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ORIGINAL ARTICLE

Image-guided dissection of human white matter tracts as a new method of modern neuroanatomical training

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Neuronavigation is a kind of image-guided surgery used during neurosurgical procedures. Based on specific equipment which is compatible with the software calculating and processing the patient's data; this method allows the determination of the location of anatomical structures and visualisation of surgical instruments in the operative field. Although standard brain dissection is still the best method of neuroanatomical training, some limitations occur. The most important of these is the inability of conversion from three-dimensional (3D) view to flat pictures of the brain structures, as viewed on computed tomography (CT) and magnetic resonance imaging (MRI), being essential in neuroanatomical training nowadays. The aim of the study was the implementation of a neuronavigating system for brain anatomy training purposes. The study was performed on 10 human brain hemispheres, dissected due to classical methods (standard brain anatomical sections, stepwise ventricular system opening and partial dissection of white matter tracts using Klingler's dissection technique). The material was scanned in a 1.5 T magnetic resonance scanner using a modified neuronavigation protocol. The brains were prepared before dissection as proposed by Klingler. The subsequent steps of the dissection were documented with a digital camera. The progress of the dissection was visualised using the neuronavigation system (Medtronic Stealth Station Treon) with cranial application software. In the course of the study, numerous 3D and 2D images were obtained. The images were related to each other and linked anatomical structures in the specimen with their appearance on CT and MRI scans. The implementation of a neuronavigation system for brain structures dissection facilitates visualization and understanding of their proper location. This new method offers a constant and precise orientation and simplifies understanding of the relation of the 3D view of a specimen to that of the 2D image. (Folia Morphol 2009; 68, 3: 135–139)

Key words: neuronavigation, white matter tracts dissection

INTRODUCTION

Recent achievements in neuroimaging and computer visualization methods have created new opportunities for neuroanatomical training. Magnetic resonance imaging (MRI)-based models gave a unique insight into the structure and function of the human brain. Both these elements can now be combined in order to show how particular systems work together [3, 4, 7, 9, 13]. Examples of implementation of modern methods are numerous:

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functional MRI helps in understanding the functional arrangement in the cerebral cortex and subcortical areas, and DTI tractography shows directions of white matter tracts [1, 14, 18]. The advantages of MRI compared to computed tomography (CT) scans are not only its higher resolution, but also the possibility of its implementation in further processing for the creation of three-dimensional models, thus making brain topography easier to understand. The usefulness of these solutions is proved by the introduction of such methods of training to many practical courses for neuroradiologists, and neurological and skull base surgeons [12].

There are two educational approaches: classical — based on personal investigation of the human brain [6, 8, 13, 19], and modern — referring to neuroimaging methods [1, 7, 21]. The point of view is distinct both for neurosurgeons and for neuroradiologists. An image acquired by a computer has different characteristics from those that can be seen intraoperatively. Thus, both approaches, even though correct, may present diverse insights into the same structure. Moreover, virtual models cannot be dissected personally by an investigator, which makes them less reliable as far as neurosurgical training is concerned. An introduction of image-guided systems created new possibilities for brain investigation.

A major problem in combining classical and modern methods of neuroanatomical training is the difficulty in relating flat, two-dimensional pictures obtained in MRI examination to real three-dimensional fixed brain specimens that are the object of dissection. MRI-based methods are used rather for the examination of living patients and have not been implemented for anatomical specimens so far. Therefore, the aim of our study was to determine the course of white matter tracts by both dissecting specimens and using a neuronavigation system.

MATERIAL AND METHODS

The study was performed on 5 brain specimens (10 hemispheres) from adult cadavers with no intracranial pathology nor description of such in their medical history. The whole material was fixed in 4% formaldehyde solution and further prepared for dissection as proposed by Klingler [10]. All the brains were frozen down to –10°C and defrosted several times. According to the method of preparation described by Klingler, growing ice crystals separated white matter tract fibres from one another and enabled them to be dissected further. Before the dissections, all brains were scanned in a Phillips 1.5 T magnetic resonance scanner with the use of a modified neuronavigation protocol (eFilm Lt). For the dissections, we used wooden blunt-ended spatulas. The dissection was supported by a neuronavigation system (Medtronic Stealth Station Treon) with cranial application software. Our workstation consisted of the dissection workstand and neuronavigation devices including the reference frame, pointer, and a neuronavigator. The neuronavigation system is a kind of image-guided surgery method. It is a tool used mostly to support a surgical procedure which cooperates with a computer that process the patient's data and visualizes brain structures together with surgical instruments in the operating field registered in a software-specific environment. It is composed of a central unit and a set of devices that reflect an infra-red signal created by a transmitter and registered by a detector. The reference frame defines a space around the patient and provides a reference point for the computer. A mobile pointer can be detected within the operative area and tracked on the screen. The neuronavigation system uses patient-specific landmarks, basing on shapes or protuberances on the skull and face. Previously performed MRI scans of the brain are registered and a virtual three-dimensional model is thus created [22].

