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Wall enhancement segmentation for intracranial aneuryms

https://doi.org/...
Received ...; accepted ...

Abstract: We present a tool for automatic segmentation of wall enhancement of intracranial aneurysms in black blood MRI. The results of the automatic segmentation with several configurations is compared to manual expert segmentations. While the manual segmentation includes some voxels of lower intensity not present in the automatic segmentation, overall the volume of the automatic segmentation is higher.

Keywords: Intracranial aneurysm, wall enhancement, black blood MRI

1 Introduction

A relevant part of aneurysm diagnosis is the rupture risk assessment. Recent research introduced wall enhancement in black blood MRI as a possible indication for a higher risk of aneurysm rupture. However, within these studies, the wall enhancement identification relies on the subjective criteria of the medical experts.

In contrast to other MR images, the vessels appear black instead of bright in black blood MRI. This technique allows to visualise the vessel lumen as well as the surrounding wall. Wall enhancement around aneurysms could be an indication of inflammatory reaction and wall damages. While morphological parameters are often used for rupture risk assessment, they are not sufficient [1]. Wall enhancement as visible in black blood MRI might be able to improve rupture risk assessment [2].

In a study by Fu et al. [3], a correlation between symptoms (sentinel headaches or third nerve palsy) and wall enhancement was found. Two radiologists were asked to determine whether aneurysm wall enhancement was present or not. With a similar approach, Edjlali et al. [4] observed that wall enhancement can be more frequently found in instable aneurysms than in stable aneurysms. Wang et al. [5] and Liu et al.[6] concluded that wall enhancement could help to predict aneurysm rupture. They compared pre- and post-contrast images to define wall enhancement. Results based on expert assessment are challenging to reproduce.

Roa et al. [7] compared different objective measurements for wall enhancement and concluded that a measurement based on the aneurysm-to–pituitary stalk contrast ratio is the most reliable method and robust in regard to different manufactures and magnet strength of the MR scanners. The measure was used to classify aneurysms with or without wall enhancement. We present a segmentation of different nuances of wall enhancement.

2 Materials and Methods

We define wall enhancement as lighter values near the aneurysm. As the absolute grey values in MR images can not be compared directly, the intensities are evaluated in comparison to a reference value from the same image. The threshold for the values which are determined as enhanced, are set as percentages of a reference value. We use five thresholds to segment the images in not enhanced tissue and five wall enhancement classes. The used thresholds are further described in Section 2.2. Motivated by the results by Roa et al. [7] we use the brightest pituitary value as reference value for our wall enhancement segmentation.

2.1 Prototype

We implemented a prototype in MATLAB (MATLAB, 2020a, The MathWorks Inc) for the segmentation of wall enhancement of intracranial aneurysm. First, a black blood MRI is loaded. Then, the pituitary is identified by searching for bright circles near the centre in the image slices. The brightest value of the pituitary stalk is proposed as reference value. The user has three options to adjust the reference value: set the reference value to the brightest value occurring in the image, manually type in a value or select a new point in the pituitary. In the last case the brightest value near

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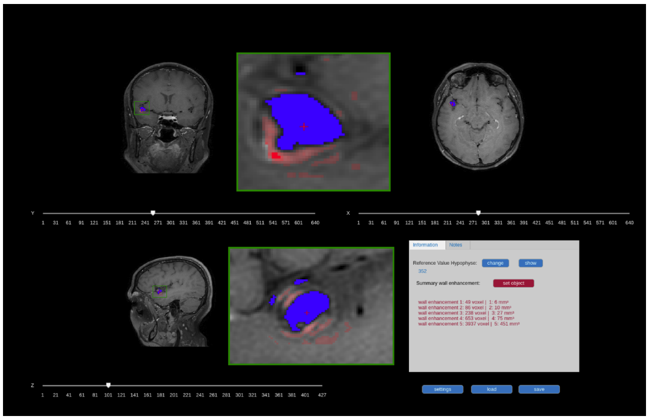

Fig. 1: Prototype of wall enhancement segmentation tool with zoomed in view of segmentation (green rectangles). Blue: aneurysm/vessel, red cross: cursor position, red overlay: segmented wall enhancement.

the selected point is used to account for imprecise point selection. With that option, a faulty automatic pituitary selection can be easily corrected. The user can use between 1 and 10 classes for wall enhancement and set the corresponding thresholds as percentages of the reference value. Additional to the semi-automatic reference value selection, it is necessary to segment the aneurysm. This is done by setting a seed point in the middle of the aneurysm and performing region growing. After the aneurysm segmentation has been performed, the neighbouring voxels can be determined and, according to their values, the amount of enhancement can be defined. The wall enhancement segmentation is overlayed in red. A darker red depicts a higher wall enhancement and a transparent red a lower wall enhancement. A summary of the wall enhancement segmentation shows the amount of voxels and respective volume of each enhancement class.

