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Less Traumatic Technique to Access Deep Brain Lesions with the "Doigt-De-Dieu"

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ABSTRACT

We describe a less traumatic technique of resecting deep brain lesions situated near vital neuronal pathways and centres. By combining preoperative diffusion tensor imaging (DTI), neuronavigation and intraoperative magnetic resonance imaging (iMRI), this simple technique can achieve complete resection of these high-risk lesions with no or minimal post-operative deficits.

Keywords: Less traumatic transcerebral dissection; Deep brain lesion; Diffusion tensor imaging; Neuronavigation; Operative technique

Abbreviations: D^3: Doigt-de-Dieu; DTI: Diffusion Tensor Imaging; MRI: Magnetic Resonance Imaging; iMRI: Intraoperative Magnetic Resonance Imaging; NF-1: Neurofibromatosis 1

INTRODUCTION

Modern neurosurgery offers many tools to minimize tissue damage without compromising results [1-7]. Yet, resecting deep lesions adjacent to eloquent brain areas may still result in functional loss from dissection injury of the lengthy surgical path [8]. Preoperative diffusion tensor imaging (DTI) helps to identify and locate functional pathways in relation to the target lesion and enables the surgeon to plot the least destructive surgical path to the target [9], whilst intraoperative navigation ensures adherence to this safe path during surgery. Still, the sharp cleaving and separation of normal brain tissue by surgical instruments could lead to permanent functional loss if the surgical path lies among crowded fibre tracts or neuronal clusters. We developed a technique that enables gentle tissue separation without sharp dissecting instruments or the need for forceful prying with brain retractors, which we call the "Doigt-de-Dieu" (Finger of God). In this manuscript, we describe this technique and present two illustrative cases in which deep lesions in eloquent areas were completely removed without postoperative neurological deficits.

METHOD

Preparation of the "Doigt-de-Dieu"

The backbone of this device is the Medtronic Navigation probe originally designed for accurate placement of ventricular catheter. It is in the shape of a christian cross, with the three short limbs of the cross each bearing an optical tracking ball, and the long limb of the cross made slender enough to fit inside a regular ventricular catheter, with its tip acting as the target point at a fixed preset distance from the tracking balls (**Figure 1A**). A ventricular catheter is fitted over the navigation probe, with the exact distance between cortex and target surface (as shown on the navigation images) pre-marked on the catheter with a 4-0 neurulon ligature.

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A 3-French, single lumen, semi-rigid, polyethylene cannula fitted with an injection port and a single opening at the tip, is tied alongside the catheter-navigation probe with several 4-0 neurulon ligatures (**Figure 1B**). A 5 to 7 cm glove finger cut from a size 10 latex surgical glove is now fitted over the entire cannula-catheter-probe assembly. The glove finger is carefully flattened by expelling interior air, and then tied tightly near its open end to the probe with a 2-0 Neurulon ligature (**Figure 1C**). The length of the glove finger must be adequate to span most if not all of the pre-measured cortex–to-target distance. Thus, the navigation probe functions as a path-finding stent, and the adjacent polyethylene cannula permits the injection of sterile saline into the glove finger to inflate it into a potential surgical corridor for the target lesion concerned (**Figure 1D).**

