

Article

Not peer-reviewed version

A Novel Landmark-Based Semi-Supervised Deep Learning Method for Aneurysm Detection Using 3D TOF-MRA

[Hyeonsik Yang](#) , [Eunyoung Regina Kim](#) , ZunHyan Rieu , [Donghyeon Kim](#) , Beomseok Sohn , [Minho Lee](#) *

Posted Date: 8 May 2024

doi: 10.20944/preprints202405.0485.v1

Keywords: neuroradiology; MRI; deep learning; aneurysm detection; semi-supervised learning; neuroradiology brain; MR; computer applications-detection; diagnosis; aneurysms



Preprints.org is a free multidiscipline platform providing preprint service that is dedicated to making early versions of research outputs permanently available and citable. Preprints posted at Preprints.org appear in Web of Science, Crossref, Google Scholar, Scilit, Europe PMC.

Copyright: This is an open access article distributed under the Creative Commons Attribution License which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Article

A Novel Landmark-Based Semi-Supervised Deep Learning Method for Aneurysm Detection Using 3D TOF-MRA

Hyeonsik Yang ¹, Eunyoung Regina Kim ¹, ZunHyan Rieu ¹, Donghyeon Kim ¹, Beomseok sohn ² and Minho lee ^{1,*}

¹ NEUROPHET, INC
² SEVERANCE HOSPITAL
* Correspondence: minho.lee@neurophet.com

Abstract: This study presents a novel semi-supervised deep learning method utilizing 3D TOF-MRA images for the detection of brain aneurysms, employing landmark-based techniques that mimic radiologist practices to enhance detection accuracy and efficiency.

Keywords: neuroradiology; MRI; deep learning; aneurysm detection; semi-supervised learning; neuroradiology brain; MR; computer applications-detection; diagnosis; aneurysms

Methods and Materials

Instead of observing the entire space of the image, the human radiologist only carefully observes the area where aneurysm is frequently found on the vessel [1,2]. Hence, we mimicked these radiologists' behavior patterns to make deep learning models train the landmarks on the vessels where aneurysm is likely to occur. The easiest way to obtain a deep learning model that predicts landmark is to train the model using human-made landmark ground truth.

Definition of human-made landmark ground truth: The human radiologist reviewed the patient's MRA image and segmented it by the name of the vessel (ICA, ACA, MCA, etc.) [3] where aneurysm may occur. As shown in Figure 1, the ground truth landmark should indicate not only the area with aneurysm but also all areas where aneurysm can occur.

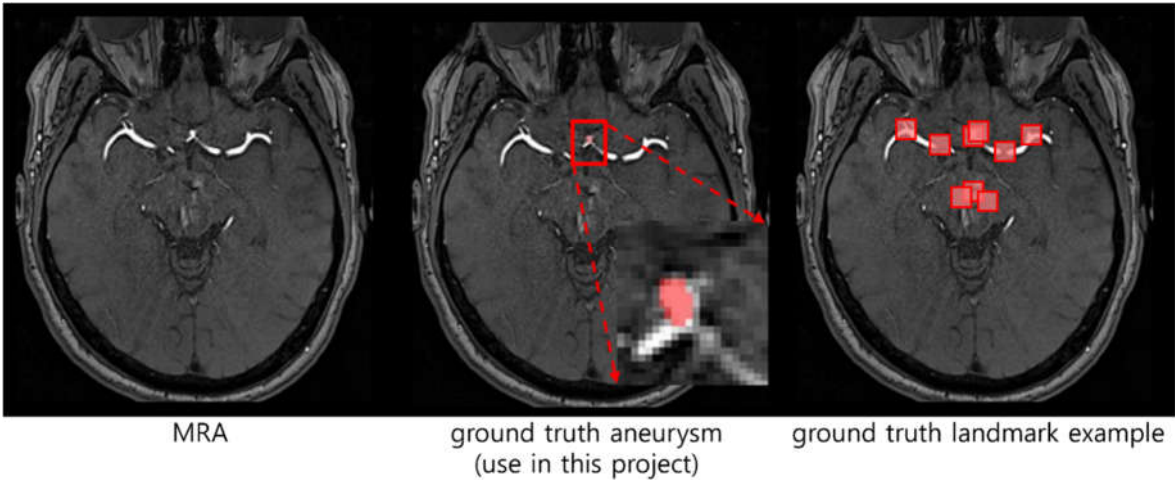


Figure 1. Original MRA(left), Manual segmentation label for cerebral aneurysms by specialist in radiology(middle), Ground truth landmark example(right).

