FLAWS and MP2RAGE Sequence at 3T for Surgical Localization in Pre Deep Brain Stimulator Patients

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Introduction

3D MRI sequences for pre-surgical planning are in everyday use. The newer Siemens Healthineers 3D sequences MP2RAGE[1] (Magnetisation Prepared 2 Rapidly Acquired Gradient Echo) and FLAWS[1] (FLuid And White matter Suppression) have allowed us to better visualize the deep grey matter structures required for accurate Deep Brain Stimulator (DBS) insertion in a cohort of neurology and neurosurgical patients.
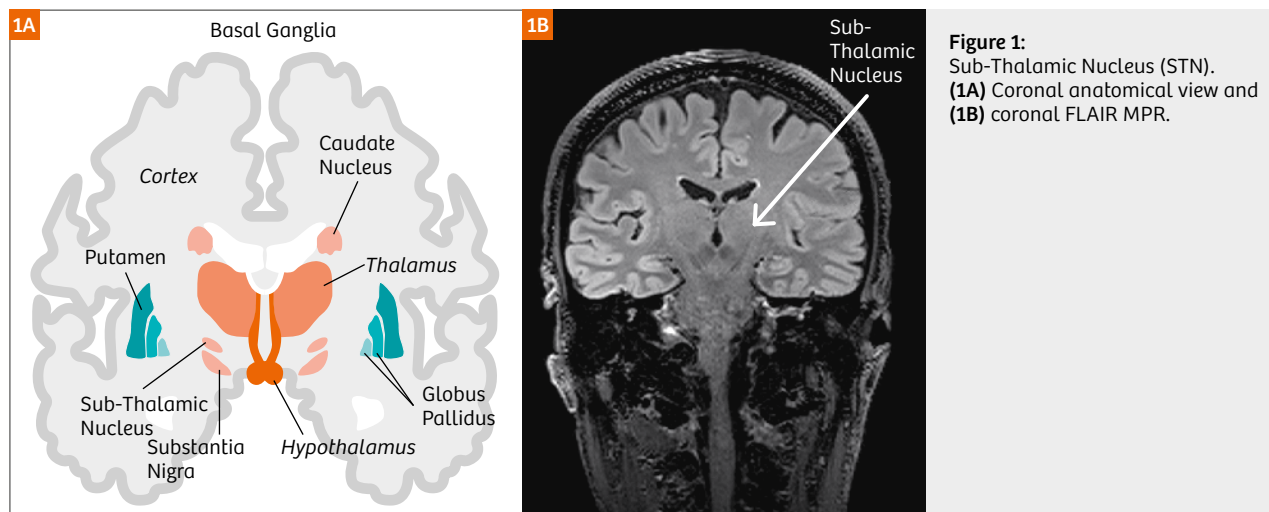
Clinical applications, surgery approaches and indications

The patient cohort requiring DBS treatment contains three sub-groups of patients with movement disorders, either (1) Parkinson's disease, (2) Parkinson's patients with severe dyskinesia, and (3) essential tremors or dystonia.

In Parkinson's disease, most patients have been on medication for many years, mainly L-DOPA ($_L$-3,4-dihydroxyphenylalanine), and perhaps dopamine agonists activating signalling pathways through the dopamine receptor. The efficacy of the administered medications may however reduce after 5 to 10 years; at this stage, a patient may become a surgical candidate. The associated side effects of these drugs (dyskinesia being involuntary muscle movements, or neuropsychiatric side effects) may also have become intolerable for the patient and family by this time. Also, some form of tremor-dominant Parkinson's disease is refractory to such treatments. DBS surgery is then an option.

The anatomical area needing accurate visualisation for these patients is the **Sub-Thalamic Nucleus (STN)**. See Figures 1A (coronal anatomical view) and 1B (coronal FLAIR MPR).

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[1] WIP, the product is currently under development and is not for sale in the US and in other countries. Its future availability cannot be ensured.

Basal Ganglia
Cortex
Caudate Nucleus
Putamen
Thalamus
Sub-Thalamic Nucleus
Substantia Nigra
Hypothalamus
Globus Pallidus

Sub-Thalamic Nucleus

Figure 1:
Sub-Thalamic Nucleus (STN).
(1A) Coronal anatomical view and
(1B) coronal FLAIR MPR.

For other Parkinson's patients with substantial cognitive or psychiatric co-morbidity, or with very severe dyskinesia, the anatomical area needing accurate visualization is the **Internal segment of the Globus Pallidus (GPi)**. See Figures 2A (coronal anatomical view) and 2B (coronal FLAWS MPR).