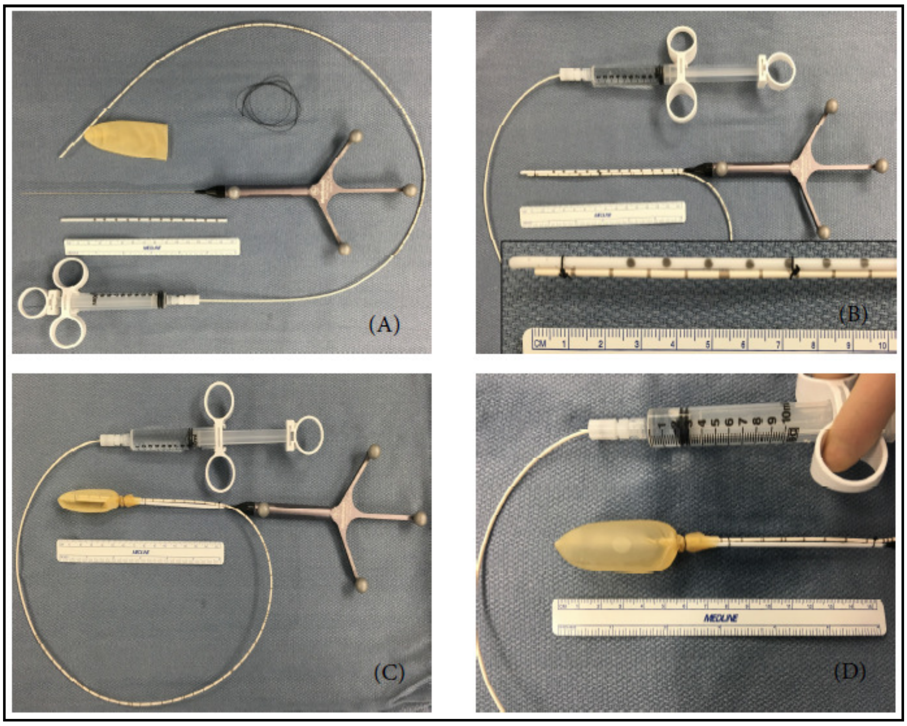

Figure 1. Assemblage of the "Doigt-de-Dieu". (A) The material needed for assemblage includes the Medtronic navigation probe, a ventricular catheter, a semi-rigid, polyethylene cannula equipped with a syringe and a glove finger cut from a size 10 latex surgical glove. (B) The slender navigation probe is fitted with a regular ventricular catheter. The probe functions as a stent whilst the catheter serves as a smooth sheath. The semi-rigid polyethylene cannula is tied firmly alongside the length of the probe-catheter stent. Inset shows details of the union. (C) After maximum expulsion of the interior air, the deflated glove finger is fitted over the probe assembly and tied tightly at its open end. (D) Saline is injected through the cannula to inflate the finger and to test for water-tightness.

Intraoperative neuronavigation and Surgical procedure:

A detailed pre-operative MRI including colour calibrated DTI of the relevant fiber tracts in the region of interest is obtained (**Figure 2A and 2B**). These preoperative DTI data are merged with the neuronavigation imaging data. In our theatre, we use the Medtronic Stealth System (Stealth Station® S7® System, Medtronic, Inc. Surgical Technologies, Neurosurgery, 826 Coal Creek Circle, Louisville, CO 80027, USA). The pre-planned trajectory of the surgical approach to the deep target lesion, designed to avoid important fibre tracts and deep neuronal centres, is now transposed to the real-time screen of the Medtronic Stealth unit. The distance from cortex to target is recorded (**Figure 2C**), and the exact location of the entrance point on the brain surface is carefully marked on the overlying scalp. The small craniotomy is fashioned around the centre of this entry point.

Through a limited corticotomy at the designated site, the "Doigt-de-Dieu" (henceforth called the D^3) is inserted into the brain under navigation guidance **(Figure 3A)** until its tip is touching the surface of the target lesion on the Stealth screen. About 15 to 20 ml of sterile saline, depending on the target distance, is slowly injected through the rigid cannula to inflate the D^3 balloon (glove finger) very gradually, until a "brain tunnel" of approximately 1.0 to 1.5 cm diameter is created (**Figure 3B**). This way, a "clean" surgical corridor is formed by *gently and gradually displacing* white matter tracts and not by sharp dissection with surgical instruments.

