Original Article

Effect of ocular magnification on macular measurements made using spectral domain optical coherence tomography

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Aim: The aim of the present study was to study the effect of ocular magnification on macular measurements made using spectral domain optical coherence tomography (OCT). **Materials and Methods:** One hundred and fifty-one subjects were included from the normative study of foveal morphology carried out at our hospital. Subjects underwent comprehensive eye examination and macular scanning using Cirrus high-definition OCT and axial length (AXL) measurement. Macular cube 512 × 128 scan protocol was used for scanning the macula. Automated measurements of the fovea namely foveal diameter, foveal slope (lateral measurements) and foveal depth (axial measurement) were taken. A correction factor for ocular magnification was done using the formula $t = p \times q \times s$, where "t" is the corrected measurement, "p" is the magnification of OCT, "q" is the ocular magnification, and "s" is the measurement on OCT without correction. The difference between corrected and uncorrected measurements was evaluated for statistical significance. **Results:** Mean AXL was 22.95 ± 0.78 mm. Refractive error ranged from −3D to +4D. Mean difference between measured and corrected foveal diameter, slope and depth was 166.05 ± 95.37 μm ($P < 0.001$), 0.81° ± 0.53° ($P < 0.001$) and 0.05 ± 0.49 μm ($P = 0.178$) respectively. AXL lesser than the OCT calibrated value of 24.46 mm showed an increased foveal diameter ($r = 0.961$, $P < 0.001$) and a reduced foveal slope ($r = −0.863$, $P < 0.001$) than the corrected value. **Conclusion:** Lateral measurements made on OCT varied with AXL s other than the OCT calibrated value of 24.46 mm. Therefore, to estimate the actual dimensions of a retinal lesion using OCT, especially lateral dimensions, we recommend correction for the ocular magnification factor.

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Optical coherence tomography (OCT) is a noninvasive imaging technology that provides cross-sectional images of the retina with high resolution.[1] Quantitative measurements of the macula are obtained which are of clinical importance in monitoring the retinal condition objectively.[2-4] There are many factors that affect these quantitative measurements like scan centration and sampling density. Apart from these, errors due to differences in axial length (AXL) causing ocular magnification effects has been documented.[5-10] The transverse mirror in OCT is calibrated for an AXL of 24.46 mm. Inter-individual differences in AXL from 24.46 mm would result in magnification errors in the measurements made on OCT.

Effect of ocular magnification was first described when measuring the size of a retinal lesion or optic disc on fundus photographs.[11,12] Later, it was found to affect the retinal nerve fiber layer (RNFL) analysis in OCT as the thickness is measured at a constant distance (1.7 mm) from optic disc center and this distance was found to vary with different AXL.[13-17] Its impact on the measurements of macula was recently reported,[6,7,18] yet it has not been applied in clinical practice when measuring the lateral dimensions of macular holes, choroidal neovascular membranes (CNVM) or geographic atrophy and when measuring choroidal thickness at various eccentricities from fovea.[19] Absence of an effect of magnification related to AXL on RNFL and macular thickness has also been reported.[7] Hence, we aimed at studying the effect of ocular magnification on macular measurements (both lateral and axial) made on OCT.

Different methods of correcting for ocular magnification using AXL, ocular refraction, keratometry have been described. Amidst these methods, we have used the AXL method which is most reliable.[11,12]

Materials and Methods

One hundred and fifty-one eyes of 151 subjects from the normative study data on the foveal morphology conducted at our hospital during the period of June 2012 and March 2013 were included in the study. The study was approved by institutional review board and was in accordance with Declaration of Helsinki. The study population included the subjects who came for routine eye examination and volunteers. A written informed consent was obtained from all subjects before enrolling into the project.

All subjects underwent comprehensive eye examination and macular scanning using Cirrus high-definition OCT (Model 4000, Version 6, Carl Zeiss Meditec, Inc., Dublin, CA) and AXL measurement using Ocuscan RxP (Alcon Laboratories, Inc., CA). All scans were performed by the same observer and care was taken to avoid obtaining decentered or tilted images. Subjects aged between 18 and 80 years having best corrected visual acuity of 20/30 or above, refractive error less than ± 3.00 DS, cylindrical error less than −2.00 DC were included in the study. Subjects with any retinal or optic nerve pathology and

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history of retinal surgery were excluded. OCT images with signal strength <6 out of 10 units and artifacts were excluded.