Dataset: 3D TOF-MRA images were retrieved from one Korean hospital to train and validate a proposed model. Multiple radiologists independently read the presence or absence of cerebral aneurysms (positive and negative), the number of cerebral aneurysms, and location. Only images with consistent opinions of radiologists were selected and used, the final number of selected data is 550. Of the 550 images, 50 images are without aneurysms, 426 images have 1 aneurysm per image, 60 images have 2 aneurysm per image, 12 images have 3 aneurysm per image, 1 image has 4 aneurysm per image, 1 image has 5 aneurysm per image. 55 images, which is 10%, were randomly selected and used as a validation only set, and there are a total of 55 aneurysm included.

However, due to the difficulty of obtaining the human-made landmark ground truth, we propose a semi-supervised learning [4]-based automatic landmark generation method that uses only aneurysm-specific ground truth.

The proposed method consists of two steps: the first step is clustering the aneurysm-positive position of all MRA images on the 3D space. This cluster center is used as the initial location of the landmark for the deep learning model. The second step is building the deep learning model that outputs predicted landmarks, which do not overlap but simultaneously contain all the aneurysms well. Additionally, we propose two novel loss functions for the landmark-generated model, described in detail below.

Clustering: Aneurysm-positive position does not occur in all the areas of the MRA images, but in specific vascular areas. The first step is to group these regions into several subgroups that share common properties. We grouped the aneurysm-positive locations close to Euclidean distance using k-means clustering [5]. As a result, sub-groups are bound with similar blood vessels shape as shown in Figure 2.

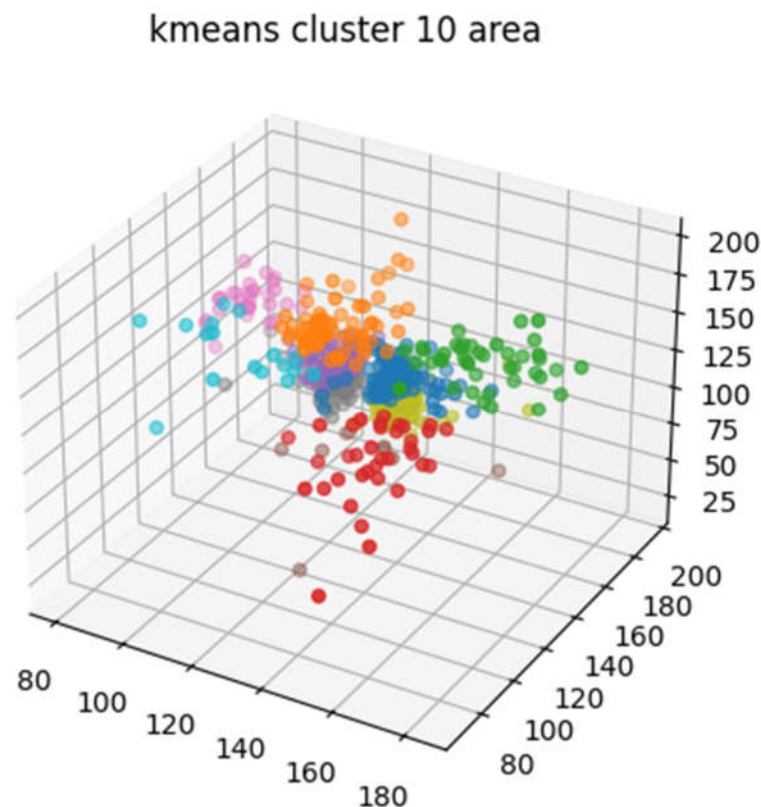


Figure 2. Clustering the anurysm point with kmeans.

Training a deep Learning model: We create a landmark that contain areas where aneurism is likely to exist using a deep learning model. By considering the shape of blood vessels, the deep learning model can predict more precisely where aneurysms are likely to occur. The deep learning

model uses a dilated residual network [6] as shown in Figure 3, it receives the MRA image resized to 256 K is the number of landmarks and R is the size of the landmark. We select experimentally suitable K and R, and described the results in the section of Results or Findings.

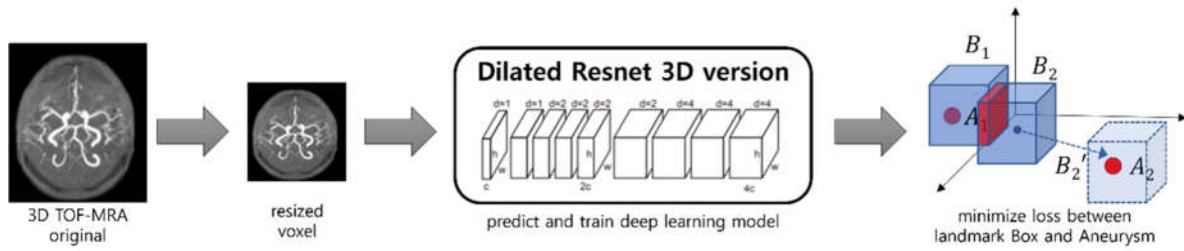


Figure 3. Overview of the proposed deep learning structure.

