Development and Validation of Novel Two-stage Vascular Segmentation Model for Interventional Angiography

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Introduction/Background
Automated vascular segmentation in interventional angiography is challenged by contrast kinetics, vessel variations, and 2D projections, limiting the effectiveness of single-model approaches. This study proposes and validates a two-stage soft segmentation strategy to enhance performance across varying vascular conditions by treating vessel width and bifurcation number as separate problem classifications.

Methods/Intervention
Retrospective review identified 234 patients who experienced interventional fluoroscopy of the celiac axis with iodinated contrast from January 1st, 2019, to December 31st, 2022. Processing of 261 acquisitions yielded 662 image-mask partition pairs of 128x128 pixels, consisting of the original ground-truth image and a corresponding hand-labeled, multi-class mask. Segmentation classes (Trunk, Bifurcation, Periphery) were defined by diameter fraction of the celiac axis and number of vessel bifurcations. A UniverSeg model was uniquely adapted as a first-stage discriminator through the sorting of the partitions into four support sets based on the class fraction of each segmentation target. Discrimination generated four SoftMax output layers representing the probability distribution for each class in the image. These probability maps were compressed and min-max normalized to create a refined input for the second stage, which was split 8:2 for training and validation. A 2D-nnU-net was employed as the refining model, selected for its proven effectiveness in medical image segmentation. Model performance was evaluated using five-fold nested cross-validation against both specialized and generalized segmentation targets.

Results/Outcome
Mean Balanced-Average-Hausdorff-Distances were 0.46, 0.58, 0.61 (σ=0.38, 0.43, 0.99) across the class specific tests, indicating strong spatial agreement in the specialized cases and improvement over comparative nnU-net results (μ=0.75, 1.16, 3.28; σ=0.31, 0.55, 0.94). While variance increased in cases with diverse vessel arrangements (σ= 0.84, 1.32, 3.55), mean performance decline was small (μ = 0.57, 0.62, 0.65) in absolute pixel difference against control conditions. All evaluation metrics increased with vessel diameter, reduced bifurcations and dataset augmentation.

Conclusion
This two-stage soft segmentation model demonstrates promising results for specialized problems within interventional angiographic segmentation, as showcased by its development and testing on this large and diverse dataset.