The dissection was performed starting from the superolateral surface on each side with following opening of ventricular system and dissection of white matter tracts according to Klingler's method. We used a self-made protocol of dissection including main target structures for white matter, such as corona radiata, corpus callosum, commissures and internal capsule. All steps of dissection were documented with a digital camera and the accuracy of MRI findings were measured with the neuronavigator-related software.

RESULTS

The preparation prior to dissection allowed us to dissect carefully targeted white matter tracts we had identified on MRI scans with a sensitivity of 87%. We recognized, by dissection, 122/140 targeted landmarks according to the protocol. In 10/10 cases after crossing the superficial layer of the pallium we reached the corona radiata and documented its relation to the genu (10/10) and splenium (10/10) of corpus callosum. Then we targeted the internal capsule and dissected its genu (9/10) as well as its anterior (8/10) and posterior limb (6/10). Successful targeting was possible thanks to exact image guidance and prior brain freezing. In these cases we were able to find the borders of the internal capsule with no damage caused by the dissection instruments. We also found the anterior commissure in all cases and the commissure of fornix in 6/10 cases.

Targeting the internal capsule, although supported by the neuronavigation system, presented some complications, especially in its retrolentiform and sublentiform portions. Numerous white matter laminae marked the borders of the basal ganglia, making us confused about the boundaries of the internal capsule.

The external capsule was found successfully in 7/10 cases. The only problematic question was the boundary of the claustrum, fusing with it externally, in 4/10 cases thin for 0.5–0.7 mm in the horizontal plane, which could be missed by the investigator or confused with a cortex of insula.

We managed to target all horns of the lateral ventricles (30/30). The most difficult was a temporal horn because of numerous white matter fasciculi around it causing misinterpretations concerning the direction of dissection.

Single fibres were identified in 8/10 cases for short and long association fibres and 8/10 cases for uncinate fasciculus. In all cases, our target was to reach the external border of the structure, so those that we cut or damaged in another way were considered to give a negative result of dissection for the protocol.

The neuronavigator measurements marked a range of indication accuracies from 1 to 2 mm. A mobile neuronavigation pointer showed the current position of the dissecting instrument so that we could always be precisely oriented within the specimen (Fig. 1–4).

DISCUSSION AND CONCLUSIONS

Neuronavigation-guided stepwise dissection allowed us to identify precisely the structures we wanted to reach. White matter tracts are difficult to dissect and show separately. This is mainly because they constitute parts of major neuronal systems, i.e. components of the limbic system or corticostriatal circuit. This fact usually makes them impossible to separate from an entire brain specimen, and thus their structure, shape, and connections may be taught only with the use of supporting models or neuroimaging techniques. However, MRI or CT scans, which are implemented for clinical anatomy courses, do not always present the structure as it is, because they depend on technical conditions (head positioning, features of device). Moreover, for neuroanatomy courses dedicated to neurosurgeons, practical dissection studies should result in gaining experience about the location of the structures and some typical surgical approaches to particular regions. The supporting methods are unable to provide the same experience [9, 13, 15].