We trained the deep learning model in a semi-supervised manner by proposed the custom loss functions because we did not have the ground truth landmark label. The deep learning model initially mimicked a sub-group simply made of k-means clustering then trains using the proposed custom loss term as shown in Figure 4.

$$L = L_1 + L_2$$

$$L_1 = \sum_i^{i \in B} \sum_j^{j \in A} D(B_i, A_j) \text{ if and only if } \text{NotContain}(A_j, B) = \text{True}$$

- B_i : landmark box i
- A_j : center of aneurysm positive point j
- $D(B_i, A_j)$: Euclidean distance between center of B_i and A_j
- $\text{NotContain}(A_j, B)$: Whether A_j is not contained any landmark box B

$$L_2 = - \sum_i^{i \in B} \sum_j^{j \in B} D(B_i, B_j) \text{ if and only if } \text{Overlap}(B_i, B_j) = \text{True}$$

- $\text{Overlap}(B_i, B_j)$: Whether the regions where $B1$ and $B2$ overlap exist

Figure 4. Proposed loss term for train deep learning model.

L_1 makes a landmark box B contain aneurysm-positive location A , which is not yet included in any landmark. For example, as shown in Figure 5, B_1 already contains A_1 so it remains in the current state. B_2 is not contained any A so it moves to a position close to A_2 .

L_2 makes a landmark box B which does not overlap each other. As shown in Figure 6, boxes with overlapping areas are pushed away from each other. Boxes where overlapping areas do not exist, are not affected.

The training process is as shown in Figure 7, and the landmark is located on a vessel where aneurysm is likely to occur.

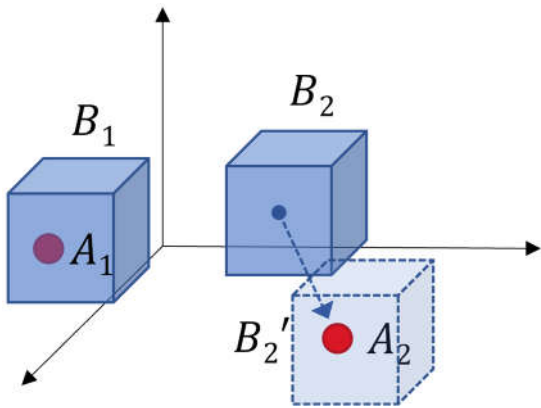


Figure 5. Example of a landmark box adjusting to loss term 1.

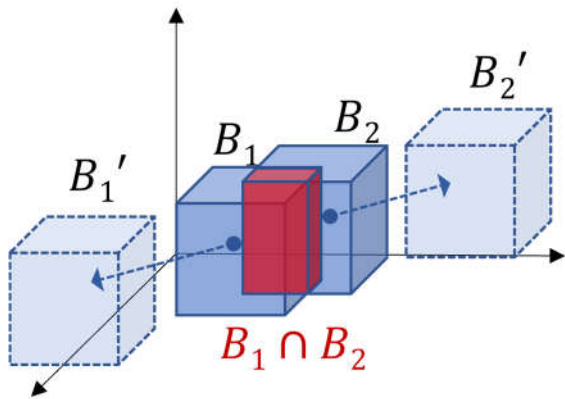


Figure 6. Example of a landmark box adjusting to loss term 2.

