Retinal Layer Distance Estimation from Instrument-integrated OCT

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Introduction: Retinal surgeries are complicated and risky since the eye is a vulnerable organ with complex structures and delicate tissues, essential for vision. This has motivated the use of robotic techniques for retinal surgery. However, determining the robot's instrument's location relative to the retina and avoiding damage to delicate tissues during instrument positioning remains difficult. Therefore, we propose to employ an instrument-integrated optical coherence tomography (iiOCT) to determine the distance to the inner limiting membrane (ILM) and retinal pigmented epithelium (RPE) during surgery. As a proof-of-concept, we estimate the distance to the ILM and RPE layers using deep learning based on simulated iiOCT acquisitions.

Method: For this proof-of-concept, we simulated a dataset of 56'560 one-dimensional iiOCT A-scans with corresponding pixel-wise labels. The simulated A-scans were extracted at random trajectories (angles and depths) from B-scans of 100 healthy optical coherence tomography (OCT) volumes. Each extracted A-scan consists of 874 pixels and a depth resolution of 3.7 µm. The pixel-wise labels include three classes: i) Neurosensory retinal (NSR), which describes the region between ILM and RPE, ii) RPE, and c) background (i.e., everything else). We trained a one-dimensional U-Net-like architecture to predict a pixel-wise segmentation of the A-scans. The distances to the ILM and RPE were determined by the first occurrence of the respective classes.

Results: Regarding the segmentation performance, we achieved a mean Dice coefficient of 0.96±0.14 and 0.89±0.12 for the NSR and RPE class, respectively. In terms of distance estimation, we obtained a mean absolute error (MAE) of 0.035±0.28 mm for ILM and 0.020±0.21 mm and for RPE. The Pearson correlation coefficient between the predicted and the true distance was 0.961 ($p < 0.001$) and 0.977 ($p < 0.001$) for ILM and RPE. Large distance errors that considerably affected the MAE were mainly observed in situations where the retina was incomplete or completely missing in the A-scan. The distance errors are in the range of the A-scans' depth resolution when considering the median absolute error, i.e., 0.0037 mm and 0.0037 mm for ILM and RPE.

Discussion: This proof-of-concept shows that, despite the restricted field of view in A-scans, accurate distance estimations of the retinal layers ILM and RPE are possible. Additionally, the results highlight the challenges related to an incomplete or missing retina in the A-scans. Overall, the results suggest that obtaining intraoperative distance estimations from iiOCT is feasible.