Fully Automated Thrombus Segmentation on CT Images of Patients with Acute Ischemic Stroke

Mahsa Mojtahedi[1] S.M.MOJTAHEDI@AMSTERDAMUMC.NL
[1] *Department of Biomedical Engineering and Physics, Amsterdam UMC, The Netherlands*

Manon Kappelhof[2] M.KAPPELHOF@AMSTERDAMUMC.NL
[2] *Department of Radiology and Nuclear Medicine, Amsterdam UMC, The Netherlands*

Elena Ponomareva[3] EPONOMAREVA@NICO-LAB.COM
[3] *Nicolab, 1105 BP Amsterdam, The Netherlands*

Henk van Voorst[1] H.VANVOORST@AMSTERDAMUMC.NL
Efstratios Gavves[4] E.GAVVES@UVA.NL
[4] *Informatics Institute, University of Amsterdam, The Netherlands*

Bart J. Emmer[2] B.J.EMMER@AMSTERDAMUMC.NL
Charles Majoie[2] C.B.MAJOIE@AMSTERDAMUMC.NL
Henk Marquering[1] H.A.MARQUERING@AMSTERDAMUMC.NL

Editors: Under Review for MIDL 2022

Abstract

Thrombus imaging characteristics are associated with treatment success and functional outcomes in stroke patients. However, assessing these characteristics based on manual annotations is labor intensive and subject to observer bias. Therefore, we aimed to create an automated pipeline for consistent and fast full thrombus segmentation. We first found the occlusion location using StrokeViewer LVO and created a bounding box around it. We trained dual modality U-Net based convolutional neural networks (CNNs) to subsequently segment the thrombus inside this bounding box. Segmentation results have high spatial accuracy with manual delineations and can therefore be used to determine thrombus characteristics and potentially benefit decision making in clinical practice.

Keywords: ischemic stroke, thrombus, segmentation, CT, U-Net

Introduction: Ischemic stroke treatment outcome is associated with thrombus imaging characteristics such as perviousness and length (Dutra et al., 2019). Due to the difficulty of manual full thrombus annotation and the high observer variance of this task, thrombus characteristics are often calculated based on partial annotations. However, since thrombi are heterogeneous, calculating thrombus characteristics based on the entire thrombus leads to more accurate results (Santos et al., 2016). An automatic thrombus segmentation method enables accurate and fast determination of full thrombus imaging characteristics, and consequently facilitates their use in the time sensitive stroke patient assessment.

Materials: The train, validation and test sets include NCCT and CTA scans of 208, 20 and 100 patients, respectively. All datasets contain multi-scanner, multi-center data.

Methods: First, an off-the-shelf algorithm, StrokeViewer LVO (Nicolab, Amsterdam, the Netherlands; www.nicolab.com/strokeviewer-home) is used to detect the thrombus location. The segmentation area of interest is then limited by creating an initial bounding box around the detected thrombus location. The second step is to adjust the dimensions of this initial bounding box to fit each thrombus using the *Dynamic bounding box algorithm*. The adjusted bounding box is used to isolate the same area on both NCCT and CTA. Finally, both the NCCT and CTA images within this bounding box are passed as input to a neural network to segment the thrombus. We experiment with different U-Net based dual modality networks for the segmentation step.

- *Dynamic bounding box algorithm:* This algorithm aims to increase the chance of including the entire thrombus in the final bounding box by adapting the initial bounding box dimensions to each case. It consists of two parts: (1) If the predicted segmentation is too small, the bounding box may not contain the thrombus. In that case, the initial bounding box is moved $\frac{2}{3}$ of its length in 6 cube side directions to create 6 alternative bounding box candidates. The candidate that results in the largest segmentation prediction is chosen. (2) If the predicted thrombus is close to the edge of the bounding box, part of the thrombus may be left outside of the bounding box. To avoid missing parts of the thrombus, the size of the bounding box in that dimension is increased. In case the resulting segmentation is still close to the edge, the size of the bounding box can be increased up to 5 times.

- *Networks:* Both NCCT and CTA are given as input to the networks. We experiment with four different feature fusion methods to combine NCCT and CTA features in U-Net: (1) U-Net with two input channels for NCCT and CTA, and U-Nets with two encoders where (2) concatenate, (3) addition, and (4)weighted-sum operators are used for feature fusion.

Results: Segmentation results of different networks are shown in Table 1. The best performing model is weighted-sum. Some examples of the segmentation results from this model are shown in Figure 1.

Table 1: Comparing different segmentation networks. Missed cases shows the percentage of cases with a Dice = 0. Non-overlapping components is the number of connected components which don't overlap with the ground truth.

