LIST OF PROJECTS (1)

CO-SUPERVISED INTERNATIONAL

FEBRUARY 2022

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PROJECT C1

Title : Deep learning segmentation methods and 7T quantitative MRI for new insights in multiple sclerosis (DL+q7T in MS)

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State of the art

Multiple sclerosis (MS) is a disabling disease of the brain and spinal cord (SC). The damaged tissue manifests as lesions, which can be seen with magnetic resonance imaging (MRI). However, conventional MRI systems (1.5 or 3T) often 'miss' lesions, rendering uncertain the diagnosis and follow-up of MS patients.
Seven tesla (7T) MRI, which provides increased resolution and contrasts, now offers more insights into the detection of MS lesions, especially when combined with advanced quantitative MRI techniques and AI-based automatic analysis methods such as those developed in Dr. Callot and Dr. Cohen-Adad teams.

Objectives

Taking advantage of these opportunities, the main objective of the project is to refine and strengthen the characterization of SC lesions in MS. Where do they preferentially locate? How do they evolve? What are their impacts on the surrounding tissues? To answer these specific questions, a key-point of the project will be the development of an analysis pipeline for longitudinal quantitative 7T MRI data of MS patients. The ultimate goal will be the evaluation of the proposed approach benefits for a more precise and personalized assessment of a patient's prognosis.

Methods

Using the open-source ivadomed framework (*), a deep learning model will be trained to refine the segmentation of the SC white and gray matter, as well as the MS lesions across multiple contrasts. In particular, the models will learn to segment new/modified lesions across multiple MRI sessions. For that purpose, 7T MRI data (T2*, qT1 and diffusion, providing quantitative insights into the damaged tissue microstructure), previously acquired from 20 MS patients at 2 time points, will be used. Methods will then be applied to study changes occurring at 5 years (to be acquired).

Expected results

The potential benefits of the approach will be demonstrated via correlations between clinical disability scores and MR outputs (qMRI, number, size and locations of MS lesions). More sensitive atrophy measurements (marker of disease progression), ultra-high resolution MS lesions cartography and new insights on lesion evolution are expected. The segmentation models, to be validated across multiple 7T sites to ensure its generalizability, will be incorporated into the widely used open-source software Spinal Cord Toolbox (**). MR and postprocessing methods should also benefit the increasing number of neuroimaging centers involved in 7T spinal cord MRI.

(*) : https://ivadomed.org, developed by Dr. Cohen-Adad's team
(**) : https://spinalcordtoolbox.com/, developed by Drs. Cohen-Adad and Callot teams

Feasibility

The local ecosystems (7T MR system, strong collaboration with the Neurology Dept of Pr. J. Pelletier at Hôp. Timone, unique dataset of 7T quantitative MR data already collected, AI world experts at NeuroPoly/Mila) and the preliminary developments achieved for 7T WM/GM segmentation based on deep learning (https://arxiv.org/abs/2110.06516) should guarantee a good success of the project.

Complementarity of the two laboratories

While the Spinal Cord MR group at CRMBM-CEMEREM currently dedicates its research to 7T quantitative MR developments and new biomarker identifications, NeuroPoly is deeply involved in AI-based automatic analysis methods. These complementary and interdisciplinary expertises have already led to fruitful collaborations in the domain (see Annex 1).

Expected candidate profil

Hard skills: experience in data science, medical image analysis and signal processing; Python programming; familiar with machine and deep learning; git/GitHub. Social skills: knowledge sharing and teamwork. Assets: medical imaging (esp. MRI).

SUPERVISED PHDS & PUBLICATIONS : CALLOT Virginie

- **Currently supervised PhD students**

- Guillaume Frébourg 50% (codirection with Y.Petit) (déc 2020 – déc 2023)
- Arash Forodighasemabadi 50% (codirection with M. Evin) (oct 2018 – march 2022)
- Kaissar Farah 50% (codirection with S. Fuentès) (april 2021 -)

- **Previously supervised PhD students**

- Simon Lévy (oct 2017- sept 2020)
- Henitsoa Rasoanandrianina (oct. 2015 – janv 2019)
- Manuel Taso (oct 2013 – april 2016)
- Slim Fellah (april 2009 – dec 2012)

