DeepAAA: Automated Detection of Abdominal Aortic Aneurysms using Deep Learning

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Introduction

Untreated abdominal aortic aneurysms (AAAs) tend to grow and eventually may rupture with mortality rates exceeding 90%. As most of AAAs are asymptomatic until onset of bleeding, incidental finding of AAAs becomes critical. However, on routine abdominal computed tomography (CT) exams, only 65% of AAAs are incidentally identified. This low reporting rate makes it difficult to provide patients optimal treatment. To address the issue, this study aims to develop a deep learning-based system (DeepAAA) for automated AAA detection on contrast and non-contrast CT scans.

Hypothesis

Driven by the ever-increasing capability of deep learning, we hypothesize that convolutional neural networks can serve as a good supporting tool for radiologists to identify incidental AAAs in routine CT examinations.

Methods

Our training and testing dataset consisted of 310 contrast or non-contrast CT examinations of the abdomen and pelvis (220 unique patients) performed at one of our institutions. The ground truth of aorta was manually contoured on the axial scans slice-by-slice until the aortic bifurcation. Each study was annotated by 1 to 4 CT technologists under supervision of 2 radiologists.

We developed an enhanced 3D U-Net architecture for aorta segmentation by modifying the 3D pooling kernels to 2×2×1, such that the network can handle variable slice dimensions. There were 5 downsampling/upsampling modules, 2 convolutional layers per module with a total of 24 million parameters in the network. We added batch normalization before each ReLU activation. Dropout regularization was utilized at the bottleneck layer with a dropout rate of 0.2. The network was trained by mixing contrast and non-contrast CT scans with 5-fold cross validation. After aorta segmentation, ellipse fitting was applied to the contours of the aorta slice-by-slice. The largest aortic diameters were thus assigned by the long axis of the ellipses. Angle correction was used to retrieve the true aorta diameter for the regions where the aorta was not parallel to the axial CT scans. All the experiments were implemented utilizing the Keras deep learning library with the Tensorflow backend on NVIDIA DGX1 with V100 GPUs.

Results

DeepAAA successfully segmented the aorta on both contrast and non-contrast CT images, and worked well with more clinically challenging cases where blood-clots were present, or the aortic boundary was not clear on the images (Fig. 1). We achieved high performance on aortic segmentation with an average Dice coefficient of 0.90, which yielded high sensitivity (0.91) and high specificity (0.95) on AAA detection (Table 1). Compared to the latest clinical performance, DeepAAA achieved on-par or higher sensitivity on incidental AAAs (Table 2).

Figure 1: DeepAAA aorta segmentation (red overlay) and the largest aortic diameter estimation (yellow crosses, the major axis of ellipse fitting [green curves] of the aorta segment): (a-c) Aneurysm with thrombus on contrast CT. (d-f) Large aneurysm on non-contrast CT where aortic boundary is hard to segment. (g-i) normal aorta.

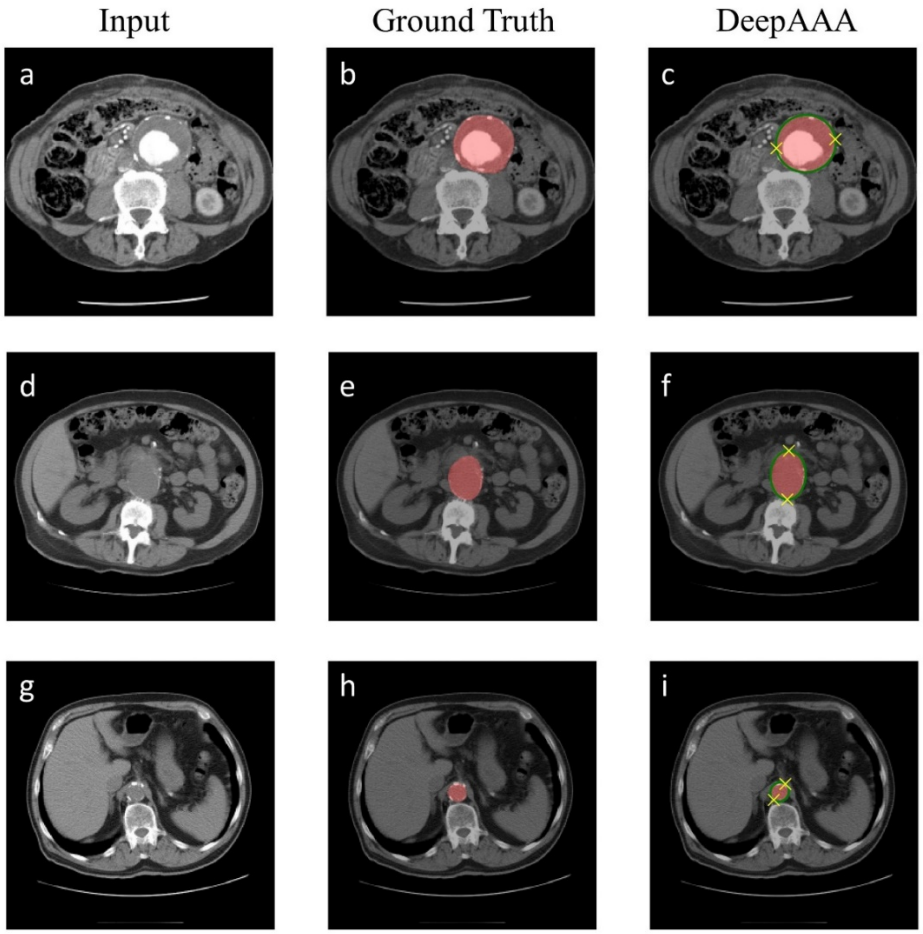

Table 1: Performance of DeepAAA on segmentation and detection (mean ± s.t.d)

	Segmentation		Detection	
CT Type	Dice	Err. in largest diameter (mm)	Sensitivity	Specificity
Contrast	0.89 ± 0.05	-2.67 ± 2.62	0.89 ± 0.08	0.94 ± 0.08
Non-contrast	0.90 ± 0.05	-1.36 ± 4.30	0.92 ± 0.01	0.95 ± 0.10
Overall	$\mathbf{0.90 \pm 0.05}$	$\mathbf{-2.02 \pm 3.62}$	$\mathbf{0.91 \pm 0.03}$	$\mathbf{0.95 \pm 0.05}$

Table 2: Comparison between DeepAAA and literature reported performance of radiologists on AAA reporting for routine abdominal CT according to aneurysm size

	AAA size (mm)		
Method	30-39	40-49	≥50
DeepAAA sensitivity	**0.68**	**1.00**	**1.00**
Radiologists' sensitivity*	0.52	0.87	1.00

* Claridge *et al*. *Journal of vascular surgery*, *65*(6), 1637-1642 (2017).

Conclusion

This work demonstrates the feasibility of automated AAA detection using neural networks. DeepAAA achieves high performance on both contrast and non-contrast CT scans and works with image volumes with varying numbers of slices. With appropriate clinical validation, this system can improve the effectiveness and efficiency of routine CT examinations.

Statement of Impact

As most of AAAs are asymptomatic and diagnosed incidentally, our work demonstrates that neural networks can be a reliable tool assisting radiologists to increase the sensitivity for detecting incidental AAAs in routine CT examinations.

Keywords

neural networks; deep learning; abdominal aortic aneurysms; computed tomography; incidental finding

Supplementary Video

Slice-by-slice aorta segmentation on CT scan: https://bit.ly/DeepAAA