A FULLY-AUTOMATIC FAST TECHNIQUE TO TRACE SUB-BASAL LAYER NERVES IN CORNEAL IMAGES

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Purpose

To develop a robust and fast algorithm capable of tracing the sub-basal plexus nerves from human corneal confocal images.

Methods

Corneal nerves changes have been linked to damage caused by surgical interventions or prolonged contact lens wear. Furthermore nerve tortuosity has been shown to correlate with the severity of diabetic neuropathy.

Confocal microscopy is capable of imaging the corneal nerves *in vivo* in a non-invasive way (Fig. 1a).

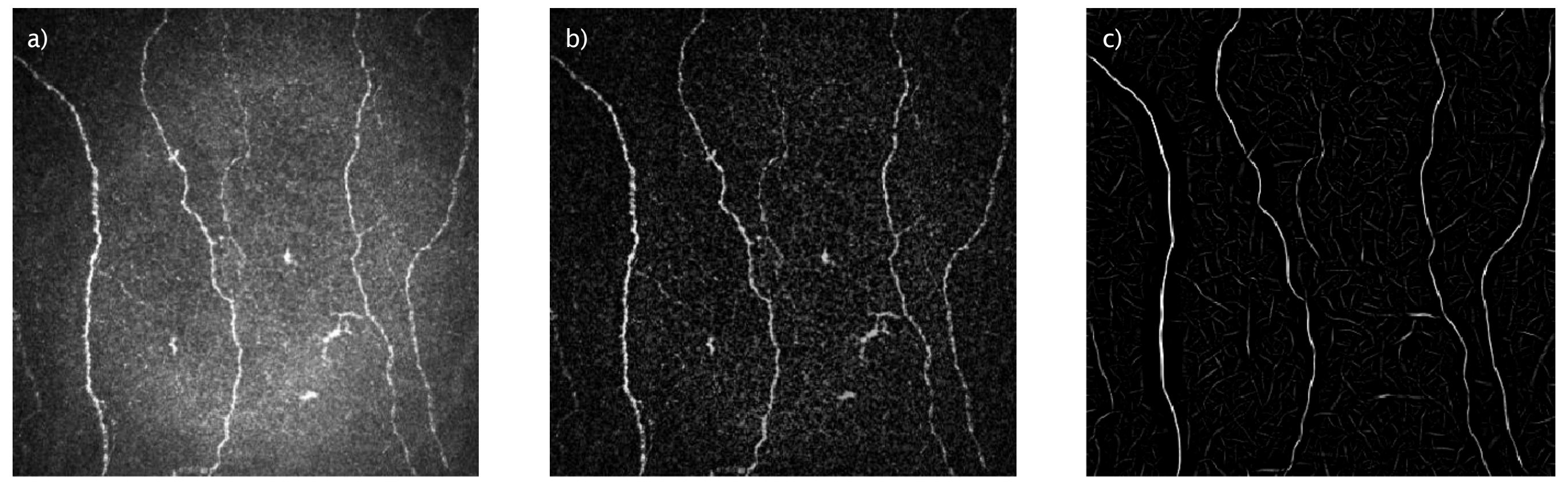

Figure 1. From left to right: the original (a), corrected for uneven illumination and contrast (b), and log-Gabor filtered (c) confocal images.

We propose a novel approach, a fast algorithm capable of tracing the sub-basal plexus nerves in a robust manner. Images are first corrected for uneven illumination and contrast by top-hat filtering (Fig. 1b).

To enhance the corneal nerves, the corrected images are filtered with a bank of log-Gabor even and odd kernels. Each value in the filtered image is defined as the difference between the even and odd maximal filter responses (Fig. 1c).

The resulting image is then thresholded to obtain candidate nerve segments. Hysteresis thresholding was used instead of a simple threshold.

The obtained candidate nerve segments are then classified using a support vector machines (SVM) approach. Feature selection was performed using a backward-elimination approach, based on the accuracy of the segmentation.

Results

A total of 246 images of the corneal nerves of healthy volunteers were acquired using the Heidelberg Retina Tomograph (HRT-II) with the Rostock Cornea Module (Heidelberg Engineering GmbH, Heidelberg, Germany). From these, 50 were used for training and optimization, and the rest for validation (N=196).

All images were manually segmented by two graders, who traced the centerlines of all visible nerves. The manual segmentation with the highest nerve density was selected as the ground truth, while the other was used to establish inter-grader variability.

Figure 2 shows the original image, the automatic segmentation, and both manual segmentations for the best and worst cases.

