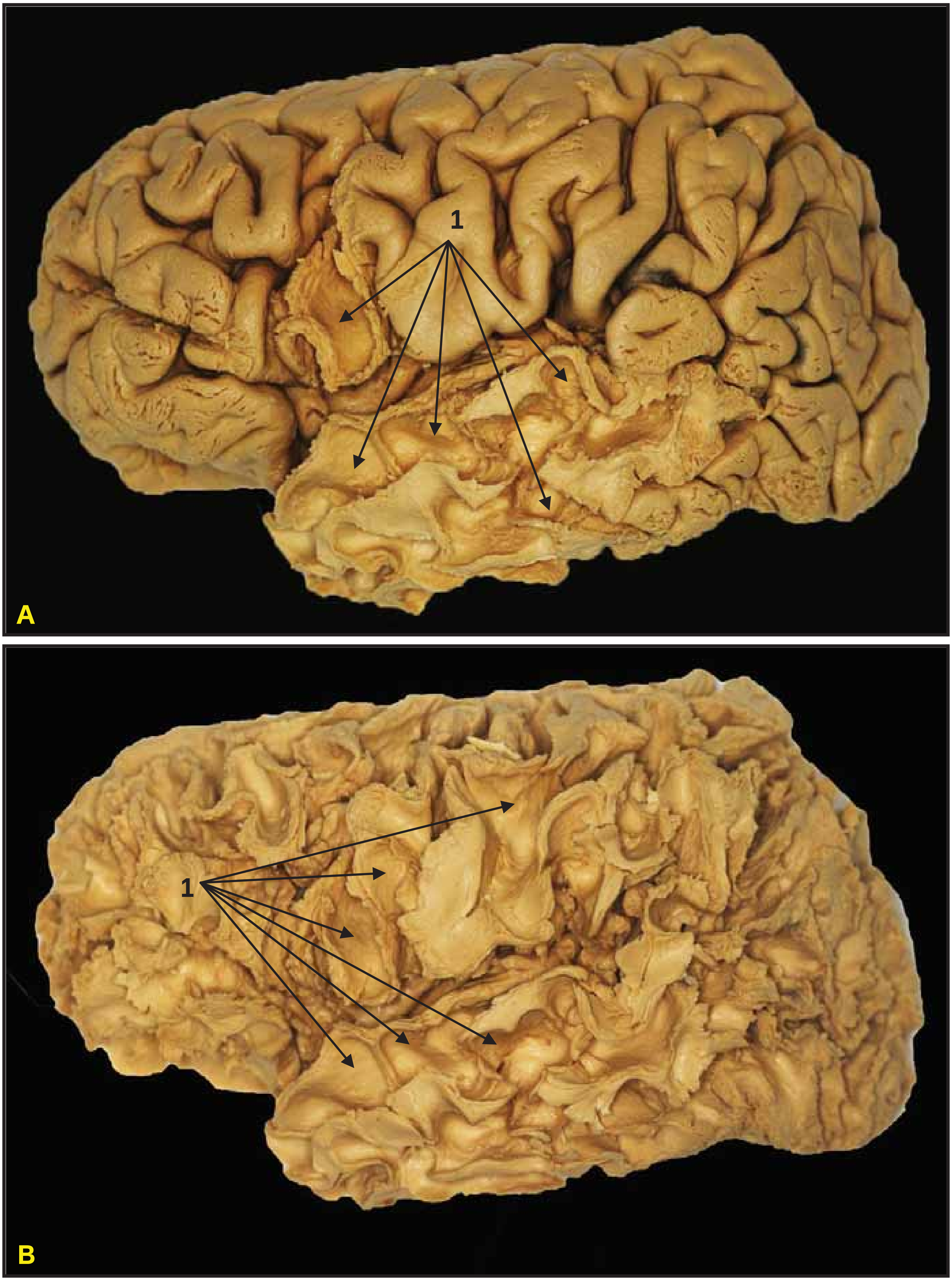

Figure 3. Left cerebral hemisphere after de-freezing. The cerebral cortex was removed from the gyri surface towards the cerebral grooves. The removal of the cerebral cortex ensures the visualization of the white substance fascicles that delimit variable depth excavations (1). Macro photos by Canon EOS Mark II Digital Camera. Macro Ultrasonic Lens EF 100mm, F/2.8.

