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Thesis

Segmentation Errors of Minimum Rim Width and Retinal Nerve Fiber Layer in Glaucoma Subject

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Abstract

To evaluate the impact of manual correction of automated OCT segmentation errors on retinal nerve fiber layer (RNFL) thickness, Bruch's membrane opening-minimum rim width (MRW) measurements, as well as its effect on glaucoma classification.

Keywords: Glaucoma; OCT Segmentation; Retinal Nerve Fiber Layer (RNFL); Minimum Rim Width (MRW)

Background

Glaucoma is an irreversible, progressive optic neuropathy that is characterized by the progressive degeneration of the optic nerve which transmits visual information from the retina to the brain. As the second leading cause of irreversible blindness worldwide [1,2].

It is a progressive optic neuropathy involving degeneration of retinal ganglion cells and their axons, leading to structural damage to the optic nerve head and visual field loss. Since glaucomatous visual impairment is irreversible, early diagnosis is essential to preserve vision. Structural changes often occur before detectable functional defects appear on visual field testing, making imaging technologies such as Optical Coherence Tomography (OCT) highly important in glaucoma evaluation [3,4].

Despite the major clinical value of RNFL measurements, RNFL analysis has certain limitations. Measurement accuracy may be affected by poor image quality, media opacity, high refractive errors, tilted optic discs, or segmentation errors. Additionally, in advanced glaucoma, OCT measurements may reach a "floor effect," where further axonal loss cannot be accurately quantified because minimal residual RNFL tissue remains measurable. [5].

Clinicians should always inspect raw B-scans and segmentation lines rather than relying solely on automated color-coded reports.

Manual correction of segmentation lines may improve diagnostic accuracy, especially in eyes with myopia, optic disc anomalies, or advanced disease [6].

A previous study evaluated the persistence of retinal nerve fiber layer (RNFL) segmentation errors in serial OCT examinations and demonstrated a high likelihood of recurrence of similar errors at the same anatomical locations during subsequent scans ($P < 0.001$). our study also reported lower measurement variability with automated segmentation compared with manually corrected segmentation, suggesting that automated algorithms may provide greater consistency during longitudinal follow-up despite the presence of recurrent segmentation artifacts. These findings are important when interpreting RNFL progression analysis in glaucoma patients [7,8].

RNFLT errors showed a significant association with sector location, being more pronounced in the superior and inferior sectors than in the horizontal sectors. Both BMO-MRW and RNFLT measurements were affected by segmentation artifacts; however, these errors did not consistently occur at the same anatomical locations. Such discrepancies may consequently influence glaucoma classification and alter diagnostic categorization into normal, borderline, or outside normal limits classifications [9,10].

Optical coherence tomography (OCT) measurements are generated through automated retinal layer segmentation algorithms. However, inaccuracies in layer identification may result in segmentation errors, although previous studies have reported that approximately 19% to 46.3% of OCT scans contain at least one segmentation artifact. Such errors may contribute to inaccurate glaucoma classification and may also reduce the sensitivity of OCT in detecting glaucomatous progression. Therefore, precise segmentation of retinal layers is essential to ensure reliable interpretation of OCT-derived parameters in glaucoma assessment and follow-up [11,12].

Segmentation errors may lead to inaccurate glaucoma classification and reduced sensitivity for detecting disease progression. In addition, identifying the location and characteristics of these errors can enhance the ability of OCT technicians and software algorithms to recognize and correct them. Overall, this knowledge may improve the diagnostic accuracy of glaucoma assessment and the monitoring of glaucoma progression, thereby benefiting both clinicians and researchers.

Methodology

60 eyes were enrolled in this study, participants had a diagnosis of open angle glaucoma and were receiving anti-glaucoma treatment. Additionally, eyes with suspicious optic disc appearance or asymmetry of optic disc cupping between the two eyes were monitored. We excluded patients with active infection, amblyopia in either eye, diabetic retinopathy and history of previous retinal surgery. We also excluded scans with vitreous traction or epiretinal membrane (ERM) prevented accurate delineation of (RNFL) or (BMO) as well as subjects with non-glaucomatous conditions.

We obtained a peripapillary retinal nerve fiber layer (RNFL) circular scan and ONH radial B-scans of each eye using a spectral domain (OCT Heidelberg engineering) to optimize the focus and the clarity of the images we entered the refractive correction into the instrument, defined the fovea in a live B-scan and centered the imaging field on the ONH. all radial scans used the real time eye-tracking algorithm. We performed manual correction of the OCT parameters using the Heidelberg eye explorer software tool (software version 5.6.1.0, Heidelberg engineering). Inspected the scans for segmentation errors and adjusted the posterior boundary of the RNFL (between the RNFL layer and ganglion cell layer) and the anterior RNFL boundary (between the vitreous and ILM) to create a manually -corrected peripapillary RNFL measurements by using custom software (BMO-MRW calculator and RNFL calculator). We corrected errors in Bruch's membrane opening and ILM when necessary and calculated the manual refinement results. Defining the error as the difference between automated and manually refined measurements.