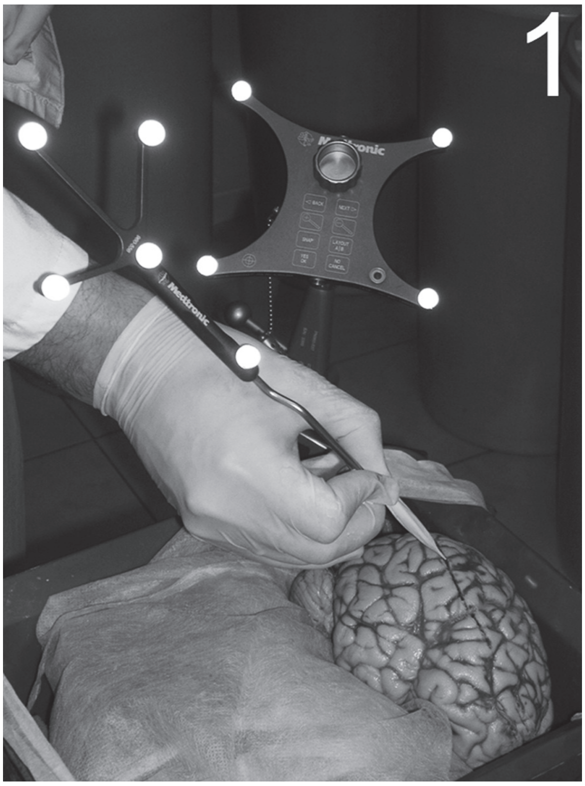


Figure 1. Registration procedure: reference frame and a pointer matching the brain surface structures to magnetic resonance imaging landmark points.

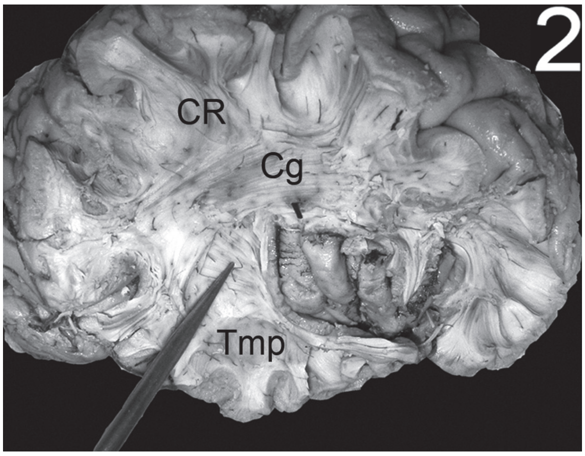
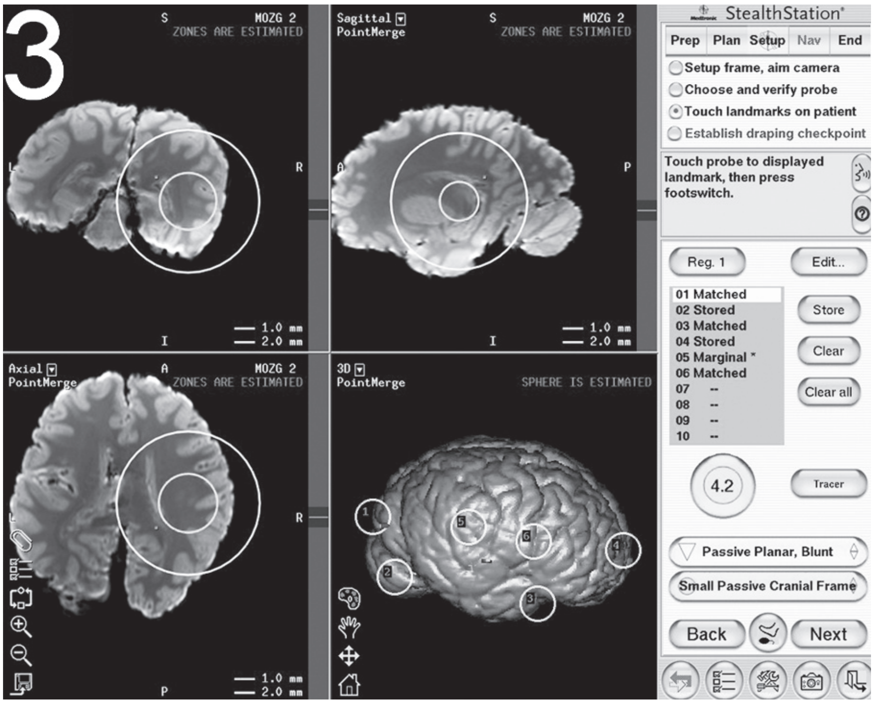


Figure 2. Dissection of right brain hemisphere: white matter tracts are exposed to view according to neuronavigation indications; CR — corona radiata, Cg — cingulum, Tmp — cortex of temporal lobe.