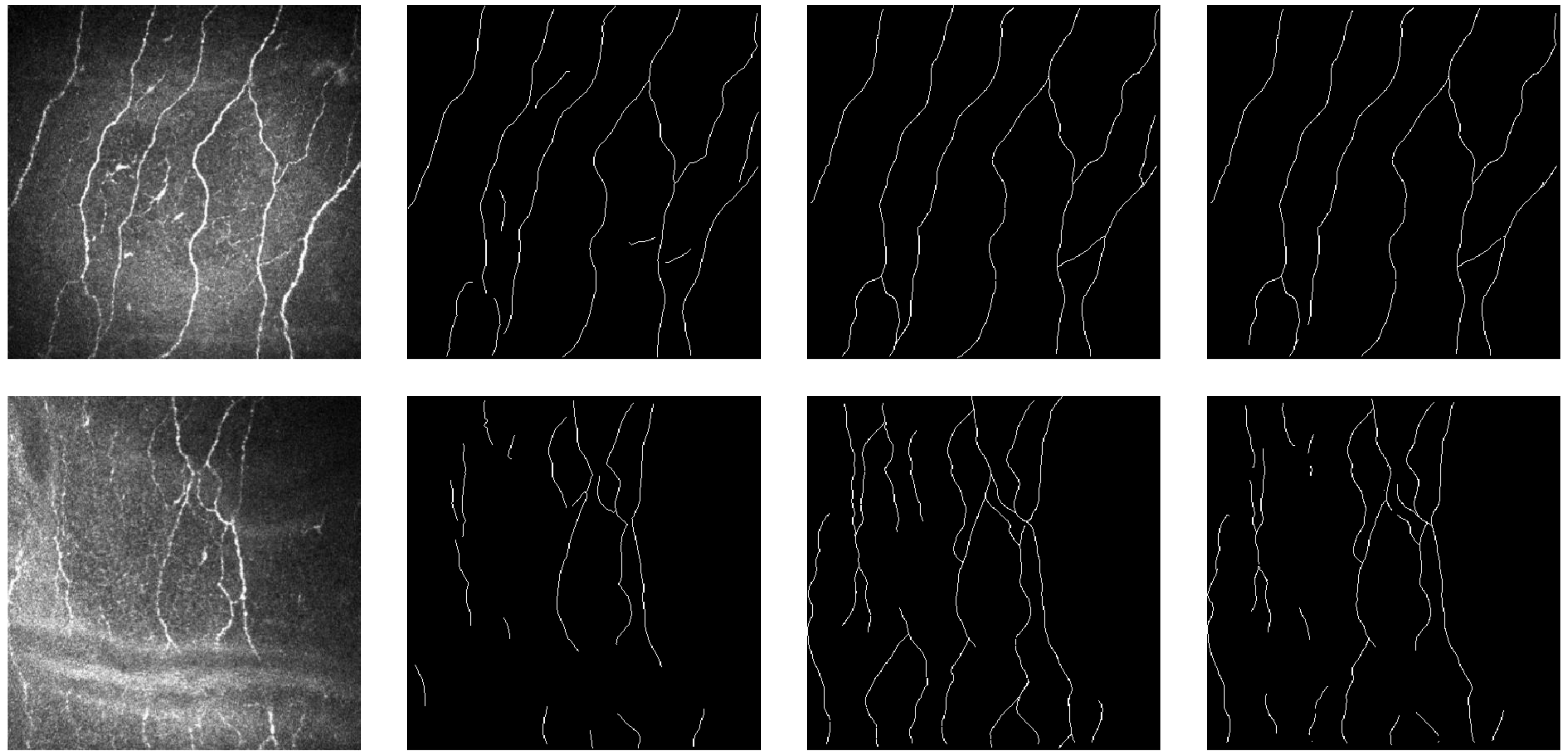

Figure 2. From left to right: the original images, the automatic segmentations, and both manual segmentations. The top row shows the best case, while the bottom one the worst case.

To evaluate the algorithm's performance, the nerve tracings obtained by the proposed automatic approach were compared with the reference ground-truth. The sensitivity (Sen) and false discovery rate (FDR) were computed. Table 1 shows the results for these metrics.

Table 1. Sensitivity (Sen) and false discovery rate (FDR) results (N=196).