If the treatment for essential tremor and dystonia – mainly being mysoline, beta blockers and botulin toxin – have proven no longer successful, DBS surgical intervention is an option. The anatomical area needing accurate visualization for these patients is the **Ventral Intermediate Thalamus Nucleus (VIM)**, see Figures 3A (coronal anatomical view) and 3B (coronal FLAWS MPR).

Anatomical dimensions

These three deep grey matter structures, the Sub-Thalamic Nucleus (STN), the Internal segment of the Globus Pallidus (GPi) and the Ventral Intermediate Thalamus Nucleus (VIM) are typically less than 10 mm x 5 mm in dimension. See Figure 4. A dataset acquired with 0.9 mm isotropic resolution is used stereotactically to precisely ascertain the positioning of the stimulating electrodes. No fiducials are required, as facial landmarks suffice. The probes used at Monash Health are Medtronic 3389 or 3387 quadripolar electrode (Medtronic plc, Dublin, Ireland), with an electrode total diameter of 1.27 mm and total longitudinal length of 10.5 mm. They can deliver stimulation using either one polar electrode or a combination of polar electrodes along their length. So ≤ 1 mm isotropic voxel size should be the target resolution of any acquisition.
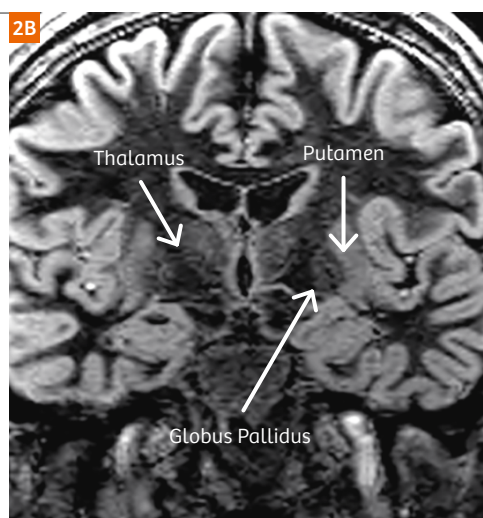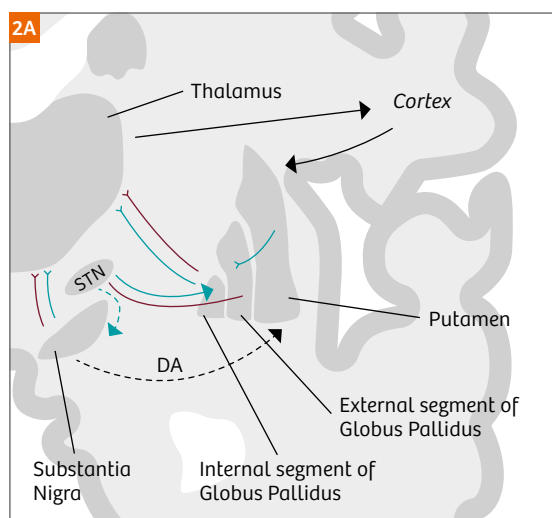
Figure 2:
Internal segment of the Globus Pallidus (GPi). **(2A)** Coronal anatomical view and **(2B)** coronal FLAWS MPR.
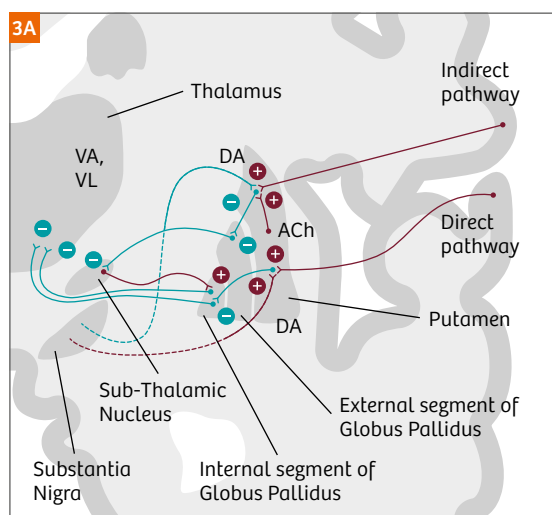
Figure 3:
Ventral Intermediate Thalamus Nucleus (VIM). **(3A)** Coronal anatomical view and **(3B)** coronal FLAWS MPR.
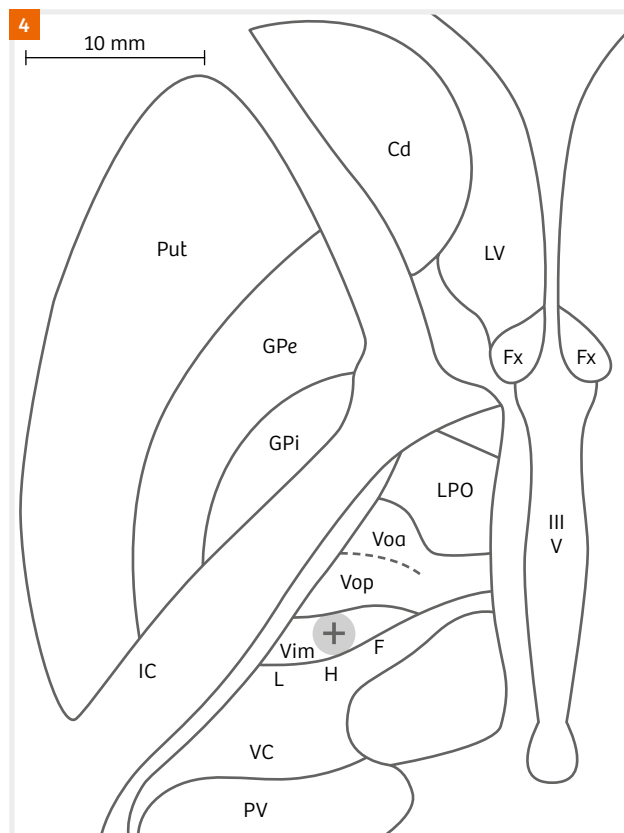
Figure 4:
Axial view of the three deep grey matter structures Sub-Thalamic Nucleus (STN), the Internal segment of the Globus Pallidus (GPi) and the Ventral Intermediate Thalamus Nucleus (Vim).

