Expanding the Dynamic Range of Glaucoma Assessment with Peripapillary Optical Coherence Tomography towards End-Stage Disease using a Deep Learning-Based Framework

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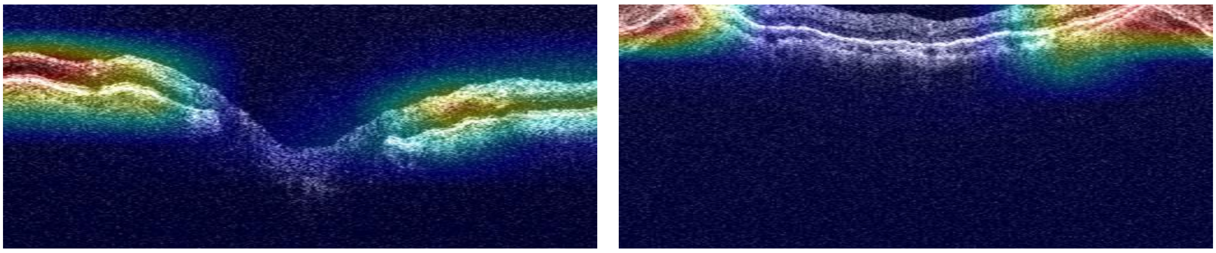
1. Background

Glaucoma is an optic neuropathy, characterized by the gradual loss of retinal ganglion cells (RGCs) and their axons. It can cause structural changes in the ganglion cell layer (GCL), peripapillary retinal nerve fiber layer (pRNFL), and the optic nerve head (ONH), which are consequently associated with visual field loss. Analysis of glaucomatous retinal properties beyond the earliest stages of glaucoma is challenging due to the presence of a "floor effect"- in the later stages of glaucoma, visual field loss continues to progress until blindness, without visible changes on optical coherence tomography (OCT) [[1], [2]]. GCL and RNFL thickness do not reach zero due to the maintained presence of glial cells and blood vessels [3]. This severely hinders the analysis of glaucomatous retinal properties. Thus, this study investigates if deep learning (DL) can improve advanced glaucoma staging. To this purpose, we first used a 3D DenseNet121 to distinguish between mild glaucoma and the advanced stages (moderate, severe, late-stage). This allows us to uncover the features utilized by the model. We will subsequently use this knowledge to extend the analysis to all four stages of glaucoma (mild, moderate, severe, and late-stage).

2. Methods and results

We employed the 3D DenseNet121 as the backbone architecture, followed by a fully connected layer with a single neuron and a sigmoid activation function to output probabilities in the range [0,1]. For this study, to train and validate the model, a total of 1514 volumetric ONH OCTs were used, which are available at the Department of Ophthalmology of the University Medical Center Groningen. All these scans were taken by the Canon HS-100 OCT device and cover a wide range of disease severity from mild to late-stage. Based on the Hodapp-Anderson-Parrish (HAP) and Bascom Palmer glaucoma staging systems [[4], [5]], this dataset includes 393 samples in the mild group and 1,121 samples in the advanced group. Training of the 3D DenseNet121 neural network was performed using the Focal loss function and the Adam optimizer. After training and validation of the network, we obtained an F1-score of 79.0%, specificity of 75.0%, AUC-ROC of 80.0%, and AUPRC of 85.0%, showing that the model is performing well on both classes. In addition, we implemented Grad-CAM++ to qualitatively interpret the model. Figure 1 shows the findings from Grad-CAM++, indicating that this deep neural network attends to the RNFL when classifying mild glaucoma, whereas for more advanced stages it shifts focus toward total retinal thickness, suggesting that the model has learned that RNFL alone is insufficient to capture advanced glaucomatous damage in OCT images.



(a) (b)

Fig. 1. Grad-CAM++ visualizations showing the regions the model attends to when predicting each class. (a) Mild glaucomatous ONH OCT; (b) Advanced glaucomatous ONH OCT.

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4. References

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