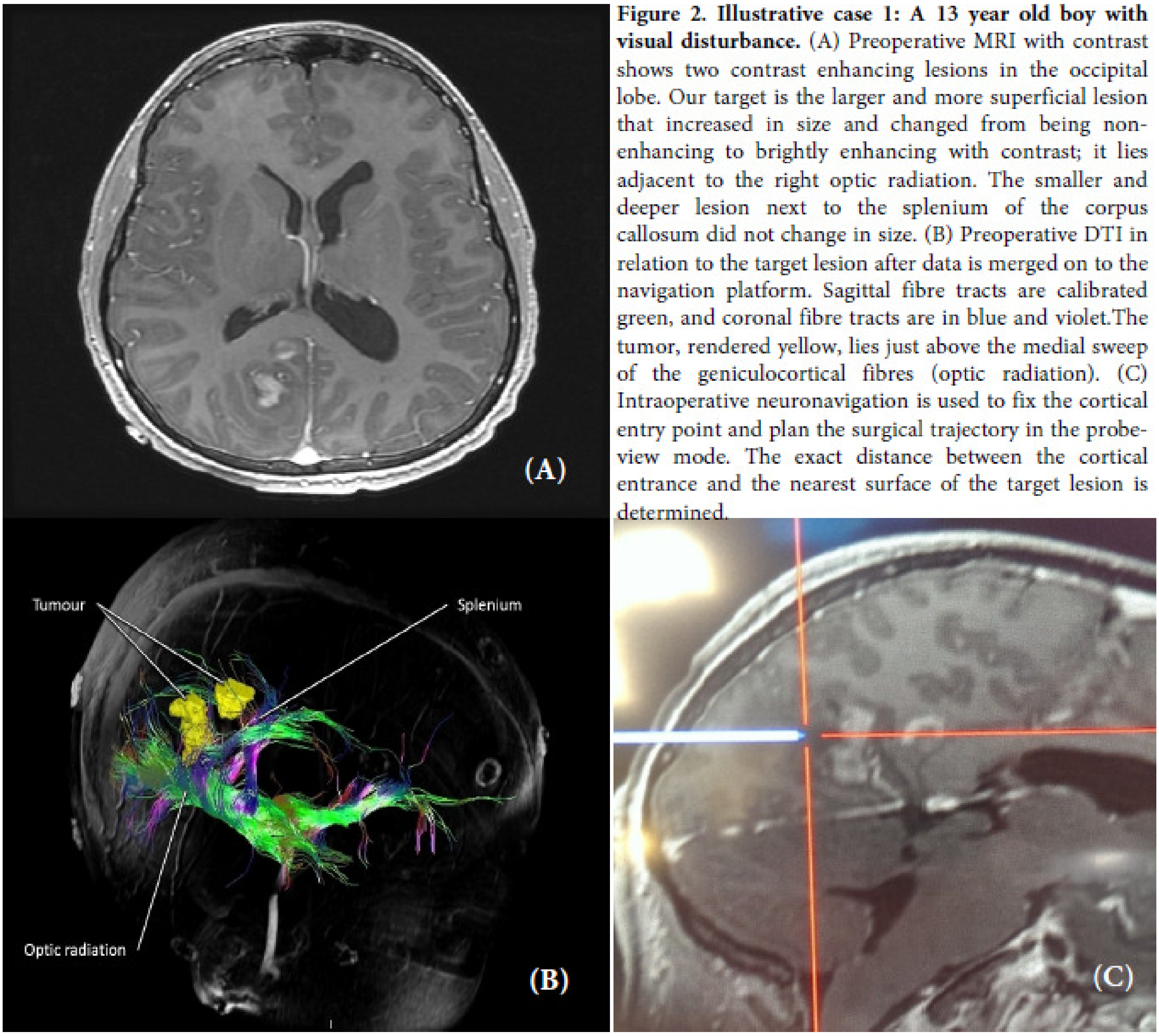

Figure 2. Illustrative case 1: A 13 year old boy with visual disturbance. (A) Preoperative MRI with contrast shows two contrast enhancing lesions in the occipital lobe. Our target is the larger and more superficial lesion that increased in size and changed from being non-enhancing to brightly enhancing with contrast; it lies adjacent to the right optic radiation. The smaller and deeper lesion next to the splenium of the corpus callosum did not change in size. (B) Preoperative DTI in relation to the target lesion after data is merged on to the navigation platform. Sagittal fibre tracts are calibrated green, and coronal fibre tracts are in blue and violet.The tumor, rendered yellow, lies just above the medial sweep of the geniculocortical fibres (optic radiation). (C) Intraoperative neuronavigation is used to fix the cortical entry point and plan the surgical trajectory in the probe-view mode. The exact distance between the cortical entrance and the nearest surface of the target lesion is determined.

The D^3 probe is allowed to remain inflated for about 5 minutes, after which the probe is gently pulled out in its inflated state. The brain tunnel should remain in place long enough for the surgeon to leisurely insert two self-retaining 3/8 inch retractor blades on to the wall of the tunnel to sustain it. The operating microscope is brought in line with the tunnel, at the end of which should be the surface of the target lesion. Neurosurgical resection of the lesion is then performed.

RESULTS

Illustrative Case 1:

A 13 year-old boy, with a history of neurofibromatosis type 1 (NF-1), presented with persistent left sided visual disturbance of 1 year duration, described as transient loss of acuity. Visual field testing showed inconclusive left homonymous visual field defects.

MRI shows two enhancing masses deep in the medial right occipital lobe; the larger and more superficial one measured 1.6 cm in diameter, located 4 cm deep to the cortex just above but apposing the deep portion of the right optic radiation as it sweeps round the occipital horn to reach the primary visual cortex of the medial occipital lobe. Serial MRI over the prior 6 months showed the lesion was enlarging and having increasingly brighter contrast enhancement and more exuberant peri-lesional oedema. The smaller lesion was deeper and pushing against the splenium of the corpus callosum, but had shown no changes in size or other characteristics over a surveillance period of 4 years (**Figure 2A**). Other MRI abnormalities common in NF-1 such as focal T2 hyperintensities were seen in both hippocampi, the right cerebellar vermis, and the left middle cerebellar peduncle. The left optic nerve was enlarged but stable.

