Simultaneous Multi-Slice: a Case-based Presentation of Pre-Operative Brain Tumor Evaluation

Louis-Olivier Bouchard, M.D., MSc[1,3]; Maxime Villeneuve, P.Eng., MSc[2]; Christian Berthelot, M.D., FRCPC[1,3]

[1] CHU de Québec, Hôpital de l'Enfant-Jésus, Radiology Department, Québec, Canada
[2] CHU de Québec, Hôpital de l'Enfant-Jésus, Neurosciences Department, Québec, Canada
[3] Université Laval, Faculté de médecine, Radiology and Nuclear Medicine Department, Québec, Canada

Abstract

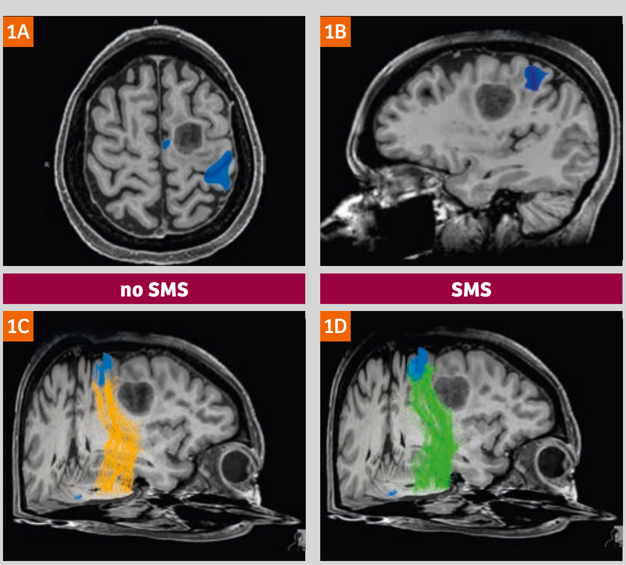
Our clinical center, with a neuro-oncologic field of expertise, has recently started using Simultaneous Multi-Slice (SMS) diffusion-weighted imaging for the pre-operative assessment of brain tumors. In our first evaluation, SMS was used to reduce the scan duration of our diffusion tensor imaging sequence. In our second evaluation, SMS was invested in improved data quality by going from a diffusion protocol with a 30% slice gap to a protocol with no slice gap. We indeed found that SMS not only provides a time benefit, but also an improvement to the data quality of our diffusion tensor imaging.

Introduction

Once the initial diagnosis of a brain tumor is made, neurosurgeons are nowadays looking, in addition to the usual clinical investigations, for a thorough imaging evaluation to assess the tumor's location, its extension, and its relation with surrounding white matter, in order to plan their intervention. The paradigm in neuro-oncology is different than in other oncologic fields, as it is not suitable to take wide margins around the tumor; the mass excision has to be balanced with the functional impairment that would result from it, which has to be minimized. Thus, knowing the exact location of functional areas and their connecting white matter tracts is deemed essential when carefully planning the operation; whether the tumor pushes back the tracts or infiltrates them, and the margins (or distance) between the tumor and functionally-important tracts, are important considerations. With that in mind, after acquiring the basic anatomical imaging data, we therefore go further with functional and tractographic data. These supplementary acquisitions, however, raise some issues,

Case 1

Figure 1: We imaged five patients with glial brain tumors, using both non-SMS and SMS imaging. The average examination time was 10 minutes 41 seconds for non-SMS imaging, as opposed to 6 minutes 42 seconds for SMS imaging, a 37% decrease in scan time, while having an average of 223% increase in the number of fibers, representing a significant data quality enhancement.



1A–B: In this patient, we found a left frontal glial tumor, which is seen in this T1w sequence as a hypointense lesion. The dark blue area is the superimposed fMRI data, showing the right hand motor area, that will then be used to draw ROIs and seed tracts. It also allows the evaluation of the close relationship between the tumor and functional areas.

1C–D: 1C shows the functional area used as a starting point (dark blue) and display the white matter tracts (as orange fibers), but without SMS imaging. On 1D, the same ROI allows the seeding of the white matter tracts (green fibers), this time with SMS imaging. If in both cases, we identify the corticospinal tract of the right hand, qualitatively, we can see that the green tracts are more numerous and denser, more precise than the orange ones. Quantitatively, this is in line with the results that show for this patient 216 fibers with no-SMS and 957 fibers with SMS.

mainly about time and quality. First, it requires increased time spent by the patients in the machine, stretching their tolerance even more than in a standard MRI acquisition. Second, it slows down considerably the workflow, raising concerns about delays and waiting lists. And third, in order to keep its relevance to clinicians, there can be no compromise on the quality of the data, even if we try to reduce the exam time.