- **Publications of previously supervised PHD students (last 5 years)**

- **A. Forodighasemabadi, H. Rasoanandrianina**, M. Mounir El Mendili, M. Guye, V Callot, An optimized MP2RAGE sequence for studying both brain and cervical spinal cord in a single acquisition, **MRI, 2021, 84:18-26.**
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- **H. Rasoanandriani**na, AM. Grapperon, M. Taso, OM. Girard, G. Duhamel, M. Guye, JP. Ranjeva, S. Attarian, A. Verschueren, V. Callot , Region-specific impairment of the cervical spinal cord (SC) in amyotrophic lateral sclerosis: a feasibility study using SC templates and quantitative MRI (DTI/ihMT)), NMR Biomed, 2017, 30(12).
- B. De Leener, **S. Lévy,** V.S. Fonov, N. Stikov, L.D. Collins, V. Callot, J. Cohen-Adad SCT: Spinal Cord Toolbox, an open-source software for processing spinal cord MRI data, **Neuroimage,** 2017, 145, 24-43
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- O. Girard, V. Callot, V. Prevost, B. Robert, **M. Taso,** G. Ribeiro, G. Varma, N. Rangwala, D. Alsop, G. Duhamel, Magnetization Transfer from Inhomogeneously Broadened Lines (ihMT): Improved Imaging Strategy for Spinal Cord Applications, **Magn Reson Med, 2017, 77(2) :581-591.**
- A. Massire, **M. Taso**, P. Besson, M. Guye, JP. Ranjeva, V. Callot, High-resolution multi-parametric quantitative magnetic resonance imaging of the human cervical spinal cord at 7T, Neuroimage, 2016, 143, 58-59.
- **M. Taso**, O. Girard, G. Duhamel, A. Le Troter, T. Feiweier, M. Guye, JP. Ranjeva, V. Callot, Tract-specific and age-related variations of the spinal cord microstructure: a multi-parametric MRI study using diffusion tensor imaging (DTI) and inhomogeneous magnetization transfer (ihMT**), NMR in Biomed,** 2016, 29(6):817-32
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- **S. Fellah,** D. Caudal, A. Maues de Paula, P. Dory-Lautrec, D. Figarella-Branger, O. Chinot, P. Metellus, PJ. Cozzone, S. Confort-Gouny, B. Ghattas, V. Callot, N. Girard, Multimodal MRI (Diffusion, Perfusion and Spectroscopy): Is it possible to predict oligodendroglial tumors grade and genotype in the pre-therapeutic diagnosis, **AJNR Am J Neuroradiol**, 34: 1326-1333, 2013
- **S. Fellah,** V. Callot, P. Viout, S. Confort-Gouny, D. Scavarda, P. Dory-Lautrec, D. Figarella-Branger, PJ. Cozzone, N. Girard, Epileptogenic brain lesions in children: the added-value of combined diffusion imaging and proton MR spectroscopy to the presurgical differential diagnosis. **Child Nervous System, 28(2):273-82, 2012**
- **S. Fellah,** N. Girard, O. Chinot, PJ. Cozzone, V. Callot, Tumoral response of glioblastoma to anti-angiogenic treatment prematurely revealed by using arterial spin labeling perfusion MRI and susceptibility weighted imaging (SWI**). J Clin Oncol, 29(11): e308-11, 201**

SUPERVISED PHDS & PUBLICATIONS : COHEN-ADAD Julien

• **Currently supervised PhD students**

- Enguix, Vicente
- Gros, Charley
- Karthik Enamundram, Muni Venkata Naga
- El Baz, Adrian

• **Previously supervised PhD students**

- Duval, Tanguy (jan 2014 - oct 2017)
- Lopez Rios, Nibardo (jan 2014 - oct 2017)
- De Leener, Benjamin (sept 2014 - oct 2017)
- Begdouri, Hadi (jan 2014 - june 2018)
- Topfer, Ryan (jan 2015 - jan 2022)
- Alley, Stephanie (sept 2019 - july 2018 (dropped))
- Perdigon, Francisco (jan 2018 - july 2018 (dropped)
- Mangeat, Gabriel (sept 2017 - may 2021)
- Badji, Atef (sept 2017 - oct 2021)