Imaging sequences

The Siemens Healthineers MP2RAGE sequence [1], featuring two gradient echo readout trains after each inversion pulse which are defined by two different inversion times (TI_1 and TI_2), yields a significant increase in grey/white matter contrast as compared to a normal MPRAGE. At Monash Health we use a TI_1 = 700 ms and TI_2 = 2200 ms. An example of a MP2RAGE contrast can be seen in Figure 5.

However, the standard protocol of the MP2RAGE sequence is optimized for highest WM/GM contrast in the cortex. By altering the two inversion times, an increased contrast between deep grey and white matter structures can be achieved. In a special MP2RAGE variant called FLAWS [2], the TI_1 is chosen so that the WM signal decay after the inversion is around zero when the first image is sampled, i.e. at the WM null point. The second TI_2 can then be adjusted to obtain a 'normal' MPRAGE contrast, yielding

two complementary contrasts from a single acquisition. At Monash Health, we use a first inversion time of 409 ms and a second inversion time of 1330 ms. An example of the two obtained image contrasts can be seen in Figure 6.

In a simple post-processing step which is performed directly during the image reconstruction on the scanner, a minimum-intensity projection (MIP) between the two contrasts (WM-nulled and MPRAGE) results in the so-called FLAWS contrast. An example can be seen in Figures 7A–C. (Axial FLAWS MPR) 7B (Cor FLAWS MPR) and 7C (Sag FLAWS acquisition).

Scan parameters

Protocol

- MP2RAGE with embedded FLAWS with 0.9 mm isotropic voxels

- 3D FLAIR, with 0.9 mm isotropic voxels

All sequences were acquired on a 3T MAGNETOM Verio, with a 32-channel head coil.

The referring neurosurgeon and neurologist both request the 3D FLAIR sequence as well as the 3D FLAWS / MP2RAGE sequence, as they believe the STN is still best displayed on the FLAIR acquisition. The other areas are best delineated on the FLAWS.

Even an acquisition time of 5 mins 30 secs can sometimes be problematic for this cohort of patients, with their tremors leading to motion artifacts. Preparation includes the patient taking their medication in the early morning as usual, and scheduling their MRI examination mid-morning. Intravenous Midazolam can be an option. As a final option to obtain diagnostic images free of motion artifacts, a general anesthetic may be rarely required.