It is in this particular context that Simultaneous Multi-Slice (SMS) imaging was seen as a promising tool in our clinical setting, and we started using it in July 2016. SMS was designed to increase the temporal efficiency [1] of MRI acquisitions, whether to reduce the exam duration or to improve the quality of imaging, for example, using more directions in diffusion imaging to reduce noise and improve tractographic data. With the progress made in parallel imaging and reconstruction algorithms [2], it is now possible to acquire several imaging slices concurrently, without affecting the signal-to-noise ratio [1], for significantly reduced exam durations.

If diffusion tensor imaging has different clinical uses, the one of interest here is the study of white matter tracts through tractographic reconstructions. To do so, we acquire through multiple directions for the whole brain voxel-wise data about diffusivity (as a vector with its strength and directionality, as well as a scalar value). If diffusion tensor imaging (DTI) has been used extensively in the last few years [4], high-angular resolution diffusion imaging (HARDI) is the promising new way to bring further the study of white matter, as it more robustly addresses the issue of crossing fibres [5], paving the way to more valid tractography.

However, diffusion imaging is time consuming to acquire; the conventional sequence used in our practice takes around 10 minutes. With SMS, it would become possible for us to reduce this time or acquire images of higher quality in the same acquisition time.

Together with SMS, we use functional magnetic resonance imaging (fMRI), coupled with Blood-oxygen-level dependent (BOLD) contrast imaging, to display and locate functional brain areas, as activated following certain tasks, for example, soliciting hand mobility or language [3].

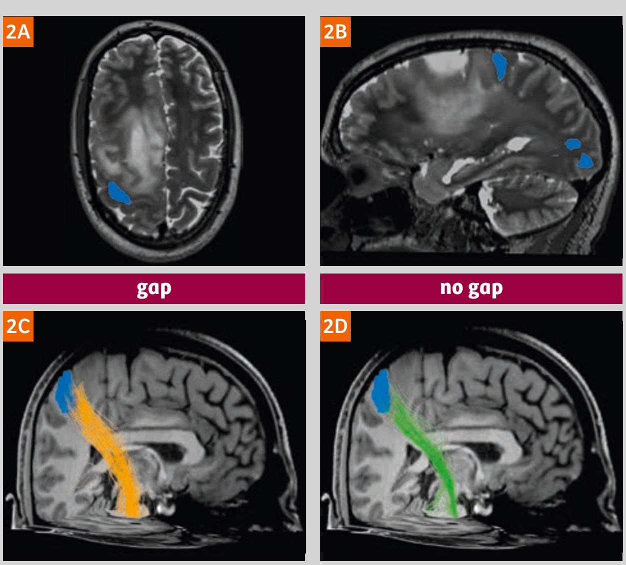
Our clinical setting is part of the CHU de Québec – Université Laval, one of the three largest medical centers in Canada. Our teaching hospital has a specialty axis in neuroscience, including expertise in neuro-oncology. For the implementation of this project, our team includes four neurosurgeons, a neuro-radiologist, a radiology resident, and a biomedical engineer, in addition to a neuro-psychologist for fMRI tasks.

Case-based presentation

In our center, when a patient is referred by neurosurgeons for a pre-operative evaluation of a brain tumor, we start by a conventional MRI acquisition, using a 3T MAGNETOM Skyra, with 32-channel head coil (Siemens Healthcare, Erlangen, Germany). Our routine exam includes a 3D MPRAGE T1-weighted (pre- and post-gadolinium), T2-weighted FLAIR and SWI sequences. This allows us to do an anatomical description, to locate the lesion precisely, and describe its extension and impact on surrounding structures (cf. Figures).

Case 2

Figure 2: We imaged five other patients, again with and without SMS, but this time, not using SMS to reduce exam duration, but to go from a 30% gap protocol with 50 slices to a no-gap protocol with 60 slices, without changing other parameters (as TR for example). We found that by doing so, in an equivalent time, we observed an average of 94% increase in the number of fibers, improving data quality significantly.



2A–B: In this patient, we found a right parietal glial tumor, with important surrounding infiltration, as shown here with hyper-intensities on a T2 sequence. The dark blue areas are superimposed fMRI data, displaying the relationship between the tumor (and its infiltration) and the functional areas (here the left hand motor area).

2C–D: On these images, we see the same fMRI areas (dark blue) used to draw ROIs and seed the tracts. On 2C, we see the cortico-spinal left hand tracts found using the «gap» protocol (224 orange fibers). On 2D, we see the same tracts, but this time using the «no-gap» protocol (516 fibers). The no-gap protocol is therefore numerically superior and qualitatively easier to interpret with thicker, denser, more precise tracts.