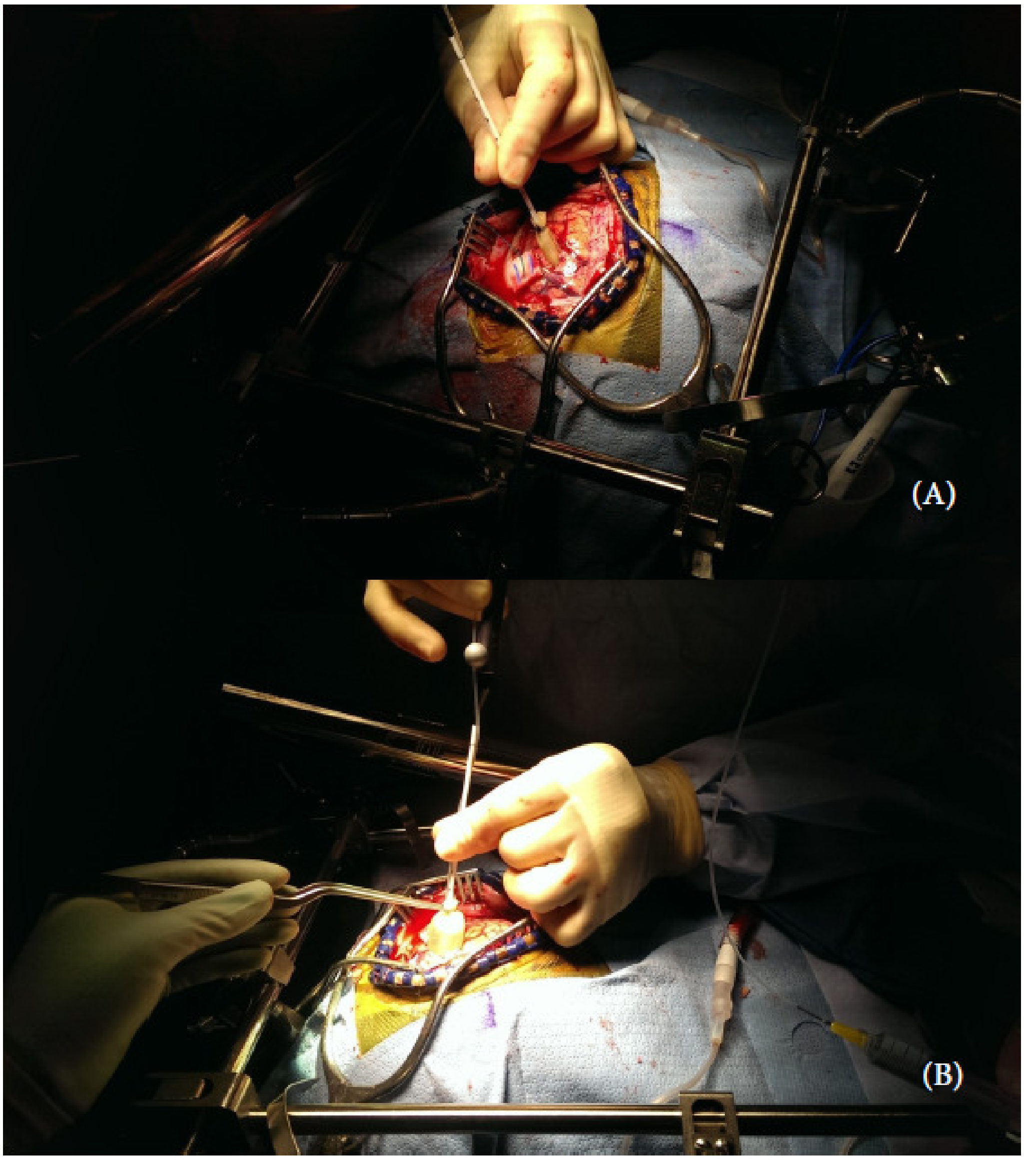

Figure 3. (A) Under navigation guidance the "Doigt-de-Dieu" is slowly inserted into the occipital lobe. (B)The probe must be firmly pressed against the brain when inflating the balloon, or the back pressure exerted by the elasticity of the deforming brain will forcefully expel the whole probe assembly.