This study included participants enrolled in Misr university for science and technology (Souad Kafafy hospital) and adhered to the tents of the declaration of Helsinki, participants signed a written informed consent before undergoing any study related testing. We collected the data and the distribution of the studied cases according to the demographic data was 38 males to 28 females 63.3% to 36.7% The distribution of the studied cases according to which eye was 32 for the right eyes to 28 eyes. We collected parameters from the all sectors of RNFL and MRW thickness (before and after segmentations). Then we made a comparison using a paired T-test (SPSS software). Data are presented as mean standard deviation (SD). A P-value <0.05 was considered statistically significant

Two tables illustrating the comparison between data measurements before and after segmentations.

RNFL parameters	Pre	Post	t	P
NS				
Min. - Max.	20.0 - 161.0	35.0 - 142.0	0.998	0.322
Mean ± SD.	81.30 ± 29.19	82.28 ± 26.82		
TS				
Min. - Max.	25.0 - 168.0	26.0 - 168.0	2.613*	0.011*
Mean ± SD.	91.52 ± 32.95	92.90 ± 32.24		
T				
Min. - Max.	17.0 - 107.0	25.0 - 91.0	0.081	0.936
Mean ± SD.	55.23 ± 16.07	55.18 ± 14.16		
TI				
Min. - Max.	26.0 - 188.0	34.0 - 188.0	1.786	0.079
Mean ± SD.	98.95 ± 40.53	99.87 ± 39.76		
NI				
Min. - Max.	7.0 - 164.0	39.0 - 164.0	1.004	0.319
Mean ± SD.	87.42 ± 31.60	88.72 ± 29.69		
N				
Min. - Max.	13.0 - 129.0	35.0 - 127.0	1.554	0.126
Mean ± SD.	66.35 ± 20.49	68.02 ± 18.93		

Table 1: Comparison between the pre and post according to RNFL parameters.

IQR: Inter Quartile Range; SD: Standard Deviation; t: Paired t-Test.

p: p value for comparing between pre and post.

*: Statistically significant at $p \leq 0.05$.

Table 1 demonstrates the comparison between two retinal nerve fiber layer (RNFL) parameters (before and after segmentation) using a paired t-test. Overall, most RNFL sectors showed no statistically significant change after the segmentation. The nasal superior (NS) sector showed a slight increase in mean RNFL thickness from 81.30 ± 29.19 to 82.28 ± 26.82 µm; however, this difference was not statistically significant (t = 0.998, p = 0.322). Similarly, the temporal superior (T), temporal inferior (TI), nasal inferior (NI), and nasal (N) sectors demonstrated minimal changes between automatic and manual segmentation measurements, with no statistically significant difference (p = 0.936, 0.079, 0.319, and 0.126, respectively).

In contrast, the temporal superior (TS) RNFL sector showed a statistically significant increase in mean thickness from 91.52 ± 32.95 µm before and after intervention to 92.90 ± 32.24 µm post-intervention (t = 2.613, p = 0.011). This indicates a significant post-intervention change limited to the TS sector only.

Except for a significant difference in the temporal superior RNFL thickness, no significance was detected across the remaining RNFL parameters.

MRW parameters	Pre	Post	t	p
NS				
Min. - Max.	68.0 - 419.0	68.0 - 419.0	0.808	0.422
Mean ± SD.	222.4 ± 81.75	221.1 ± 79.55		
TS				
Min. - Max.	26.0 - 349.0	43.0 - 349.0	0.383	0.703
Mean ± SD.	183.8 ± 75.05	183.5 ± 75.20		
T				
Min. - Max.	37.0 - 311.0	37.0 - 311.0	1.751	0.085
Mean ± SD.	143.8 ± 56.30	147.2 ± 54.13		
TI				
Min. - Max.	30.0 - 385.0	33.0 - 386.0	0.093	0.926
Mean ± SD.	201.0 ± 90.17	200.9 ± 89.53		
NI				
Min. - Max.	68.0 - 462.0	68.0 - 462.0	0.456	0.650
Mean ± SD.	245.8 ± 88.09	246.4 ± 86.31		
N				
Min. - Max.	62.0 - 400.0	62.0 - 379.0	1.047	0.299
Mean ± SD.	206.5 ± 77.18	207.2 ± 75.99		

Table 2: Comparison between the pre and post according to MRW parameters.

IQR: Inter Quartile Range; SD: Standard Deviation; t: Paired t-Test.

p: p value for comparing between pre and post.