We then proceed to perform the BOLD fMRI data acquisition. A neuropsychologist in our center thoroughly evaluates each patient to determine which paradigms are most adapted to his/her condition and consequently chooses the appropriate series of tasks, for example to define specifically the motor areas of hand, foot and mouth, and the language areas. While resting in the scan, the patient is therefore asked to perform these various tasks to activate these functionally-important areas (cf. Figures). In addition to the clinically-relevant data they give by themselves, these activated zones shown on fMRI sequences will then be used in the next step to draw regions-of-interest (ROI) to seed white matter tracts.

For the DTI, we acquire diffusion tractography data (64 directions, b-value = 1500 s/mm^2), using high-angular resolution diffusion imaging (HARDI). This gives us numerical values for fractional anisotropy (FA), a scalar value which can be used to assess the integrity of the fibers (as FA is known to be a proxy of microstructural damage in white matter tracts, indicating the directionality of diffusion in axons [4]), but also gives us vector values which are then processed to extract tractographic data. Our data post-processing involves the use of FSL 5.0.9 [6], MRtrix [7], Mi-brain by Imeka [8] softwares to make the brain extraction, segmentation, statistics, reformatting and to draw ROIs to seed tracts (cf. Figures).

The combination of anatomical, functional, and tractographic data can now finally be interpreted as a whole to craft the surgical approach.

Conclusion

When we first started using Simultaneous Multi-Slice imaging, we compared our data, with and without SMS (cf. Figure 1), mainly to save acquisition time; lately, we have focused on optimizing the quality of data, using SMS to improve acquisition of diffusion data, comparing protocols with and without gaps (cf. Figure 2).

We found that SMS imaging in a pre-operative evaluation of a brain tumor is useful, with regards to time and quality. By reducing acquisition time, it improves the patient's experience, spending less time in the device, sometimes going as far as to make additional sequence acquisitions possible in patients who would have otherwise asked to stop the exam out of discomfort. Also, the quality of the data was improved, possibly by reducing motion artifacts, as the scanning time was reduced (and patient's restlessness concurrently) [9]. This improvement, paired with the integration of a no-gap technique, allowed for improved spatial resolution. This gave more precise and denser tracts, a precious tool for neurosurgeons when planning their intervention. By clearly drawing the thin line between tumor and sane brain parenchyma, it optimizes the balance between removing as much neoplasm as possible and preserving brain functions; it may also make fully anesthetized surgery possible (instead of the more complicated and patient-displeasing awaken surgery), the full extent of functionally-relevant white matter tracts close to the lesion being known.

Now that we have integrated SMS imaging to our routine and used it to optimize our diffusion tractography data, our next step is to compare the temporal benefit of going from SMS-2 to SMS-3, while maintaining data quality. Then, we will use SMS to try to improve our fMRI-BOLD technique, by doubling acquired volumes to enhance data quality, to further enhance our value-based approach to clinicians.

References

1 Setsompop K et al. Advancing diffusion MRI using SMS EPI. MAGNETOM Flash. 63 (3), 2015.
2 Barth M, Breuer F, Koopmans PJ et al. Simultaneous multislice (SMS) imaging techniques. Magnetic resonance in medicine. 2016, 75 (1): 63-81.
3 Schuknecht B, Barath K. Introduction to advanced techniques in MR neuroimaging. MAGNETOM Flash 52 (2), 2013.
4 Basser PJ, Pierpaoli C. Microstructural and physiological features of tissues elucidated by quantitative-diffusion-tensor MRI. J Magnet Reson B. 1996, 111(3): 209-219.
5 Descoteaux M, Angelinao E, Fitzgibbons S. Apparent diffusion coefficients from high angular resolution diffusion imaging: estimation and applications. Magn Reson Med. 2006, 56(2): 395-410.
6 Jenkinson M, Beckmann CF, Behrens TE, Woolrich MW, Smith SM. FSL. NeuroImage. 2012 62:782-90.
7 MRtrix, Tournier JD et al., Brain Research Institute, Melbourne, Australia, 2012;
8 MI-Brain, Imeka Medical Imaging, Descoteaux M et al., Imeka Solutions inc., Sherbrooke, Canada, 2015.
9 Bartsch A. SMS imaging for presurgical BOLD fMRI and diffusion tractography: Case Illustrations, MAGNETOM Flash, 63 (3), 2015.

Contact

Christian Berthelot
CHU de Québec – Université Laval

1401, 18ième rue
Québec, QC, Canada
G1J 1Z4
christianberthelot@gmail.com


Louis-Olivier Bouchard


Maxime Villeneuve


Christian Berthelot