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Literature-based feasibility assessment of T1-CE MRI based cerebral vessel segmentation for DBS planning purposes

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General purpose

The purpose of this literature search is to see whether an attempt at cerebral vessel segmentation based on the current pre-operative MRI protocol is reasonable. We will not be taking the DBS screening protocol into account, since up-to-date anatomical accuracy is deemed vital for DBS planning. An initial search of literature and the scan protocols revealed that the T1-CE scan ("3D ISO T1 GADO TRA" in the protocol) seems most promising for this purpose [1]. The search will thus mostly focus on this scan.

Setup

Our search will focus on the *Pubmed*, *Arxiv* and *IEEE* databases. We will restrict our search to papers published after 01-01-2010.

For *Pubmed*, we'll be using the following search phrase:
("vessel segmentation"[Title/Abstract] OR "vascular segmentation"[Title/Abstract]) AND (brain[Title/Abstract] OR cerebral[Title/Abstract] OR cerebro[Title/Abstract] OR intracranial[Title/Abstract] OR stereotaxy[Title/Abstract] OR stereotactic[Title/Abstract]) AND (MRI[Title/Abstract] OR "magnetic resonance"[Title/Abstract] OR "MP-RAGE"[Title/Abstract] OR "MP RAGE"[Title/Abstract] OR "MR"[Title/Abstract] OR "T1CE"[Title/Abstract] OR "T1-CE"[Title/Abstract])*

For *Arxiv*, we won't use a search phrase that specific, but instead we perform a simple search with the following keywords: *[vessel segmentation brain].*

For *IEEE*, we'll use the following search phrase, which is just the *Pubmed* search command in a slightly different format:
(("Abstract":"vessel segmentation" OR "Abstract":"vascular segmentation") AND ("Abstract":brain OR "Abstract":cerebral OR "Abstract":cerebro OR "Abstract":intracranial OR "Abstract":stereotaxy OR "Abstract":stereotactic) AND ("Abstract":mri OR "Abstract":"magnetic resonance" OR "Abstract":"MP-RAGE" OR "Abstract":"MP RAGE" OR "Abstract":"MR" OR "Abstract":"T1CE" OR "Abstract":"T1-CE"))

Results

Initially, the *Pubmed*, *Arxiv* and *IEEE* search phrases yielded 33, 22 and 11 matches, respectively, after which 10 [2]–[11], 7 [12]–[19] and 6 [11], [20]–[24] articles were deemed relevant. Extracting doublets yields a total of 23 relevant papers.

In general, it is apparent that in the last couple of years, quite a lot of work has been done on (cerebral) vessel segmentation. While generally TOF-MRA, CTA or DSA seems to be preferred to yield a better vessel-no vessel contrast, it is known that T1-CE scans do in fact yield very noticeable vessel enhancement [1], and multiple studies have been performed that show there is definitely some value to T1-CE MRI in cerebral vessel segmentation as well [2], [19], [21].

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Nowadays, the most accurate vessel segmentation strategies may very roughly be subdivided into two main groups. Namely, these are the vesselness filter-based methods [2], [4], [23], [5], [6], [9]–[11], [17], [18], [20] and machine learning methods [7], [13], [15], [16], [19], [22], [24].
It is worth noting that when selecting a segmentation method for our work on DBS planning, we should take into account the fact that the dataset available for this project is NOT annotated. We will thus either have to go for a method that requires very little optimization or manually segment a few subjects for optimization purposes. This can probably best be achieved by trying a vesselness filter-based approach. Machine learning methods, while being very accurate in most cases, would most of the time have to be (partly) retrained to function on our specific scan type (e.g. a network trained on TOF-MRA will likely not perform well on T1-CE scans and this principle extends to voxel size, other scan parameters etc.), which would require us to create annotated data. Given the amount of work this would take, I think it's wise to steer clear of this approach the best we can.
It is, however, a viable option to annotate two or three subjects manually for testing or very basic model tuning purposes (I could probably do this by myself in a few hours without needing too much assistance). We could for instance use this approach to optimize a vesselness filter-based strategy or to retrain the last couple of layers of a pretrained neural network.