Model	**Trainable Parameters**	**Dice**	**Surface Dice**	**Non-overlapping Components**	**Missed Cases**
U-Net	82M	0.59	0.75	2.5	6%
Concatenate	115M	0.60	0.76	0.6	8%
Weighted-sum	97M	**0.62**	**0.78**	0.7	**4%**
Addition	96M	0.53	0.69	0.3	11%
U-Net without CTA input	82M	0.38	0.51	**0.2**	26%

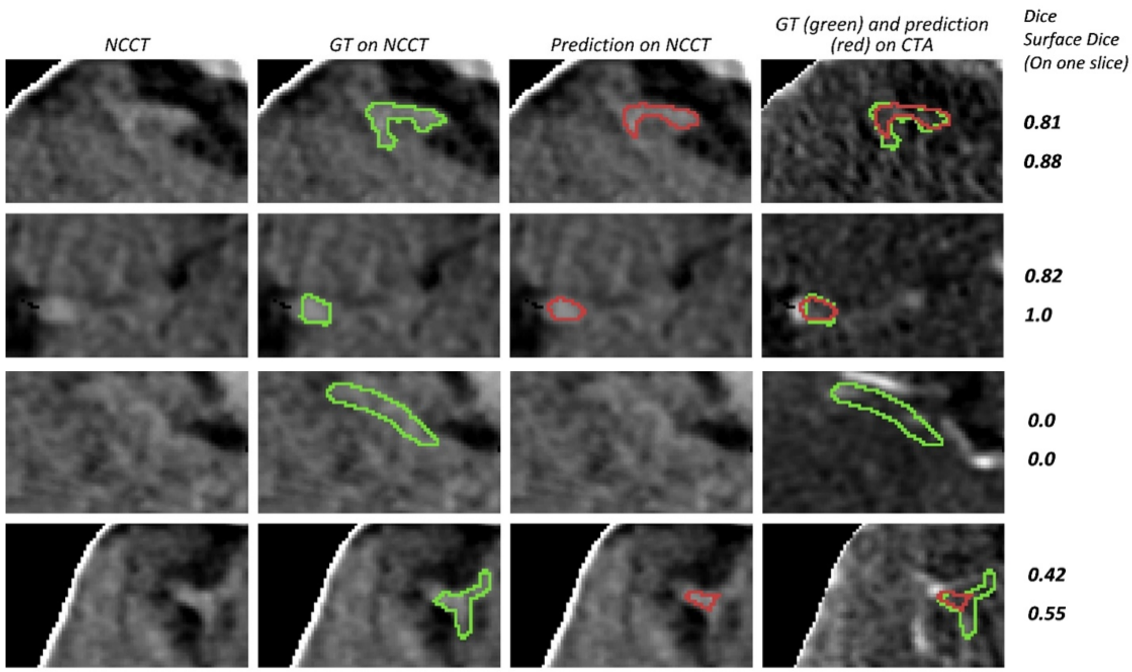

Figure 1: Two cases with high (top) and low (bottom) Dice. The bounding box in the axial slice with the largest ground truth (GT) surface is depicted. Dice and surface Dice values for the displayed 2D slice are shown at the right side for each row.

Conclusion: Our fully automated segmentation method facilitates the quick, effortless, and unbiased assessment of thrombus imaging markers in the acute setting of stroke. Consequently, it can assist radiologists in making decisions about the optimal treatment strategy or thrombectomy device for stroke patients. Furthermore, an automatic thrombus segmentation method can be used to quickly and consistently annotate large clinical datasets, thereby accelerating stroke research.

References

Bruna G. Dutra, Manon L. Tolhuisen, Heitor C.B.R. Alves, Kilian M. Treurniet, Manon Kappelhof, Albert J. Yoo, Ivo G.H. Jansen, Diederik W.J. Dippel, Wim H. van Zwam, Robert J. van Oostenbrugge, Antônio J. da Rocha, Hester F. Lingsma, Aad van der Lugt, Yvo B.W.E.M. Roos, Henk A. Marquering, and Charles B.L.M. Majoie. Thrombus Imaging Characteristics and Outcomes in Acute Ischemic Stroke Patients Undergoing Endovascular Treatment. *Stroke*, 50(8):2057–2064, 8 2019. ISSN 0039-2499. doi: 10.1161/STROKEAHA.118.024247.

Emilie M. M. Santos, Wiro J. Niessen, Albert J. Yoo, Olvert A. Berkhemer, Ludo F. Beenen, Charles B. Majoie, and Henk. A. Marquering. Automated Entire Thrombus Density Measurements for Robust and Comprehensive Thrombus Characterization in Patients with Acute Ischemic Stroke. *PLOS ONE*, 11(1):e0145641, 1 2016. ISSN 1932-6203. doi: 10.1371/journal.pone.0145641.