Because of the visual symptoms and the worrisome enlargement and changes in imaging characteristics of the larger right occipital lesion, craniotomy and tumor removal was recommended.

The surgical trajectory was planned just skirting above the optic radiation, as shown in the merged DTI image on the navigation platform (**Figure 2B and 2C**). The goal was to reach the target without cutting through or severely distorting the geniculocortical fibres. After navigation-controlled insertion of the D^3 probe till the deflated glove fingertip just touched the posterior surface of the target lesion, the finger was slowly inflated with saline injection through the polyethylene cannula to create a brain tunnel, to be used as the surgical corridor after withdrawal of the D^3probe and placement of the brain retractors. The posterior surface of the tumor was crisply visualized exactly at the end of this corridor (**Figure 4A**) and microsurgical complete resection was easily accomplished (**Figure 4B**).

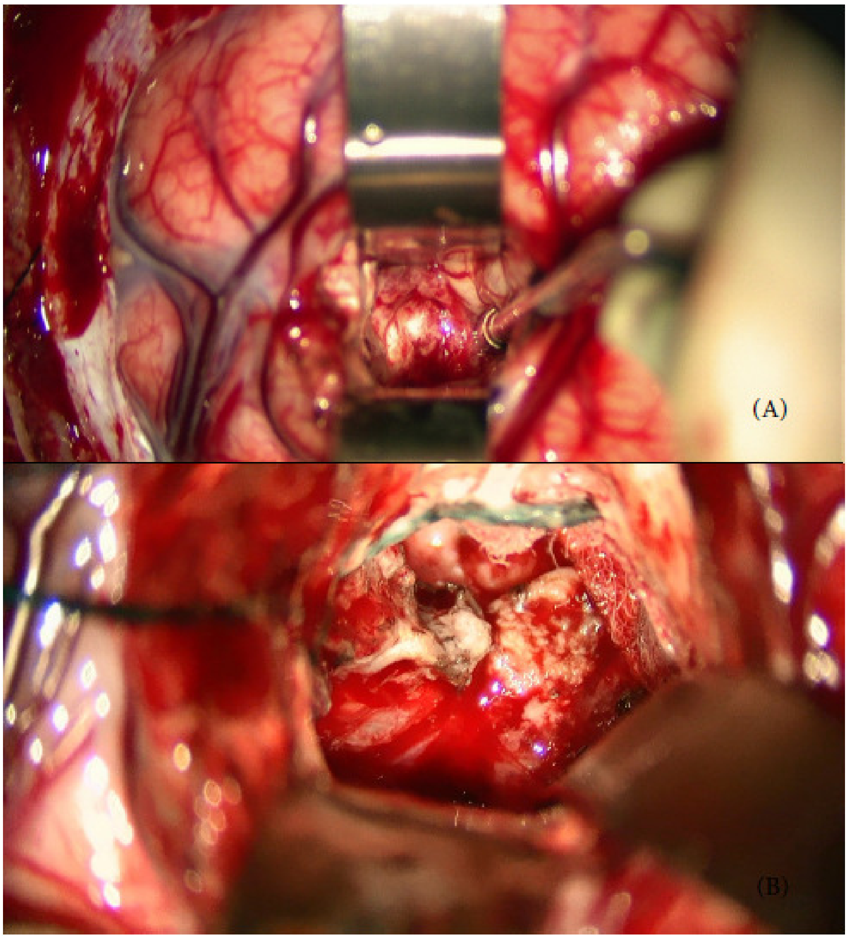

Figure 4. (A) Intraoperative view through the operating microscope immediately after removal of D^{3}and placement of two self-retaining retractors. The tumor is visualized precisely at the end of the newly created working tunnel. (B) Clean tumor bed after complete resection. Note that the tunnel is still in place after removal of the upper retractor blade.

Intraoperative MRI confirmed complete resection, and MRI with DTI on the first post-operative day clearly delineated the surgical path skirting but not traversing the upper aspect of the right optic radiation. The deep surface of the resection cavity was almost touching the splenium of the corpus callosum, without actually involving it **(Figure 5).**

Histopathology of the lesion confirmed a diagnosis of benign ganglioglioma. Examination at 6 months after surgery showed that he had a full visual field and normal visual acuity. MRI showed no residual or recurrent tumor **(Figure 6).**

Illustrative Case 2:

A 15 year old, right-handed, previously healthy girl lost consciousness for several minutes without any obvious seizure activity, but showed transient confusion afterwards. One month later, she had a similar episode, this time with tonic-clonic movements of both arms and legs. Her post-ictal neurological examination was entirely normal. She was loaded with phenytoin. MRI showed a non-enhancing deep lesion in the left frontal periventricular white matter with signal characteristics compatible with a cavernous malformation that had undergone prior hemorrhages **(Figure 7A).**

Because of the lesion's propensity to re-bleed and its association with epilepsy, we recommended craniotomy and resection of the cavernous malformation using the "D^3" technique to minimize damage to Broca's area and avoid permanent speech deficits.