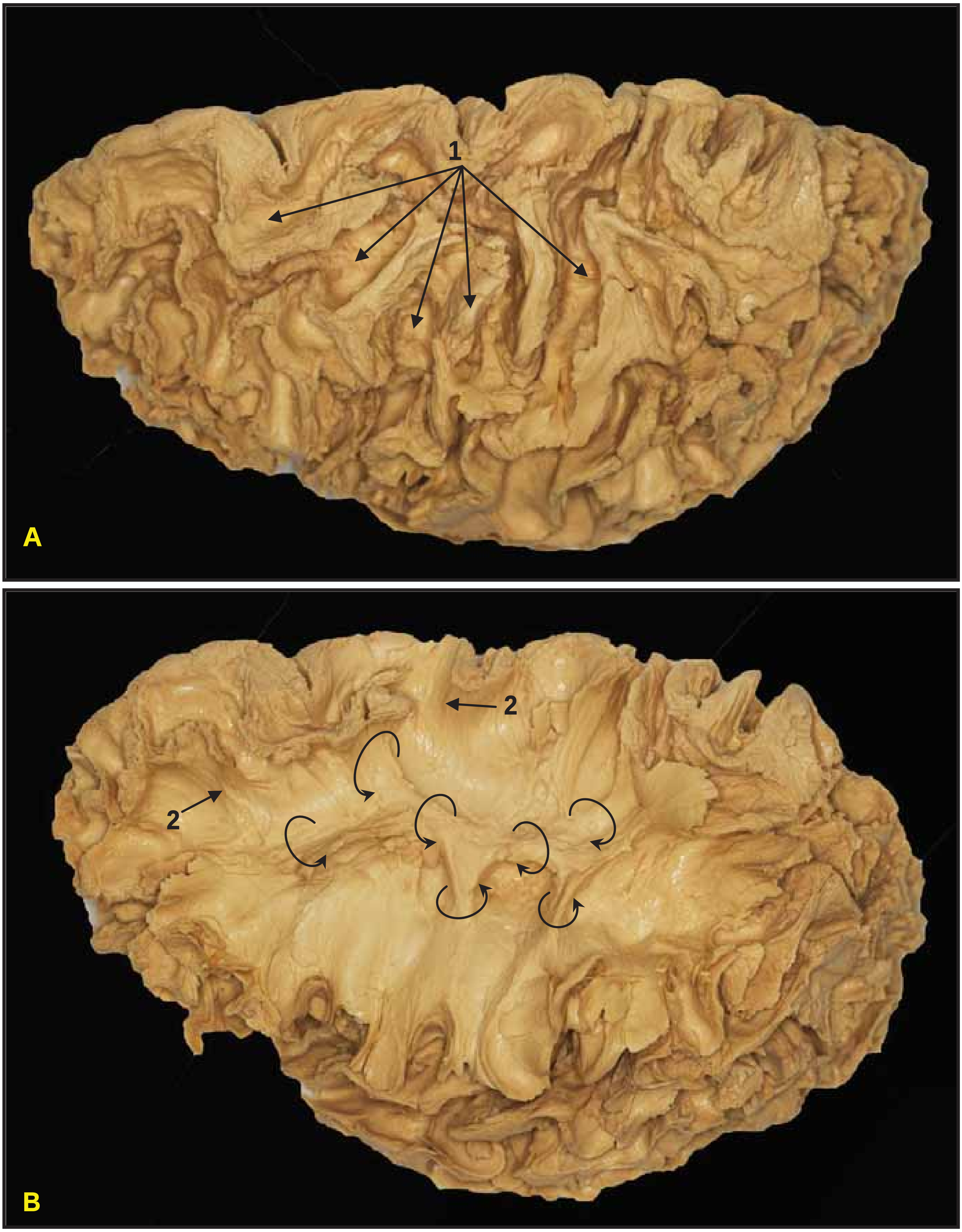

Figure 4. Dissection stages of a de-frozen left hemisphere for the visualization of the superior longitudinal fascicle. A. The superior-lateral face of cerebral hemisphere is crossed by excavations after the removal of cerebral cortex from gyri structure (1); B. Visualization of extreme capsule and of prominences determined by the segments of the Superior Longitudinal Fascicle; the last ones are pointed with arch arrows. Short association fascicles are visible (2). Macro photos by Canon EOS Mark II Digital Camera. Macro Ultrasonic Lens EF 100mm, F/2.8.