I would argue that a nice place to start is the method described in the paper by Neumann et al. [2], which did some testing of several vesselness filter-based approaches on TOF-MRA and T1-CE data. This, since this is reasonably simple to implement, performs relatively well and is also relatively well documented online. This enables us to not spend too much time on this step, which would otherwise be very time-consuming if e.g. we were to build, train and optimize a whole machine learning approach from scratch. If it becomes apparent that this method does not perform adequately on our data or there is time to spare (which I doubt), we may always look at some methods which have been proven to improve results of methods like these, like the one described by Forkert et al. [3].

Conclusion

In conclusion, I think it is safe to say that literature has shown that the scans currently implemented as pre-operative MRI protocol are sufficient to develop an automatic DBS planning assistance tool. Tools like TOF-MRA or subtraction of non-contrast and contrast enhanced T1w scans may of course be implemented in the protocol at a later stage (e.g. if this project proved successful and a follow-up project is commissioned), but my assessment would be that this would in no way be required for this project to succeed.
The best way to approach the vessel segmentation in this project setup would probably be a vesselness filter-based approach, with the possibility of some finetuning with the help of a couple (probably two or three) of manually segmented subjects.

References

[1] B. Bapst *et al.*, "Post-contrast 3D T1-weighted TSE MR sequences (SPACE, CUBE, VISTA/BRAINVIEW, isoFSE, 3D MVOX): Technical aspects and clinical applications," *J. Neuroradiol.*, vol. 47, no. 5, pp. 358–368, 2020, doi: 10.1016/j.neurad.2020.01.085.

[2] J. O. Neumann *et al.*, "Evaluation of three automatic brain vessel segmentation methods for stereotactical trajectory planning," *Comput. Methods Programs Biomed.*, vol. 182, p. 105037, 2019, doi: 10.1016/j.cmpb.2019.105037.

[3] N. D. Forkert *et al.*, "Automatic correction of gaps in cerebrovascular segmentations extracted from 3D time-of-flight MRA datasets," *Methods Inf. Med.*, vol. 51, no. 5, pp. 415–422, 2012, doi: 10.3414/ME11-02-0037.

[4] X. Du, H. Ding, W. Zhou, G. Zhang, and G. Wang, "Cerebrovascular segmentation and planning of depth electrode insertion for epilepsy surgery," *Int. J. Comput. Assist. Radiol. Surg.*, vol. 8, no. 6, pp. 905–916, 2013, doi: 10.1007/s11548-013-0843-5.

[5] S. Cetin and G. Unal, "A higher-order tensor vessel tractography for segmentation of vascular structures," *IEEE Trans. Med. Imaging*, vol. 34, no. 10, pp. 2172–2185, Oct. 2015, doi: 10.1109/TMI.2015.2425535.

[6] U. S. Choi, H. Kawaguchi, and I. Kida, "Cerebral artery segmentation based on magnetization-prepared two rapid acquisition gradient echo multi-contrast images in 7 Tesla magnetic resonance imaging," *Neuroimage*, vol. 222, Nov. 2020, doi: 10.1016/j.neuroimage.2020.117259.

[7] Z. Zhang, C. Wu, S. Coleman, and D. Kerr, "DENSE-INception U-net for medical image segmentation," *Comput. Methods Programs Biomed.*, vol. 192, Aug. 2020, doi: 10.1016/j.cmpb.2020.105395.

[8] R. Xiao, H. Ding, F. Zhai, W. Zhou, and G. Wang, "Cerebrovascular segmentation of TOF-MRA based on seed point detection and multiple-feature fusion," *Comput. Med. Imaging Graph.*, vol. 69, pp. 1–8, Nov. 2018, doi: 10.1016/j.compmedimag.2018.07.002.

[9] R. Xiao *et al.*, "Segmentation of Cerebrovascular Anatomy from TOF-MRA Using Length-Strained Enhancement and Random Walker," *Biomed Res. Int.*, vol. 2020, 2020, doi: 10.1155/2020/9347215.

[10] K. Li *et al.*, "Stereoelectroencephalography electrode placement: Detection of blood vessel conflicts," *Epilepsia*, vol. 60, no. 9, pp. 1942–1948, Sep. 2019, doi: 10.1111/epi.16294.