Optical coherence tomography

Scan protocol and ocular magnification correction

Macular cube 512 × 128 scan protocol was used for scanning the macula. It consists of 6 mm × 6 mm square grid consisting of 128 B-scans with each B-scan having 512 A-scans. The spacing between 2 A-scans is 11.72 μm for an AXL of 24.46 mm which is the instrument's default setting. Due to inter-individual differences in AXL, the scan length and A-scan spacing would differ between subjects. In order to correct for this resultant ocular magnification, a correction factor was applied for obtaining the actual scan length. The formula used was $t = p \times q \times s$; where "t" is the true scan length, "p" is the magnification related to the instrument, "q" is the magnification related to eye and "s" is the default scan length.[8] The value of P is 3.382 for the instrument calibrated AXL of 24.46 mm which is a constant for a telecentric imaging system. Ocular magnification factor "q" is calculated by the formula 0.01306 × (AXL-1.82) where 1.82 is the distance between corneal apex and 2nd principal point of the eye.

Automated macular measurements

A custom written program was used for extracting foveal parameters like foveal diameter, foveal slope which were the lateral measurements and foveal depth, an axial measurement [Fig. 1]. Raw data of retinal thickness at all A-scan positions of the cube scan were imported into Matlab. In Matlab, the retinal thickness data from the horizontal B-scan representing foveal center were taken. Foveal center was identified as the deepest point in the foveal depression and the central light reflex. The A-scan numbers on the foveal B-scan were converted to microns using the AXL corrected scan length. The B-scan profile was fitted with polynomials with root mean square error of <1. The maximum degree of the polynomial that was fitted to a sample was 9. Nasal and temporal foveal rims where the retinal thickness is maximum were located automatically, and the distance between the rims was taken as foveal diameter. Foveal depth was the distance between the foveal center and the line connecting the rims.[6,20] For foveal slope, the first derivative of the polynomials was found from which the maximum foveal slope was taken.[6,20] This was converted to degrees and the average of nasal and temporal slope was taken as a horizontal foveal slope [Fig. 2]. The foveal parameters uncorrected and corrected for ocular magnification were obtained from custom written algorithm in Matlab.

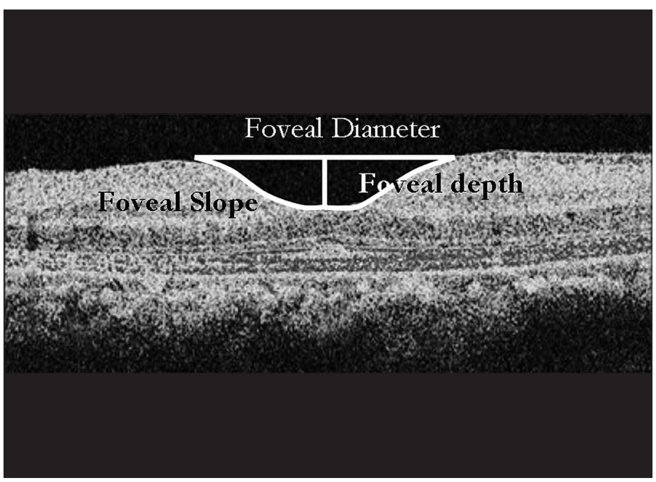

Figure 1: Optical coherence tomography image depicting foveal diameter, slope and depth

Statistical analysis

Statistical analysis was performed in MS Excel 2003 and SPSS (SPSS Inc, Version 14, Chicago). All parameters followed the normal distribution, tested using Kolmogorov–Smirnov test. Mean and standard deviation is given for all parameters. Paired t-test was used to compare foveal parameters pre- and post-ocular magnification correction. Correlation between AXL difference and magnitude of error in foveal parameters was assessed. Alpha error was kept at 5%.