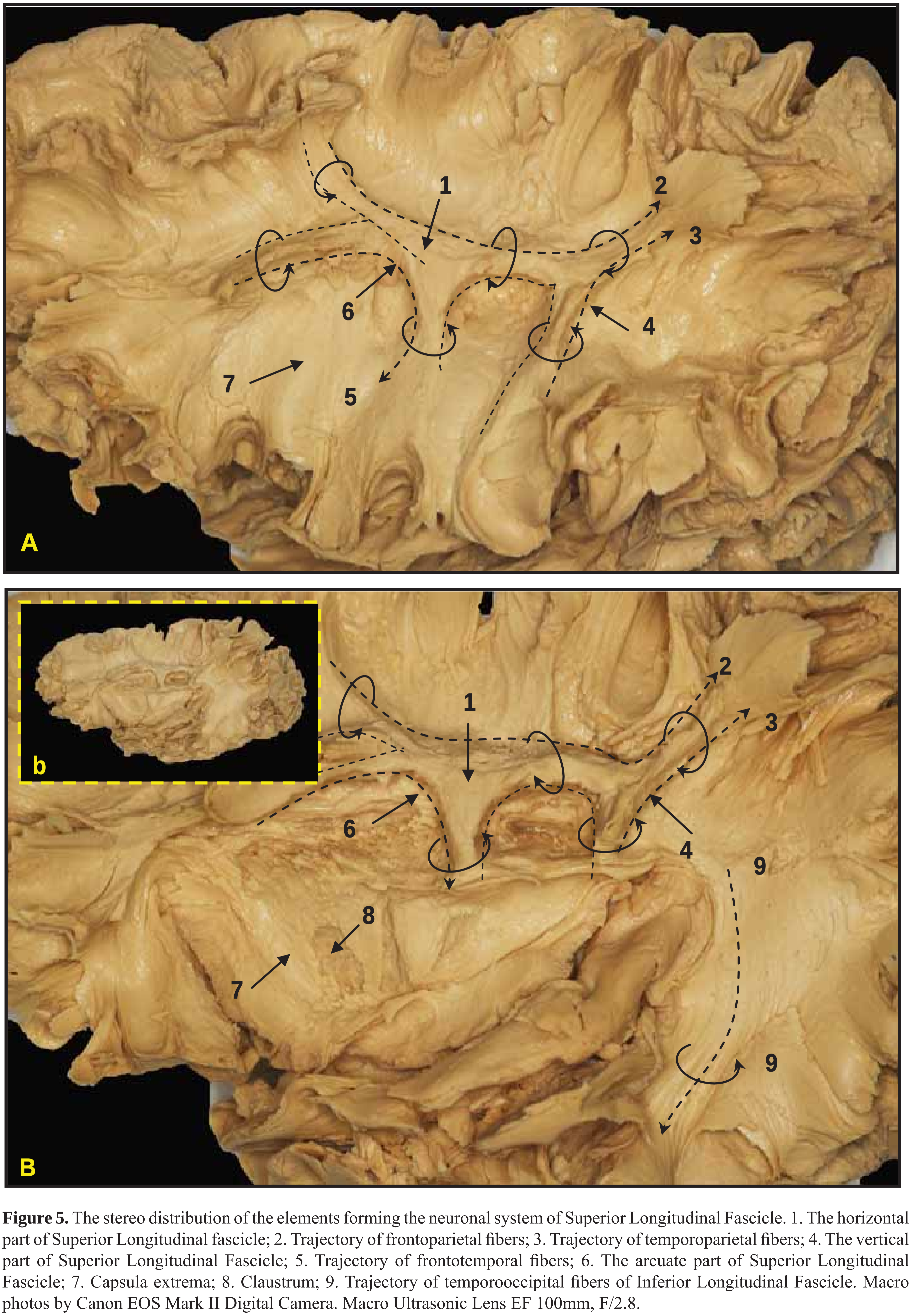

Figure 5. The stereo distribution of the elements forming the neuronal system of Superior Longitudinal Fascicle. 1. The horizontal part of Superior Longitudinal fascicle; 2. Trajectory of frontoparietal fibers; 3. Trajectory of temporoparietal fibers; 4. The vertical part of Superior Longitudinal Fascicle; 5. Trajectory of frontotemporal fibers; 6. The arcuate part of Superior Longitudinal Fascicle; 7. Capsula extrema; 8. Claustrum; 9. Trajectory of temporooccipital fibers of Inferior Longitudinal Fascicle. Macro photos by Canon EOS Mark II Digital Camera. Macro Ultrasonic Lens EF 100mm, F/2.8.