Acknowledgements

References

1   Marques JP, Kober T, Krueger G, van der Zwaag W, Van de Moortele PF, Gruetter R. „MP2RAGE, a self bias-field corrected sequence for improved segmentation and T1-mapping at high field", Neuroimage. 2010 Jan 15;49(2):1271-81.
2   Tanner M, Gambarota G, Kober T, Krueger G, Erritzoe D, Marques J, Newbould R, "Fluid and White Matter Suppression with the MP2RAGE Sequence", JMRI 35:1063-1070 (2012).
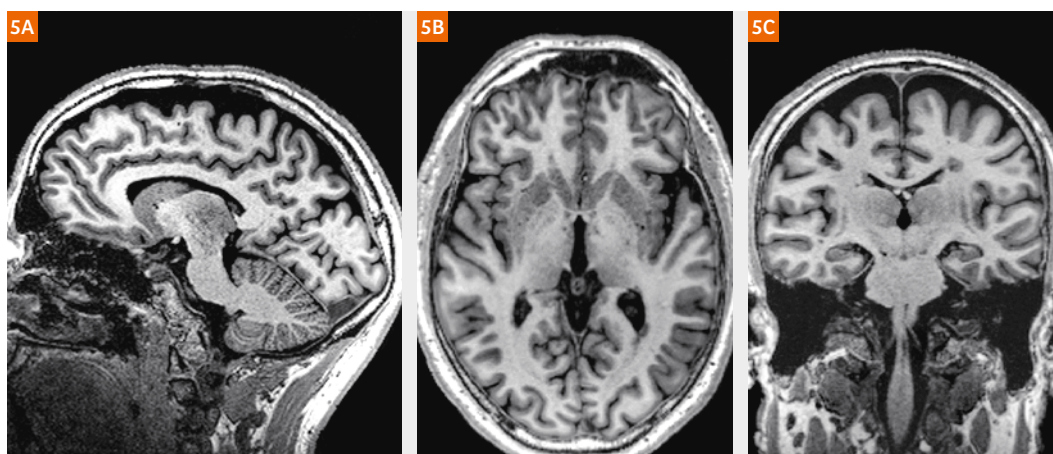
Figure 5:
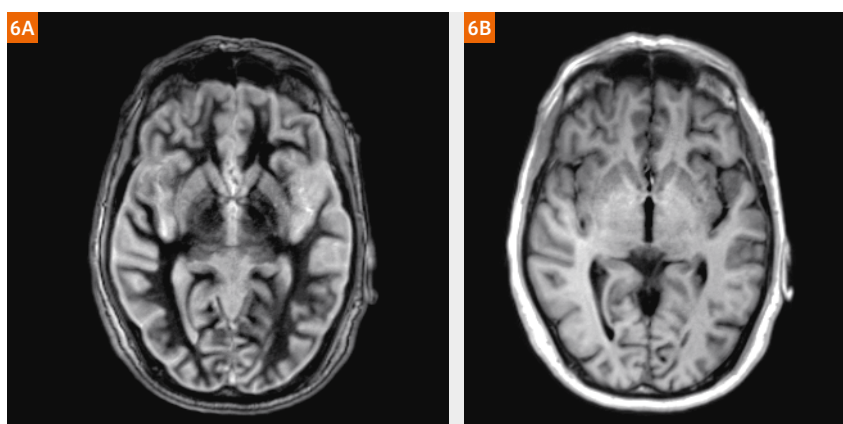Examples of the MP2RAGE contrast. **(5A)** sagittal, **(5B)** axial, **(5C)** coronal.

Figure 6:
Image contrasts obtained using a first inversion time of 409 ms **(6A)** and a second inversion time of 1330 ms **(6B)**.
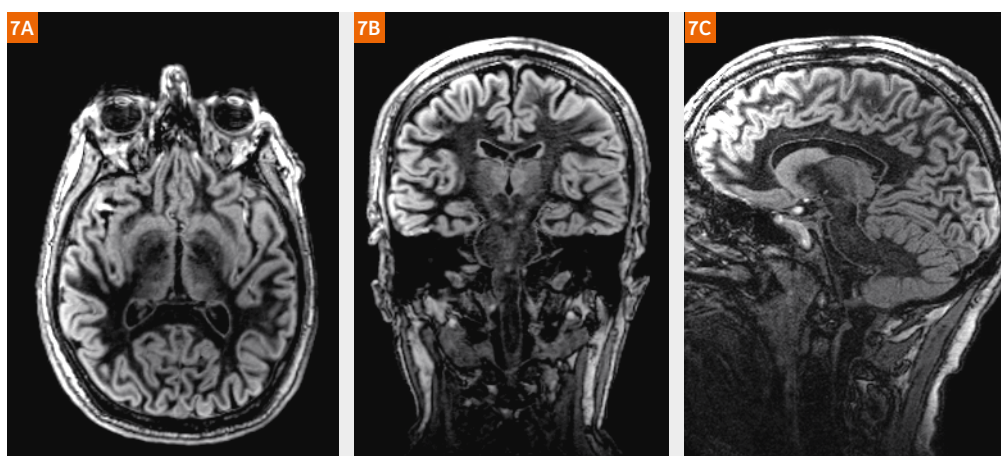
Figure 7:
A minimum-intensity projection (MIP) between the two contrasts (WM-nulled and MPRAGE) results in the so-called FLAWS contrast. **(7A)** Axial, **(7B)** coronal, **(7C)** sagittal.

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