The operation went well. Postoperative MRI showed the less traumatically created surgical corridor and complete removal of the cavernous malformation. There was minimal oedema surrounding the surgical path **(Figure 7B).** Histopathology confirmed the diagnosis of a cavernous malformation with old and recent hemorrhages.

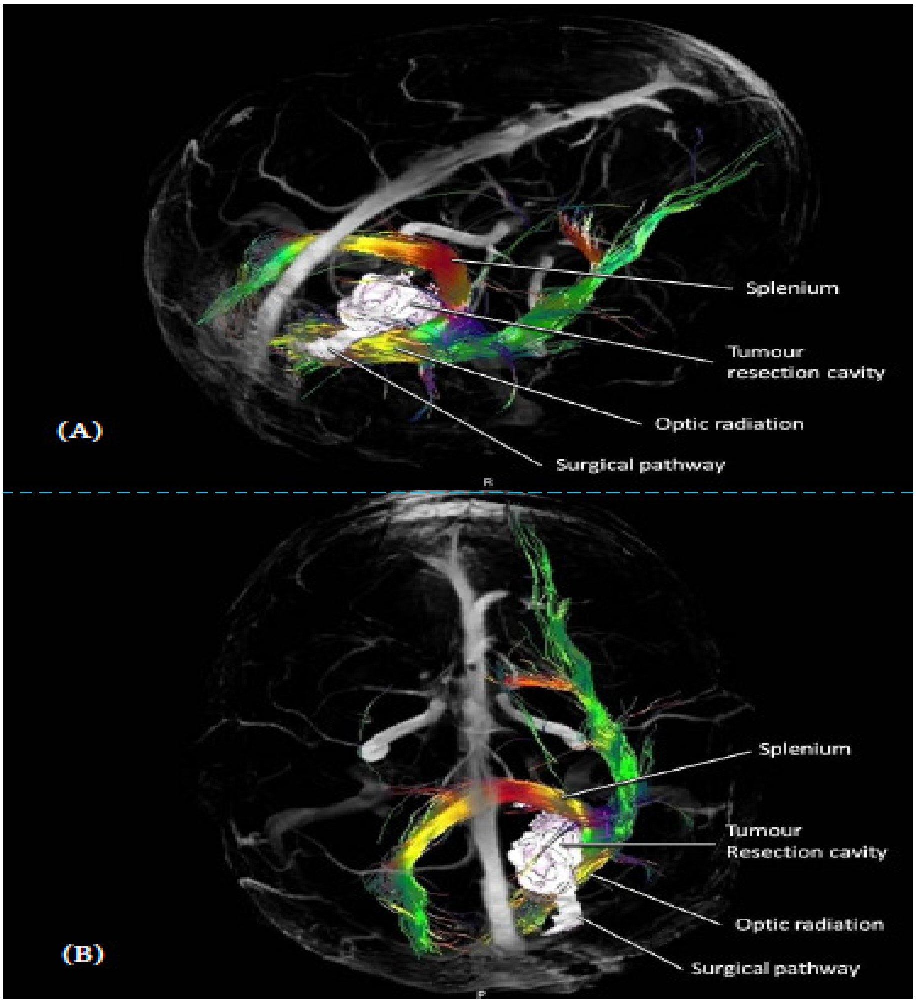

Figure 5. MRI on postoperative day 1 with DTI. (A) Right posterior oblique view. (B) View from the top. The postoperative resection cavity (white) is located just superior to the spared medial sweep of the right optic radiation (green) round the occipital horn to reach the primary visual cortex of the medial occipital lobe. The splenium (red and yellow) is just rostral to the resection cavity. The surgical pathway created by the "Doigt-de-Dieu" (also in white) is shown stretching from the brain surface to the resection cavity above the optic radiation.

On post-operative day one, the patient showed mild memory deficits and moderate word finding and object naming difficulties, but these improved rapidly, and had completely resolved by the time of hospital discharge 3 days later. Four months later, her Lansky performance score [10] was 100.