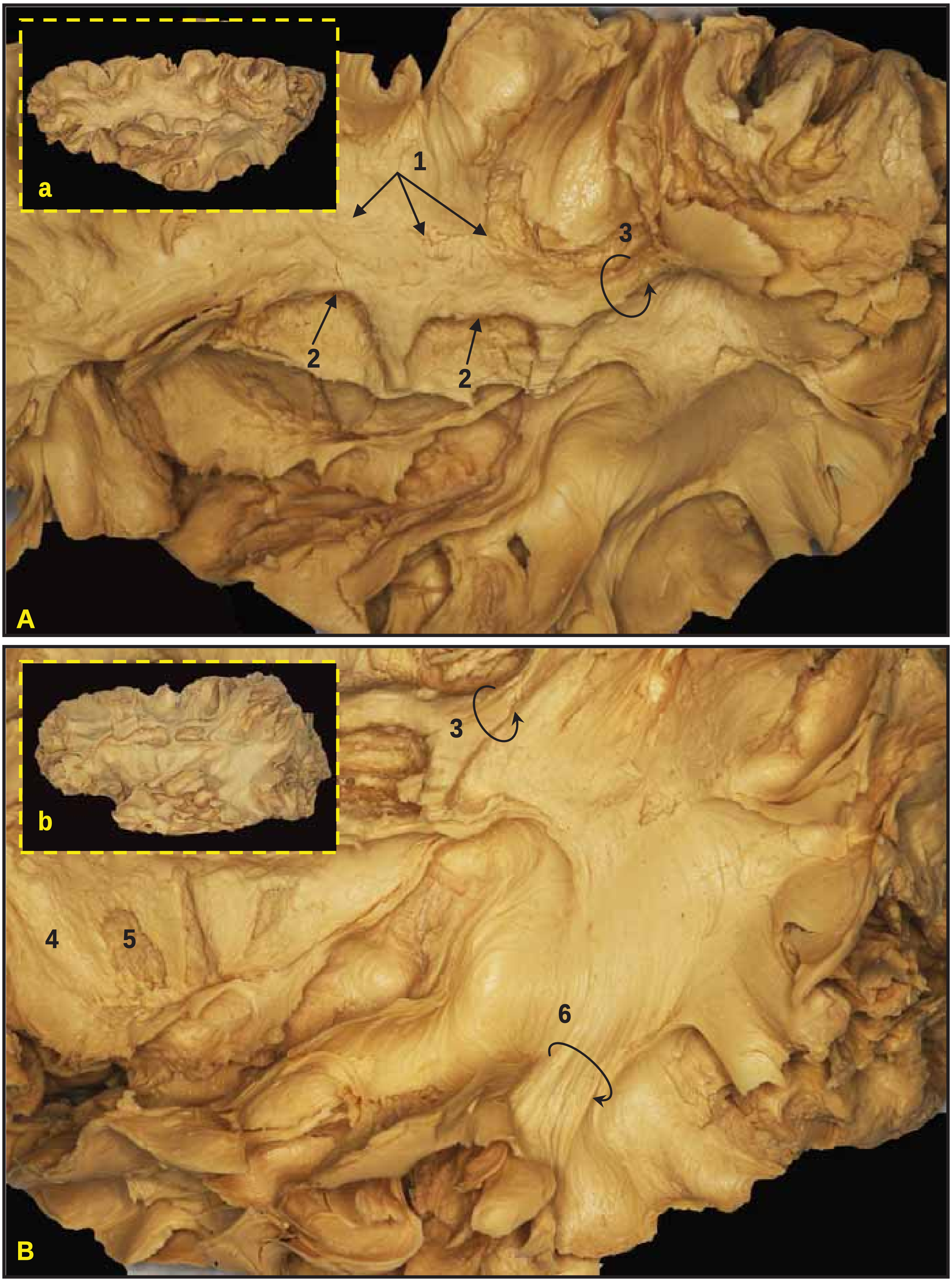

Figure 6. The relations of the posterior extremity of superior longitudinal fascicle. 1. Superior face of SSuperior Longitudinal Fascicle; 2. Lateral margin; 3. Parietal segment; 4. Capsula extrema; 5. Claustrum; 6. Inferior Longitudinal Fascicle. Macro photos by Canon EOS Mark II Digital Camera. Macro Ultrasonic Lens EF 100mm, F/2.8.

The physiopathology of schizophrenia remains unknown although studies of functional neuroimaging demonstrated the implication of frontal and temporal regions (Shergill *et al.*, 2000;2007; Kircher *et al.*, 2001). The models proposed consider that symptoms reflect frontal and temporal functional disconnections (Frith *et al.*, 2000).

CONCLUSIONS

1. The knowledge of the space distribution and heterogeneity of the segments of Superior Longitudinal Fascicle by macro anatomic dissection is really necessary for an accurate neuroimaging evaluation achieved by DT-MRI technique.
2. The identification of the location for Superior Longitudinal Fascicle and its segments by real dissection becomes possible on encephalon processes by freezing and de-freezing water inside neuronal tissue.
3. Superior Longitudinal Fascicle is a marker for the specialized linguistic functions with great proof value in pathology due to disconnections between segments of its neuronal system.
4. The knowledge and evaluation of disconnections inside Superior Longitudinal Fascicle neuronal system is useful in understanding symptoms in schizophrenia, autism, dyslexia and in posttraumatic cranial and encephalic syndrome.

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