Statement of Impact
This study validates a potential method for arterial segmentation in interventional fluoroscopic procedures and facilitates development of vascular disease models and imaging research applications.
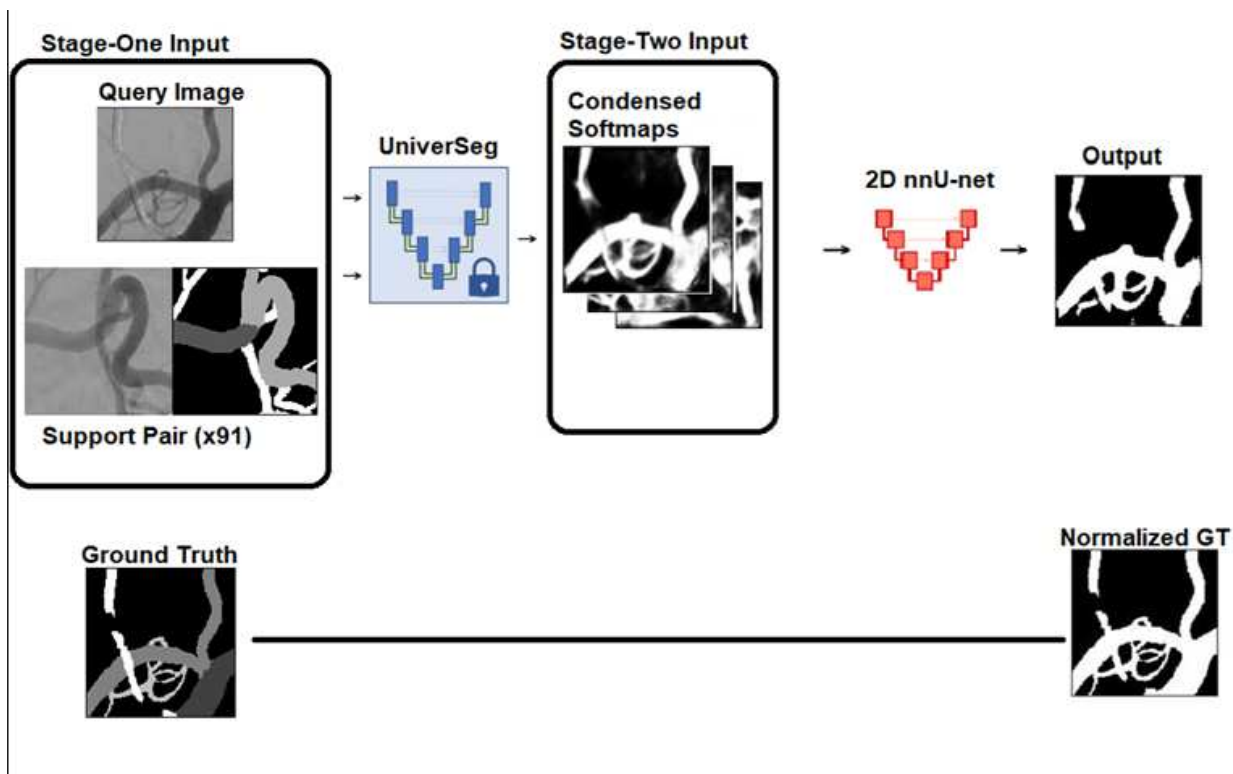
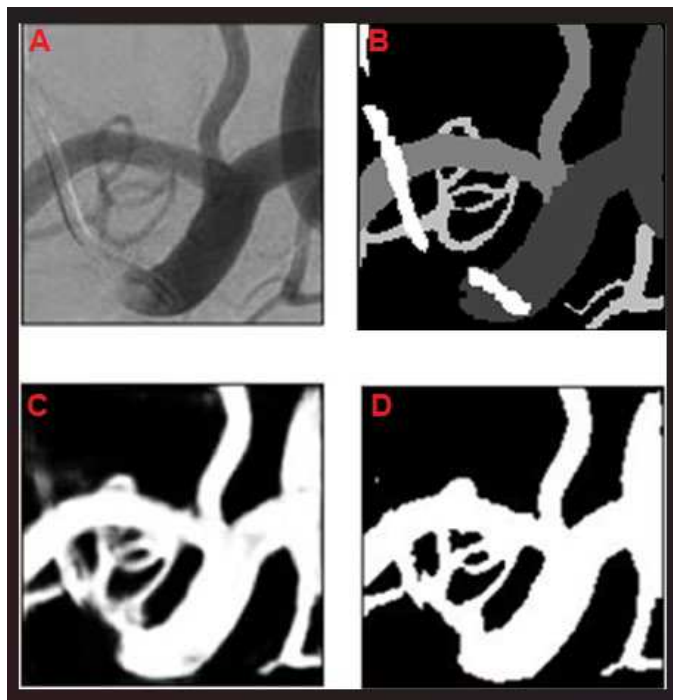Figure 1: Overview of two-stage methodology demonstrating training process.

Figure 2: Example of two-stage segmentation. Sub-figure A represents the ground truth of the image. B represents the hand labeled segmentation mask, separated out into four classes based on structural category. C represents the compressed probability layer after discrimination. D is the final segmentation of the anatomical classes. This example had a Balanced-Average-Hausdorff-Distance of 0.4 pixels

Two-Stage Segmentation Validation Test Results			
Model	Region	Balanced-Average-Hausdorff-Distance (pixels)	
		μ	σ
Two-Stage Specialized	Trunk	0.46	0.38
	Bifurcation	0.58	0.43
	Periphery	0.61	0.99
Two-Stage Generalized	Trunk	0.57	0.84
	Bifurcation	0.62	1.32
	Periphery	0.65	3.55
Augmentation Specialized	Trunk	1.05	0.43
	Bifurcation	2.70	0.76
	Periphery	5.73	3.71
Augmentation Generalized	Trunk	1.31	1.20
	Bifurcation	3.29	0.85
	Periphery	5.80	3.80
nnU-net Specialized	Trunk	0.75	0.31
	Bifurcation	1.16	0.55
	Periphery	3.28	0.94

Table 1: Two-Stage 5-Fold Nested Validation Test Results