Table 2 presents the comparison between two minimum rim width (MRW) parameters (before and after segmentation) using a paired t-test. Across all evaluated MRW sectors, no statistically significant differences were detected between pre- and post-intervention measurements.

The nasal superior (NS) sector showed a minimal decrease in mean MRW from 222.4 ± 81.75 to 221.1 ± 79.55 µm, which was not statistically significant (t = 0.808, p = 0.422). Similarly, the temporal superior (TS) sector demonstrated virtually unchanged values (183.8 ± 75.05 pre versus 183.5 ± 75.20 post; t = 0.383, p = 0.703).

The temporal (T) sector showed a slight increase in mean MRW from 143.8 ± 56.30 to 147.2 ± 54.13 µm; however, this change did not reach statistical significance (t = 1.751, p = 0.085). Likewise, the temporal inferior (TI) sector revealed no significant difference between pre- and post-measurements (201.0 ± 90.17 versus 200.9 ± 89.53 µm; t = 0.093, p = 0.926).

In the nasal inferior (NI) and nasal (N) sectors, mean MRW values showed negligible changes between pre- and post-intervention assessments, with no statistically significant differences (p = 0.650 and p = 0.299, respectively).

So paired t-test analysis demonstrated that the manual segmentation did not result in statistically significant changes in MRW measurements across any of the examined sectors.

Results

Our study was conducted on 60 eyes of 45 patients, consists of 38 males and 22 females with mean age 59 years, with mean IOP 14.48 mmHg (under treatment), mean C/D ratio of 0.67, fifteen eyes with upper arcuate field defect, thirteen eyes with tubular defect, ten eyes with nasal step, seven eyes with double arcuate scotoma and fifteen without field defects. Those 60 eyes consist of 39 eyes (outside normal limits), 20 eyes (borderline) and one eye (within normal limits).

We found that the absolute segmentation errors occurring in RNFL parameters were significantly larger in the superior and inferior sectors compared with horizontal sectors. (Especially in superior temporal sector) and the absolute errors of RNFL and BMO-MRW parameters were insignificant.

Discussion

RNFL thickness measurement has become one of the most important structural parameters for glaucoma diagnosis as RNFL thinning may precede visual field loss by several years. Therefore, OCT can identify preperimetric glaucoma, where structural glaucomatous damage exists despite normal findings on standard automated perimetry [13,14].

All OCT imaging in the present study was performed in a controlled research environment with adequate acquisition time to ensure high-quality scans. Consequently, the prevalence of segmentation errors observed in our study may be lower than that encountered in routine clinical practice, where image quality is often affected by patient cooperation, media opacity, or operator-related factors. In addition, this study utilized the Heidelberg Spectralis SD-OCT system (870-nm wavelength), and therefore the findings may not be directly generalizable to other OCT devices because segmentation algorithms, software architecture, and hardware specifications differ among manufacturers. Previous studies have also demonstrated that reduced scan quality significantly increases automated segmentation errors, while manual correction of segmentation boundaries can improve the accuracy of RNFL measurements and glaucoma classification [6,10].

In this study, manual correction of segmentation boundaries was performed for the same OCT parameters in order to evaluate errors associated with automated segmentation. Statistical analysis was subsequently conducted to determine whether the observed differences between automated and manually corrected measurements were statistically significant and whether these discrepancies could influence glaucoma assessment and diagnostic interpretation.

Segmentation errors were more frequent in superior sectors and glaucoma classification remained unchanged despite manual correction. Segmentation errors were most pronounced in the superior sectors, whereas errors in the vertical sectors were insignificant, therefore careful inspection of segmentation line on all oct scans is recommended, particularly in these sectors. Manual correction of segmentation errors resulted in a statistically significant change only in the temporal superior RNFL sector, with a small mean increase of 1.38 μm, while no significant changes were observed in the remaining RNFL sectors or any BMO-MRW parameters. Furthermore, manual correction did not alter glaucoma classification, indicating that the detected segmentation errors had limited clinical impact. NFL parameters resulted in statistically significant change only in superior temporal sector. No significant differences were detected in BMO-MRW measurements.

Our results that show localized superior-sector difference was detected, whereas global RNFL, BMO-MRW measurements, and glaucoma classification remained unchanged, indicating that the automated Spectralis algorithm maintained acceptable diagnostic reliability despite minor segmentation errors.

Conclusion

Automated OCT segmentation provides reliable RNFL and MRW measurements for glaucoma assessment in most cases. Although manual correction improves measurement accuracy, the magnitude of segmentation errors is generally too small to produce clinically meaningful changes in glaucoma classification. Nevertheless, careful review of segmentation boundaries remains advisable, particularly in the superior sector where segmentation errors occur more frequently especially in borderline glaucoma.

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