	Sen		FDR	
	AVG	SD	AVG	SD
Automatic Segmentation	0.86	0.07	0.08	0.07
Second Observer	0.92	0.05	0.08	0.05

The time required to analyze a single image was 0.61 ± 0.07 s on an Intel Core i7-4770 CPU at 3.4 GHz. This might be important especially when considering mosaicing. A mosaic with 250 images and segmented with the proposed approach is shown in fig. 3. To segment this image the algorithm took 46.4 s.

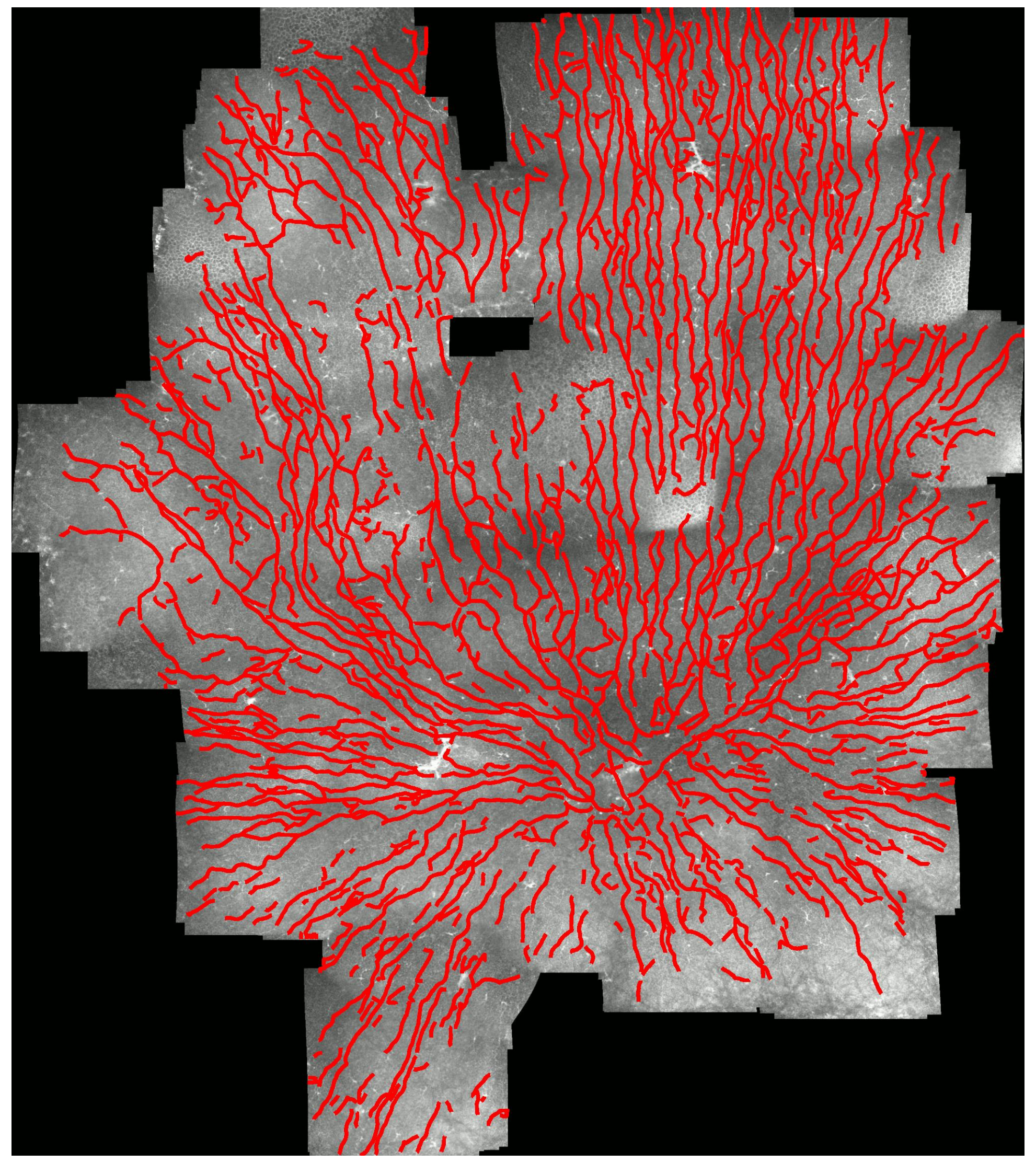

Figure 3. Mosaic image segmented with the proposed algorithm.

Conclusions

A fully automatic robust algorithm is of major importance as it can lead to more robust corneal nerve descriptors, such as nerve tortuosity, computed in due time, and consequently the possibility of an improved diagnosis.

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