DISCUSSION

The "Doigt-de-Dieu" technique enables less traumatic access to deep brain lesions located in eloquent brain areas such as the vicinity of important deep gray (neuronal) centres and fibre tracts, especially in the dominant frontal and parietal lobes. Its advantage resides in the gentle displacement of brain tissue by the slow expansion of the smooth glove finger into an elongated, roughly cylindrical balloon, thereby creating a surgical working tunnel. It obviates the undoubtedly more destructive method of standard microsurgical sharp dissection using hard dissectors, suction tips, and advancing metallic brain retractors, which are made to plough through and forcefully pry open soft brain tissues while cleaving open the surgical tunnel. In the D^3 technique, the self-retaining brain retractors are merely used to hold open and sustain the already gaping tunnel whilst microsurgical resection of the deep lesion is being carried out.

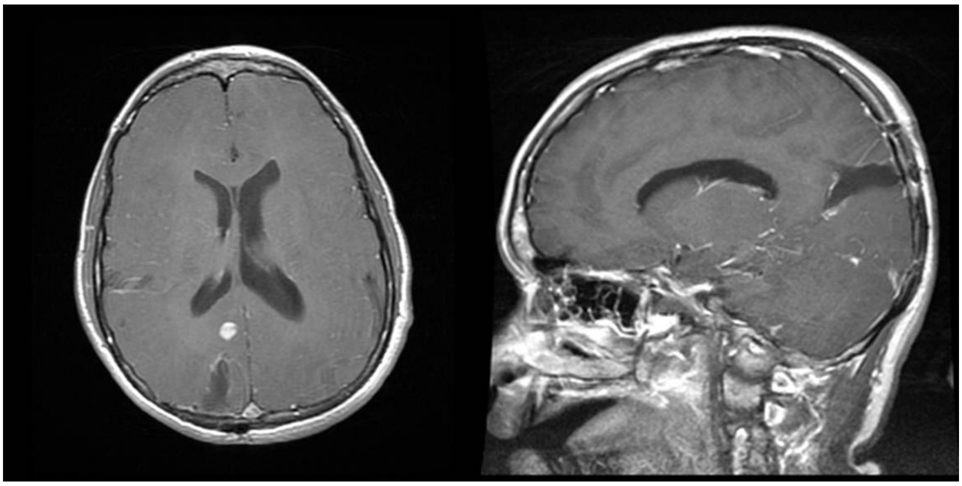

Figure 6. Postoperative axial and sagittal MRI in case 1 show no residual or recurrent tumor. The surgical corridor created by the D^3 from the brain surface to the resection cavity is well visualized. The deeper lesion adjacent to the splenium was not removed.

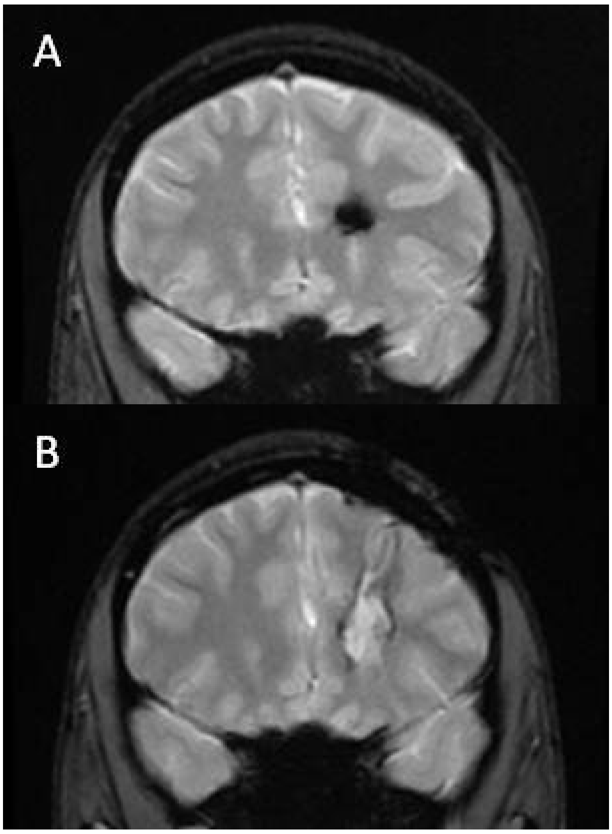

Figure 7. Illustrative case 2: (A) Preoperative MRI (T2 weighted) showing the left frontal periventricular deep lesion consistent with a cavernous malformation that had bled. (B) Postoperative MRI (T2 weighted) 4 months later shows the resection cavity and the narrow surgical pathway, which was less traumatically created by the "Doigt-de-Dieu". There is no residual vascular malformation.