Results

Of 151 subjects included in the study, 84 (55.6%) were males. Mean age of the subjects was 43.9 ± 14.4 years. Spherical equivalent of refractive error ranged from −3.00D to +3.75D with 58 (38.4%) subjects being emmetropic. A total of 25 subjects (16.6%) were mild myopes and the remaining 68 subjects (45%) were hyperopes. Mean AXL was 22.95 ± 0.78 mm ranging from 21.35 to 24.98 mm. The scan length of OCT (6 mm) was corrected for ocular magnification and the calculated actual scan length ranged from 5.18 to 6.14 mm with a mean of 5.60 mm. The mean ocular magnification (q) was 0.276 ± 0.01 and mean total magnification ($p \times q$) was 0.934 ± 0.03.

The effect of ocular magnification on OCT measurements was assessed on the axial and lateral measurements of fovea namely foveal depth and foveal diameter and slope respectively. Table 1 gives the comparison of ocular magnification corrected and uncorrected measurements of foveal parameters. The mean difference between corrected and uncorrected parameters was statistically significant for lateral measurements namely foveal diameter and foveal slope ($P < 0.001$). Foveal depth was not statistically different before and after ocular magnification correction ($P = 0.178$).

The larger the deviation of the subject's AXL from the default AXL, larger was the error in lateral measurements. AXL lesser than OCT calibrated AXL (24.46 mm) resulted in an overestimation of foveal diameter (Pearson correlation; $r = 0.961$, $P < 0.001$) and an underestimation of foveal slope measurement (Pearson correlation; $r = -0.863$, $P < 0.001$)

Table 1: Comparison of corrected and uncorrected measurements of foveal parameters made using OCT

Foveal parameters	Uncorrected measurement	Corrected measurement*	Mean difference (95% CI)	P†
Foveal diameter (μm)	2490.97±259.19	2323.16±228.19	166.05±95.37	<0.001
Foveal slope (degrees)	11.35±2.61	12.16±2.86	0.81±0.53	<0.001
Foveal depth (μm)	113.68±17.26	113.62±17.3	0.05±0.49	0.178

*Corrected for ocular magnification, †Paired t-test. OCT: Optical coherence tomography, CI: Confidence interval