[11] M. W. K. Law and A. C. S. Chung, "Segmentation of intracranial vessels and aneurysms in phase contrast magnetic resonance angiography using multirange filters and local variances," *IEEE Trans. Image Process.*, vol. 22, no. 3, pp. 845–859, 2013, doi: 10.1109/TIP.2012.2216274.

[12] N. D. Forkert, J. Fiehler, S. Suniaga, H. Wersching, S. Knecht, and A. Kemmling, "A statistical cerebroarterial atlas derived from 700 MRA datasets," *Methods Inf. Med.*, vol. 52, no. 6, pp. 467–474, 2013, doi: 10.3414/ME13-02-0001.

[13] V. N. Dang *et al.*, "Vessel-CAPTCHA: an efficient learning framework for vessel annotation and segmentation," 2021, [Online]. Available: http://arxiv.org/abs/2101.09321.

[14] A. Deshpande *et al.*, "Automatic segmentation, feature extraction and comparison of healthy and

stroke cerebral vasculature," *NeuroImage Clin.*, vol. 30, 2021, doi: 10.1016/j.nicl.2021.102573.

[15] S. Chatterjee *et al.*, "DS6: Deformation-aware learning for small vessel segmentation with small, imperfectly labeled dataset," *arXiv*, 2020.

[16] G. Tetteh *et al.*, "DeepVesselNet: Vessel Segmentation, Centerline Prediction, and Bifurcation Detection in 3-D Angiographic Volumes," *Front. Neurosci.*, vol. 14, pp. 1–13, 2020, doi: 10.3389/fnins.2020.592352.

[17] N. Strisciuglio, G. Azzopardi, and N. Petkov, "Detection of curved lines with B-COSFIRE filters: A case study on crack delineation," *Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics)*, vol. 10424 LNCS, pp. 108–120, 2017, doi: 10.1007/978-3-319-64689-3_9.

[18] L. Ballerini *et al.*, "Perivascular Spaces Segmentation in Brain MRI Using Optimal 3D Filtering," *Sci. Rep.*, vol. 8, no. 1, pp. 1–8, 2018, doi: 10.1038/s41598-018-19781-5.

[19] C. Cui, H. Liu, D. J. Englot, and B. Dawant, "Brain vessel segmentation in contrast-enhanced T1-weighted MR Images for deep brain stimulation of the anterior thalamus using a deep convolutional neural network," in *Medical Imaging 2021: Image-Guided Procedures, Robotic Interventions, and Modeling*, Feb. 2021, vol. 11598, p. 17, doi: 10.1117/12.2581896.

[20] T. Wozniak and M. Strzelecki, "Segmentation of 3D magnetic resonance brain vessel images based on level set approaches," in *2015 Signal Processing: Algorithms, Architectures, Arrangements, and Applications (SPA)*, Sep. 2015, pp. 56–61, doi: 10.1109/SPA.2015.7365133.

[21] N. Li, J. Yang, S. Zhou, Z. Wu, and B. Zhang, "Automatic arteriovenous separation of brain via TOF-MRA and MR-T1," in *2019 International Conference on Medical Imaging Physics and Engineering, ICMIPE 2019*, Nov. 2019, vol. 3, pp. 1–5, doi: 10.1109/ICMIPE47306.2019.9098208.

[22] H. Kandil, A. Soliman, F. Taher, A. Mahmoud, A. Elmaghraby, and A. El-Baz, "Using 3-D CNNs and Local Blood Flow Information to Segment Cerebral Vasculature," *2018 IEEE Int. Symp. Signal Process. Inf. Technol. ISSPIT 2018*, pp. 701–705, 2019, doi: 10.1109/ISSPIT.2018.8642676.

[23] S. Zhao, M. Zhou, Y. Tian, P. Xu, Z. Wu, and X. Shang, "An effective brain vasculature segmentation algorithm for time-of-flight MRA data," *Proc. - 2015 Int. Conf. Virtual Real. Vis. ICVRV 2015*, pp. 238–245, 2016, doi: 10.1109/ICVRV.2015.29.

[24] F. Zhao *et al.*, "Semi-supervised cerebrovascular segmentation by hierarchical convolutional neural network," *IEEE Access*, vol. 6, pp. 67841–67852, 2018, doi: 10.1109/ACCESS.2018.2879521.