The rapidly evolving field of minimally invasive neurosurgery witnesses the emergence of many different techniques of cerebral dissection with the common goal of minimizing collateral brain damage along the surgical pathway, especially when accessing deep lesions. A brain retractor blade pressure exceeding 20 mmHg has been found to be the critical threshold for direct injury and secondary injury due to ischemia [8,11,12]. Tubular retractors distribute pressure equally to the surrounding tissue, resulting in a lower maximum pressure at any one point along the cylindrical wall [13]. Also, the material of the retractor was thought to be important; it varied from metal [14] to electrically non-transmissive polyester equipped with a transparent medium to visualize the surrounding tissue [2,6,15]. Progressively thicker dilating tubes were also proposed to be less invasive [4]. Combining these special retractors with neuronavigation [15] and/or DTI [16] made minimally invasive neurosurgery even more precise: Kelly et al. in the 1980s increased accuracy by using stereotactically directed retractors [17,18], and Harris et al. approached intraventricular lesions with a combination of neuroendoscopy, microsurgery, and stereotactic image guidance [7].

Besides improvement in instrumentations, invasive brain dissection may be minimized by the transsulcal approach to subcortical lesions [5]. Disadvantages of this approach are inadvertent injury to the sulcal vessels, and limitations imposed by the location of available sulci for the lesion in question.

Precise intraoperative localization of the lesion requires accurate registration of the navigation feducials, but to avoid adjacent fibre tract injury, pre-planning with clearly delineated, colour-calibrated DTI is absolutely essential. The pre-operative DTI data are merged into the intraoperative navigation platform so that fine adjustment of the pre-planned surgical path can be done “in the field” to finalize the exact probe trajectory and the marking of the cortical entrance point on the overlying scalp. However, it must be said that the usefulness of MR diffusion tractography as a trajectory planning reference may be limited [19,20]. Diffusion-weighted imaging depicts only differences in anisotropy of proton movements along parallel neuronal fibres, and thus may underestimate the true size of white matter tracts which often contain axons in slightly divergent paths. Also, there is often a shift of fibre tracts during the initial brain dissection, especially after debulking a large intracerebral mass, which can give a false sense of security if surgical planning is only based on pre-operative DTI images. This latter point emphasizes the need for the intraoperative acquisition of real-time DTI data to enable a sort of “continuous”, real-time neuronavigation [21].

If an intraoperative MRI (iMRI) is available, real-time DTI data can be obtained after the initial passage of the D^3 probe and the first round of lesion resection, when the intraoperative images are acquired to display whether complete resection has actually been achieved. If not, and a second attempt is contemplated, then visualization in real-time of the eloquent fibre tract**,** inevitably shifted by the initial creation of the surgical corridor, would be enormously helpful when the brain retractor or even the probe assembly is to be re-inserted into the now partially collapsed surgical tunnel. The only caveat would be a prolongation of the iMRI interlude, for the post-acquisition processing of the DTI data can take up to 30 minutes.

With practice, the execution of the “Doigt-de-Dieu” technique should be straight-forward and carry minimal risk, but a few technical nuances must be mentioned. The probe assembly must be firmly pressed against the brain when inflating the balloon, or the back pressure exerted by the elasticity of the deforming brain will forcefully expel the whole probe. Once the working tunnel is created and the holding retractors are placed, no time should be wasted to tackle the lesion before natural tissue turgor rises to collapse the tunnel wall against the rigidity of the retractor blades. Also, the trajectory distance between the corticotomy and the nearest surface of the lesion must be accurately measured, which therefore demands that the registration error of the navigation platform be kept at a minimum. This way, the surface of the lesion can be immediately displayed in full measure without being abraded when the operating microscope is first brought in (**Figure 4A**). An inaccurately short tunnel will require supplementary sharp dissections with hard instruments for the last stretch of the surgical corridor, often the most perilous precinct in regards to functional preservation. Conversely, a tunnel-too-long may cause unintended scraping of the lesion by the probe tip and result in inadvertent bleeding within a very restricted surgical field if the lesion is highly vascular.

CONCLUSION

Combining it with preoperative DTI and intraoperative neuronavigation, the “Doigt-de-Dieu” technique allows for safer approaches to deep brain lesions, with minimal disruption of adjacent eloquent brain. This approach helps in the decision making of how and when to operate on previously deemed inoperable deep lesions that are situated near vulnerable grey matter and fibre tracts.

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