• **Publications of previously supervised PHD students (last 5 years)**

- Lemay A, Gros C, Zhuo Z, Zhang J, Duan Y, Cohen-Adad J, Liu Y. Automatic multiclass intramedullary spinal cord tumor segmentation on MRI with deep learning. **Neuroimage Clin,** 22;31:102766, 2021
- Yu FF, Huang SY, Kumar A, Witzel T, Liao C, Duval T, Cohen-Adad J, Bilgic B. Rapid simultaneous acquisition of macromolecular tissue volume, susceptibility, and relaxometry maps. **Magn Reson Med,** 2021
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- Kuntke P, Kurniawan ND, Kusmia S, Labounek R, Laganà MM, Laule C, Law CS, Lenglet C, Leutritz T, Liu Y, Llufriu S, Mackey S, Martinez-Heras E, Mattera L, Nestrasil I, O'Grady KP, Papinutto N, Papp D, Pareto D, Parrish TB, Pichiecchio A, Prados F, Rovira À, Ruitenberg MJ, Samson RS, Savini G, Seif M, Seifert AC, Smith AK, Smith SA, Smith ZA, Solana E, Suzuki Y, Tackley G, Tinnermann A, Valošek J, Van De Ville D, Yiannakas MC, Weber KA 2nd, Weiskopf N, Wise RG, Wyss PO, Xu J. Generic acquisition protocol for quantitative MRI of the spinal cord. **Nat Protoc** (IF: 10.42), 2021
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ANNEX 1 – V. Callot & J. Cohen-Adad co-authorships

1) NJ. Laines Medina, C. Gros, **J. Cohen-Adad**, **V. Callot**, A. Le Troter, 2D Multi-Class Model for Gray and White Matter Segmentation of the cervical spinal cord at 7T, **arXiv(preprint 2021) : 2110.06516**

2) **J. Cohen-Adad**, E. Alonso-Ortiz, M. Abramovic, C. Arneitz, N. Atcheson, L. Barlow, R. Barry, M. Barth, M. Battiston, C. Buchel, M. Budde, **V. Callot**, A. Combes, B. De Leener, M. Descoteaux, P. de Sousa, M. Dostal, J. Doyon, A. Dvorak, F. Eippert, K. Epperson, K.S. Epperson, J. Finsterbusch, A. Foias, M. Fratini, P. Freund, Issei Fukunaga, C. Wheeler-Kingshott, G. Germani, G. Gilbert, F. Giove, C. Gros, F. Grussu, A. Hagiwara, PG. Henry, T. Horák, M. Hori, J Joers, K. Kamiya, H. Karbasforoushan, M. Keškovský, A. Khatibi, J.W. Kim, N. Kinany, H. Kitzler, S. Kolind, Y. Kong, P. Kudlička, P. Kuntke, N. Kurniawan, S. Kusmia, R. Labounek, M. Marcella Laganà, C. Laule, C. Law, C. Lenglet, T. Leutritz, Y. Liu, S. Llufriu, S. Mackey, E. Martinez-Heras, L. Mattera, I. Nestrašil, K. O'Grady, N. Papinutto, D. Papp, D. Pareto, Todd Parrish, A. Pichiecchio, F. Prados, A. Rovira, M. Ruitenberg, R. Samson, G. Savini, M. Seif, A.C. Seifert, A. Smith, S. Smith, Z.A. Smith, E. Solana, Y. Suzuki, G. Tackley, A. Tinnermann, J. Valošek, D. Van De Ville, M. Yiannakas, K. Weber, N. Weiskopf, R. Wise, P. O. Wyss, and J. Xu,
"**Generic acquisition protocol and open-**

access data for quantitative MRI of the spinal cord", Nature Protocols (MR), 2021 : ***doi: 10.1038/s41596-021-00588-0***