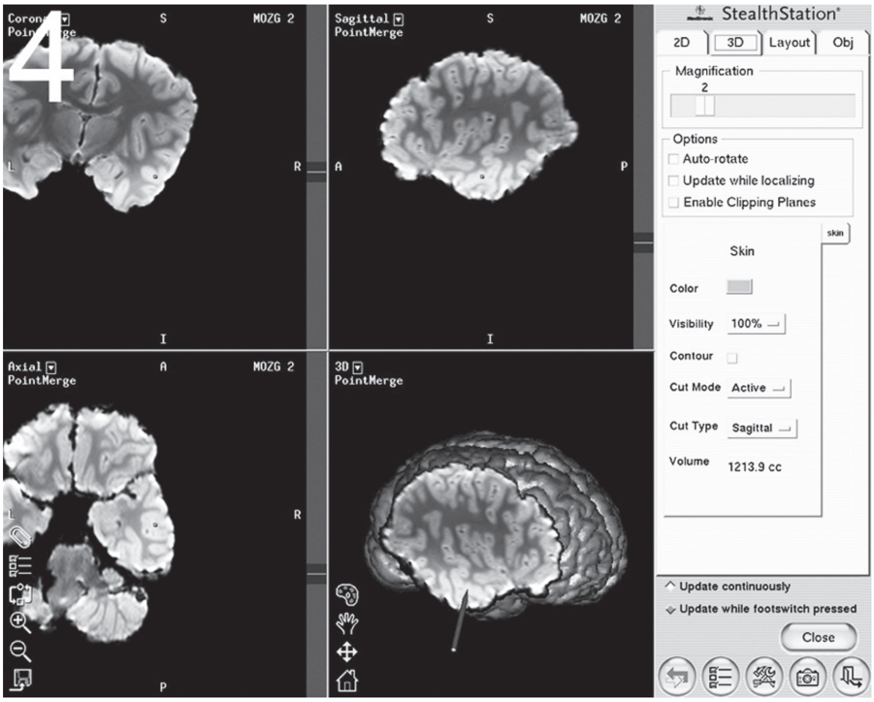
○ Setup frame, aim camera
○ Choose and verify probe
● Touch landmarks on patient
○ Establish draping checkpoint

Touch probe to displayed landmark, then press footswitch.

01 Matched
02 Stored
03 Matched
04 Stored
05 Marginal *
06 Matched
07 --
08 --
09 --
10 --

Passive Planar, Blunt
Small Passive Cranial Frame

Figure 3. Neuronavigation registration: landmarks indicated by a pointer are registered with a 1.0 and 2.0 mm range of indication accuracy.



Magnification 2

Options
☐ Auto-rotate
☐ Update while localizing
☐ Enable Clipping Planes

Skin
Color
Visibility 100%
Contour ☐
Cut Mode Active
Cut Type Sagittal
Volume 1213.9 cc

Update continuously
Update while footswitch pressed

Figure 4. Neuronavigator on-line indications: a probe shows the position of the pointer.

The implementation of Klingler's method of dissection for white matter tracts and prior preparations also gave us the possibility to observe more precisely the directions of fibres: especially association and commissural fibres. Using blunt wooden instruments minimizes the possibility of damage to delicate fibres [8, 10, 11, 19]. Thanks to this fact, we could easily dissect them from deeper grey matter nuclei and thus show the relations between the tracts and basal ganglia. Such findings may be used furthermore to create new dissection-based models and graphs. The pictures we made with a digital camera may provide valuable support for interactive presentations designed for medical students or participants in courses of detailed neuroanatomy. However, the results of our study cannot be applied for intraoperative surgical dissections because of the different consistency of nervous tissue.

Neuronavigation-related software provided safety and care in our dissections. Thanks to its indications and measurements, we could not only identify white matter tracts and compare them to other scans or specimens, but also find the borders between structures. Some elements might not have been dissectable, as was reported by other authors [2, 8, 9, 13, 16, 20], because of their external resemblance, but the implementation of MRI scans and the combination of them with the real dissection facilitated the distinguishability between two fusing or similar structures, in most cases. However, the 1–2 mm range of precision still produces a slight uncertainty during 13% of dissections.

We think that the implementation of the image guidance significantly improved our dissections and gave a required insight into the spatial arrangement of white matter tracts. The accuracy of dissection and the possibility to compare online the neuroimaging scans with the real specimen provide more advantages and valuable knowledge than classical methods. This combination may be used to prepare specimens focused on particular circuits and functional systems for anatomical exhibitions.

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