2.2 Experiments

We used the tool to segment wall enhancement around intracranial aneurysms for ten patients (patient ids: 1, 4-12). Our wall enhancement segmentation divided the wall enhancement into five groups. The thresholds are given as percentage of the intensity at the pituitary. Four sets of thresholds (a,b,c,d) are explored. The wall enhancement classes are based on the intensity as summarised in table 1. The wall enhancement segmentations of the tool were compared with manual, binary segmentations.

Tab. 1: Thresholds used for wall enhancement segmentation

	class 1	class 2	class 3	class 4	class 5
a	85%	75%	70%	65%	60%
b	75%	65%	55%	45%	35%
c	70%	60%	50%	40%	30%
d	60%	50%	40%	30%	20%

3 Results

The segmentation results of the automatic segmentation differ depending on the selected thresholds. When all classes are combined, the automatic segmentation includes a larger volume than the manual segmentation. Fig. 5 shows this exemplary for patient 1 and patient 4. For patient 4, the additional segmentation volume increases with lower thresholds. For patient 1, this does not happen, as already all voxels in the search area around the aneurysm are segmented with the highest threshold set (a). In both cases, the volume of the higher wall enhancement classes increase with lower thresholds. The same can be seen in Fig. 4, where the segmented volume of each wall enhancement class is shown for patient 7 and patient 12.

Sometimes the manual segmentation includes voxels with intensities much smaller than the reference value at the pituitary. For example, in patient 10, the manual segmentation includes many voxels of low intensities. As Fig. 6 shows, even with the lowest threshold combination (d), where the minimum threshold to include voxels in the wall enhancement segmentations is 20% of the maximal pituitary intensity, some voxels of the manual segmentation are below this threshold. With lower thresholds, more of the manual segmentation is included and sorted in higher wall enhancement class (Fig. 2).

In Fig. 3, the manual segmentation volume is compared to the volume segmented as wall enhancement class 1. The necessary threshold to achieve a segmentation volume of wall enhancement class 1 comparable to the manual segmentation is between 55% and 65%. For patient 5 a threshold between 45% and 55% would be optimal.

4 Discussion

While a consistent and reproducible definition of wall enhancement is used, it is challenging to find thresholds suitable for all data sets. To include all of the manual segmented wall enhancement area, low thresholds (<20%

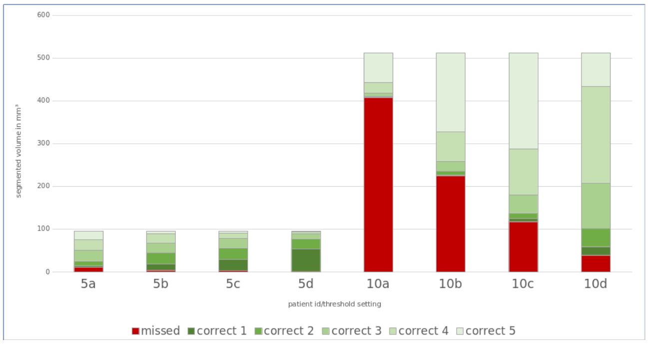

Fig. 2: Comparison of wall enhancement segmentation of our tool with manual segmentation for patient 5 and 10: missed volume (volume segmented by expert but not by the tool) and correct volume (volume segmented by both; for the tool the corresponding wall enhancement class of the segmentation is shown)

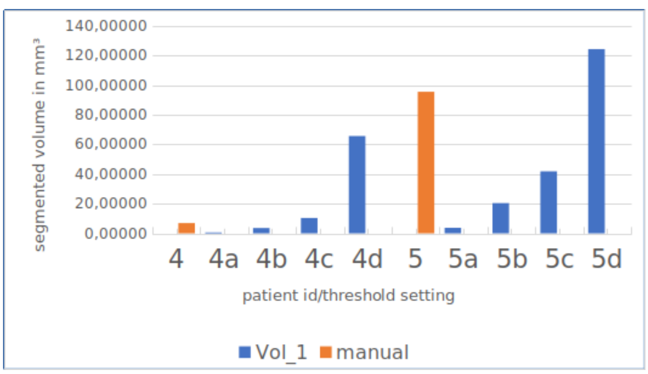

Fig. 3: Comparison of segmented volume of manual segmentation and automatic segmentation of wall enhancement class 1 for patient 4 and 5