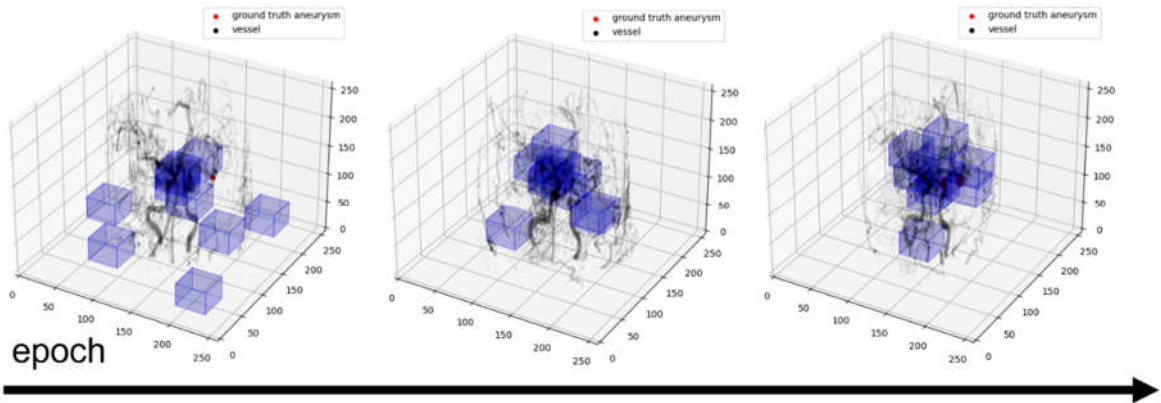


Figure 7. Changes in the form of landmark location as learning progresses.

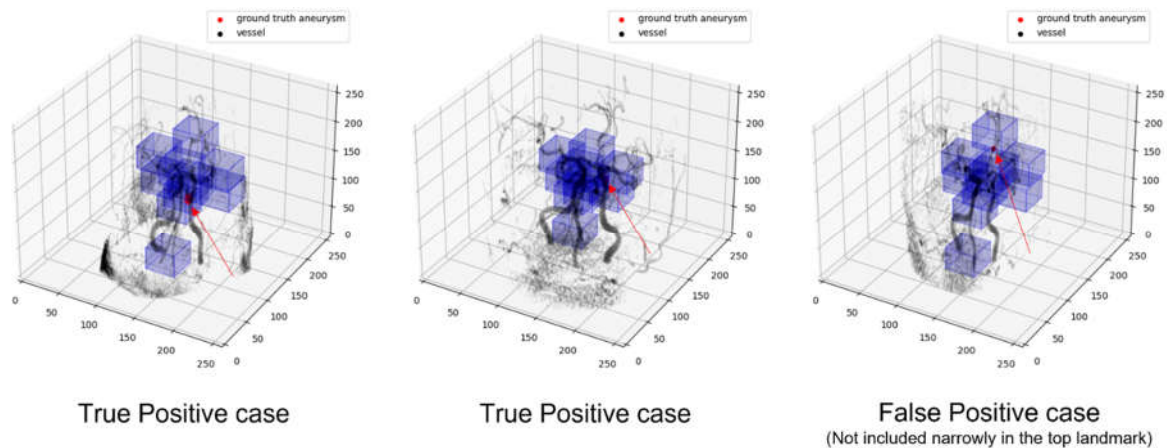


Figure 8. Examples of learning outcomes of the proposed deep learning model.

Experiment Results

Assess the outcomes of landmark extraction utilizing the introduced model, followed by the training of a distinct detection AI. Estimate the algorithm's sensitivity and false positive (FP) rate through a comparison of the detection outcomes as predicted by the AI against the bounding box outcomes annotated with the reference standard in Intersection over Unions (IoUs) [7]. A per-lesion IoU exceeding 0.01 is classified as a per-lesion detection positive. In contrast, a per-lesion IoU not surpassing 0.01 is regarded as a per-lesion detection negative. Within the framework of performance evaluation on the Validation only dataset, the derived metrics were Sensitivity of 0.83, FP rate of 3.4, and Dice Similarity Coefficient (DSC) [8] of 0.66.

Reference

1. Yoon, N.K., McNally, S., Taussky, P. et al. Imaging of cerebral aneurysms: a clinical perspective. *Neurovasc Imaging* 2, 6 (2016). <https://doi.org/10.1186/s40809-016-0016-3>
2. <https://appliedradiology.com/articles/aneurysmsall-you-need-to-know>
3. <https://radiopaedia.org/articles/middle-cerebral-artery>
4. <https://www.ibm.com/topics/semi-supervised-learning>
5. Krishna, K., and M. Narasimha Murty. "Genetic K-means algorithm." *IEEE Transactions on Systems, Man, and Cybernetics, Part B (Cybernetics)* 29.3 (1999): 433-439.
6. Zagoruyko, Sergey, and Nikos Komodakis. "Wide residual networks." *arXiv preprint arXiv:1605.07146* (2016).
7. van Beers, Floris, et al. "Deep neural networks with intersection over union loss for binary image segmentation." *Proceedings of the 8th international conference on pattern recognition applications and methods*. SciTePress, 2019.
8. Thada, Vikas, and Vivek Jaglan. "Comparison of jaccard, dice, cosine similarity coefficient to find best fitness value for web retrieved documents using genetic algorithm." *International Journal of Innovations in Engineering and Technology* 2.4 (2013): 202-205.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.