Correlation of Macular Vessel Density and Vision in Proliferative Diabetic Retinopathy: Development and Application of an Automated Deep Neural Network for Fluorescein Angiography Vessel Detection

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Purpose:
Develop an automated deep neural network to detect and quantify macular vessel density from fluorescein angiography (FA) images in an automated fashion and apply it to correlate vessel density and best corrected visual acuity (BCVA) in proliferative diabetic retinopathy (PDR) patients.

Methods:
Retinal blood vessels were detected using a deep neural network organized in the U-Net architecture. The network was trained on a dataset consisting of 8 FA images and the corresponding binary ground truth vessel maps using a novel human-in-the-loop procedure that reduces the burden of annotation. The output from the deep neural network is a vessel map where pixel intensity, ranging from 0 to 1, indicates the probability of a corresponding pixel being a vessel. The probabilistic vessel map is then converted into the binary representation by setting a threshold of 0.5. The algorithm was then applied to the baseline FAs of patients with PDR without macular edema enrolled in the prospective RECOVERY trial. Macular vessel density was then calculated as the ratio of vessel pixels to the total pixels in the macula. Algorithm reliability was tested using the intraclass correlation (ICC). Correlation between baseline vessel density and BCVA was analyzed.

Results:
The deep neural network achieved an area under the curve (AUC) receiving operator characteristic (ROC) of 0.987, an AUC precision recall (PR) of 0.930. Baseline FAs from 42 patients enrolled in the RECOVERY trial were then analyzed using the algorithm. Mean time for automated vessel detection from a FA image was 22.1 seconds (standard deviation 0.21 seconds). The algorithm analyzed FA images with a high reliability (ICC of 0.98). A positive correlation ($r = 0.4071, p = 0.0075$) was found between baseline macular vessel density and BCVA in PDR patients.

Conclusions:
The automated deep neural network is able to reliably detect and quantify retinal vessel density from FA images in an automated fashion. We found a positive correlation between computed vessel density and BCVA in PDR patients using the developed neural network.