Using Deep Learning to Estimate Penumbra for Acute Ischemic Stroke Patients with DWI and ASL

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Introduction
In acute ischemic stroke, estimating the penumbra, or region at-risk of infarction in the absence of reperfusion, is important to determine whether the patient is likely to benefit from treatment. The current gold standard for penumbra is based on the time-to-peak of the residue function (Tmax) map, which is reconstructed from bolus contrast perfusion weighted imaging (PWI), where tissue with a Tmax > 6s is generally considered to represent penumbra. Yet up to 25% of stroke patients cannot receive contrast due to poor kidney function or allergy. We demonstrate that a deep learning model can predict the penumbra region based on non-contrast DWI and ASL-CBF images.

Hypothesis
An acute stroke patient’s penumbra region can be outlined with an attention-gated UNET using diffusion weighted imaging (DWI), Apparent Diffusion Coefficient (ADC) and cerebral blood flow map from arterial spin labeling (ASL-CBF).

Methods
90 patients were identified retrospectively from a multi-center stroke study. All patients underwent 3T MR imaging at baseline, with DWI, PWI, and ASL (either single post-label delay [2000 ms, 1.5T] or multidelay [700-3000 ms, 3T]). DWI images were acquired with TR/TE 4000/77.5ms and b=1000s/mm². Penumbra mask was calculated using RAPID software using a criterion of Tmax > 6s (version 4.5.1, iSchemaView, Menlo Park, CA, USA) and used as ground truth. A residual deep convolutional neural network with a U-Net architecture was constructed using DWI, ADC maps, and ASL-CBF as input with Tmax>6s segmentations as ground truth. The model’s output is an image where each voxel ranges between 0 and 1, representing the probability of the voxel being included in penumbra. 5-fold cross validation was used to evaluate the model performance. Assessments included receiver-operator characteristic metrics (area-under-the-curve [AUC]), Dice score, precision, recall, specificity, and penumbra volume at optimal threshold.

Results
The model produced a median voxel-based AUC of 0.873, and a median per-subject AUC of 0.87 (IQR 0.83 – 0.92). At the prediction threshold yielding best performance, median Dice score was 0.36 (IQR 0.18 – 0.59. Median volume difference from ground truth was 6 (IQR -40 - 42)ml and median absolute volume difference was 42 (IQR 18 – 61).

Conclusion
Using information available in ASL and DWI scans, a deep learning model can estimate the size and location of the penumbra without the use of contrast agents.

Statement of Impact
Using deep learning, an acute stroke patient’s penumbra can be accurately outlined without contrast injecting perfusion scans, providing a quicker and safer way for stroke triaging.

Keywords
acute ischemic stroke, machine learning, deep learning, UNet, arterial spin labeling
Figure 3. Model prediction output examples, compared with the RAPID segmentation of Tmax. DWI was used as the background. Tmax maps were provided as reference but never included in the model. Green area: True positive, Red area: False positive, Blue area: False negative.

**Example 1.** Clear indication of lesion on DWI and ADC with lowered ASL-CBF signal on matching hemisphere. The model made mostly great prediction.

**Example 2.** Mediocre prediction dice score was achieved for this patient with none observable DWI and ADC lesion.

**Example 3.** Obtained from a follow-up scan, there are no penumbra region outlined by RAPID on the Tmax map and the model correctly predicted the negative case in most slices. There are no true positives in this case so the AUC and dice cannot be calculated or compared.

**Example 4.** A poor performing example with a very low dice score. The ASL CBF map is particularly noisy and there are no visible lesion on the DWI and ADC scans.