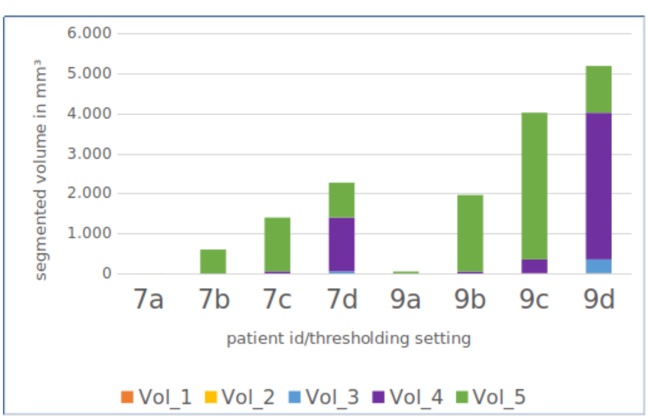

Fig. 4: Result of automatic segmentation: Volume of each wall enhancement class for patient 7 and patient 9 (wall enhancement class 1 and 2 occur in 9c and 9d in very small amounts (less than 5 mm^3)

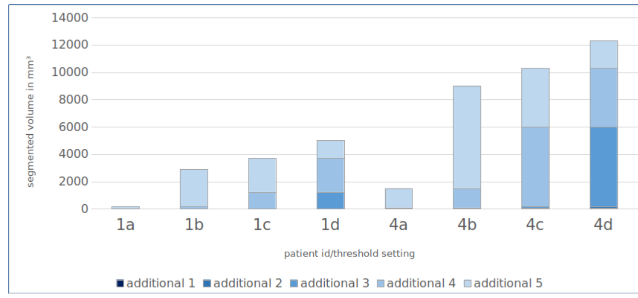

Fig. 5: Additional segmented volume of each wall enhancement class in patient 1 and 4

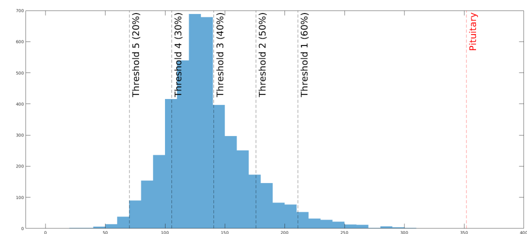

Fig. 6: Histogram of voxel intensities inside manual segmention of patient 10 and corresponding thresholds d

or smaller) can be necessary. At the same time, these tend to include larger areas not included in the manual segmentations and increase the volume of the higher wall enhancement classes. The optimal thresholds might be further evaluated by comparing the different segmentation and resulting volumes for the wall enhancement classes to the rupture risk. That might determine which configuration for the automatic segmentation produces the best results for rupture risk prediction.

Small inaccuracies might be present in the manual segmentation due to several circumstances. The voxelisation of the smooth contours can lead to small differences at the segmentation border. The algorithm evaluates each voxel separately and decides whether wall enhancement is visible and which wall enhancement class the voxel belongs to. Partial volume effects might influence the segmentation. It is unlikely that a manual segmentation would be that detailed. Instead, an expert likely evaluates several voxels together. Therefore, the manual segmentation is more prone to include voxels with darker intensity.

A problem for manual segmentation might be the unreliable perception of grey values. While the computer evaluates the exact intensity value and compares it to the reference value, human perception of grey intensities is influenced by the surrounding values. Depending on the adjacent voxels, the same value might appear lighter or darker to a human performing the segmentation. The automatic segmentation is therefore more constant and reliable in the evaluation of grey intensities.

Here, the automatic segmentation was only compared to one manual segmentation per patient. Different persons might provide slightly different segmentations and it would be interesting to compare the automatic segmentation to other manual segmentations. Additionally, further configurations for the automatic segmentation (number of wall enhancement classes, thresholds) could be considered.

This segmentation works on individual voxels. To better correspond with human segmentations, it might be useful to develop an algorithm which decide on wall enhancement not on individual voxels but on small groups. Furthermore, the overall shape (for example avoiding small holes) might be taken in account to fit manual segmentations.

5 Conclusion

We presented a detailed, automatic wall enhancement segmentation for intracranial aneurysms. The automatic segmentation with five wall enhancement classes and different thresholds for these classes was compared to binary manual segmentation. The definition of thresholds, which are able to fit the manual segmentation for all patients, are challenging to find.

Author Statement

Research funding: This work is partly funded by the German Research Foundation (SA 3461/2-1) and the Federal Ministry of Education and Research within the Forschungscampus *STIMULATE* (13GW0095A). Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent has been obtained from all individuals included in this study. Ethical approval: The research related to human use complies with all the relevant national regulations, institutional policies and was performed in accordance with the tenets of the Helsinki Declaration, and has been approved by the authors' institutional review board or equivalent committee.

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