3) **J. Cohen-Adad**, E. Alonso-Ortiz, M. Abramovic, C. Arneitz, N. Atcheson, L. Barlow, R. Barry, M. Barth, M. Battiston, C. Buchel, M. Budde, **V. Callot**, A. Combes, B. De Leener, M. Descoteaux, P. de Sousa, M. Dostal, J. Doyon, A. Dvorak, F. Eippert, K. Epperson, K.S. Epperson, J. Finsterbusch, A. Foias, M. Fratini, P. Freund, Issei Fukunaga, C. Wheeler-Kingshott, G. Germani, G. Gilbert, F. Giove, C. Gros, F. Grussu, A. Hagiwara, PG. Henry, T. Horák, M. Hori, J Joers, K. Kamiya, H. Karbasforoushan, M. Keškovský, A. Khatibi, J.W. Kim, N. Kinany, H. Kitzler, S. Kolind, Y. Kong, P. Kudlička, P. Kuntke, N. Kurniawan, S. Kusmia, R. Labounek, M. Marcella Laganà, C. Laule, C. Law, C. Lenglet, T. Leutritz, Y. Liu, S. Llufriu, S. Mackey, E. Martinez-Heras, L. Mattera, I. Nestrašil, K. O'Grady, N. Papinutto, D. Papp, D. Pareto, Todd Parrish, A. Pichiecchio, F. Prados, A. Rovira, M. Ruitenberg, R. Samson, G. Savini, M. Seif, A.C. Seifert, A. Smith, S. Smith, Z.A. Smith, E. Solana, Y. Suzuki, G. Tackley, A. Tinnermann, J. Valošek, D. Van De Ville, M. Yiannakas, K. Weber, N. Weiskopf, R. Wise, P. O. Wyss, and J. Xu, "Open-access quantitative MRI data of the spinal cord: Reproducibility across subjects, sites and vendors", Scientific Data, **8(1):219. doi: 10.1038/s41597-021-00941-8**, **2021**.

4) A. Kerbrat, C. Gros, A.Badji, E. Bannier, F. Galassi , B. Combès , P.Labauge, X. Ayrignac, C. Carra Dallière , J. Maranzano, R. Zhuoquiong, T.Granberg, R. Ouellette, Leszek Stawiarz, J. Hillert, J. Talbott, Y. Tachibana, M.Hori, K.Kamiya, L. Chougar, J. Lefeuvre, D. S. Reich, G. Nair, P.Valsasina, M.A. Rocca, M. Filippi, R. Chu , R. Bakshi, **V. Callot**, J. Pelletier, B. Audoin, A. Maarouf, N. Collongues, J. De Seze, G. Edan, **J. Cohen-Adad**, Multiple sclerosis lesions in motor tracts from the brain to the cervical cord: spatial distribution and correlation with functional deficits, **Brain, 2020, 143(7):2089-2105, doi: 10.1093/brain/awaa162**

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6) C. Gros, B. De Leener, A. Badji, J. Maranzano, D. Eden, S.M Dupont, J. Talbott, R. Zhuoquiong, Y. Liu, T. Granberg, R. Ouellette, Y. Tachibana, M. Hori, K. Kamiya, L. Chougar, J. Hillert, L. Stawiarz, E. Bannier, A. Kerbrat, G. Edan, P. Labauge, **V. Callot**, J. Pelletier, B. Audoin, H. Rasoanandrianina, JC. Brisset, P. Valsasina, MA. Rocca, M. Filippi, R. Bakshi, S. Tauhid, F. Prados, M. Yiannakas, H. Kearney, O. Ciccarelli, S. Smith, CA. Treaba, C. Mainero, J. Lefeuvre, DS. Reich, G. Nair, V. Auclair, DG. McLaren, AR. Martin, MG. Fehlings, S. Vahdat, A. Khatibi, J. Doyon, T. Shepherd, E. Charlson, S. Narayanan, **J. Cohen-Adad**, Automatic segmentation of the spinal cord and intramedullary multiple

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7) C. Gros, B. De Leener, SM. Dupont, AR. Martin, MG. Fehlings, R. Bakshi, S.Tummala, V. Auclair, DG. McLaren, **V. Callot**, **J. Cohen-Adad**, M. Sdika, Automatic spinal cord localization, robust to MRI contrasts using global curve optimization. **Med Image Anal**.;44:215-227. doi: 10.1016/j.media.2017.12.001, **2018**

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12) S.Lévy, M. Benhamou; C. Naaman, P. Rainville, **V. Callot**, **J. Cohen-Adad,** White matter atlas of the human spinal cord with estimation of partial volume effect, ***Neuroimage,*** **2015**;119:262-71. doi: 10.1016/j.neuroimage.2015.06.040

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14) V. Fonov, A. Le Troter, M. Taso, G. Leveque, M. Benhamou, M. Sdika, H. Benali, PF. Pradat, L. Collins, **V. Callot**, **J. Cohen-Adad**, Framework for integrated MRI average of the spinal cord white and gray matter: the MNI-Poly-AMU template, ***Neuroimage*** 2014, 102 Pt 2:817-27, doi: 10.1016/j.neuroimage.2014.08.057