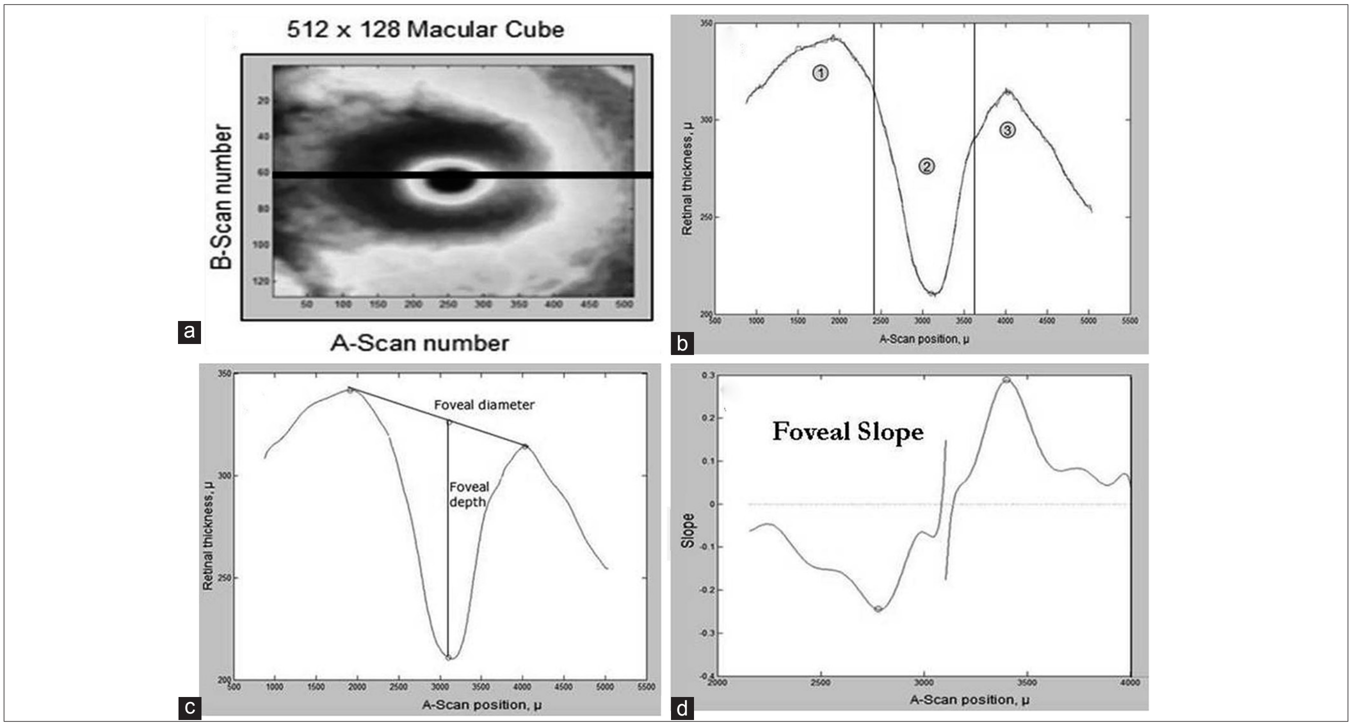

Figure 2: (a) Retinal thickness map of the macula. Darker regions indicate increased retinal thickness/elevated surface while lighter regions indicate areas of reduced thickness or depression. Central dark region is the fovea. (b) B-scan along the foveal center (black line in Fig. 2a) split into 3 sections and fitted with polynomials. Note the change in X-axis where the A-scan number is converted into micron scale. (c) Polynomial curves depicting foveal diameter and foveal depth. (d) First derivative of the polynomial curve showing foveal slope measurement

when compared with corrected measurements [Figs. 3 and 4]. Difference in foveal depth between corrected and uncorrected measurement did not have any relation with AXL [Fig. 5]. An error of around 118 μm occurred in foveal diameter for every 1 mm difference in AXL. In our sample, the maximum error in foveal diameter was 390 μm for an AXL of 21.58 mm. An error of 0.6° occurred in foveal slope for every 1 mm difference in AXL. There was no significant error in foveal depth with difference in AXL.

Discussion

This study assessed the effect of ocular magnification due to inter-individual differences in AXL on macular measurements made on OCT. Variations in AXL cause alterations in the OCT B-scan length and consequently, the measurements made on it due to ocular magnification. Unlike axial measurements which are made vertically in depth, lateral measurements that are made along the horizontal extent were affected by differences in AXL, which is in agreement with previous studies.[5,6] Wang *et al*. have reported no effect of magnification related to AXL on RNFL and macular thickness, but the authors attribute it to the narrow distribution of AXL in their sample.[7]

When lateral measurements were not corrected for differences in AXL, an individual with a shorter AXL was found to have an increased foveal diameter, and a decreased the foveal slope compared to actual dimensions. For instance, the actual OCT scan length of an eye with shorter AXL (say 22.43 mm) would be 5.46 mm instead of default 6 mm. Therefore, 512 A-scans which makes up one B-scan would be accommodated within this smaller scan length that result in smaller separation between 2 A-scans (10.66 μm for scan length of 5.46 mm instead of 11.72 μm for the default 6 mm scan). This results in a smaller foveal diameter after correcting for ocular magnification factor. Consequently, for such a small change in the A-scan, the change in the retinal thickness would be greater, thus, increasing the foveal slope value. After correcting for ocular magnification, lateral measurements were found to be larger for longer eyes and vice versa. This finding was consistent with studies on RNFL thickness that measured a larger scan radius on myopic eyes with longer AXL.[10,16,17,21]

In our sample, most of the subjects had AXL lesser than the OCT calibrated AXL of 24.46 mm with only 6 (4%) subjects having a longer AXL. The degree of error due to ocular magnification depends on the distribution of AXL in the study population. As the subjects' AXL deviated more from 24.46 mm, the error in foveal diameter and foveal slope increased. Our finding is in agreement with that of Wagner-Schuman *et al*.[6] Reported effects of AXL on macular and RNFL thickness cannot be interpreted correctly without correcting for magnification factors.[14,17,22,23]

Lateral dimensions measured on OCT such as size of a macular hole, extent of a CNVM, are of clinical importance in assessing prognosis of surgery and monitoring the disease. Retinal thickness displayed in Early Treatment Diabetic Retinopathy Study (ETDRS) retinal thickness map is also prone to changes due to differences in AXL because it consists of measurements taken at specific points measured laterally from the center, the concentric rings of diameter 1 mm, 3 mm and 6 mm.[5,6] An overall error of 44.9 μm in nine ETDRS segments

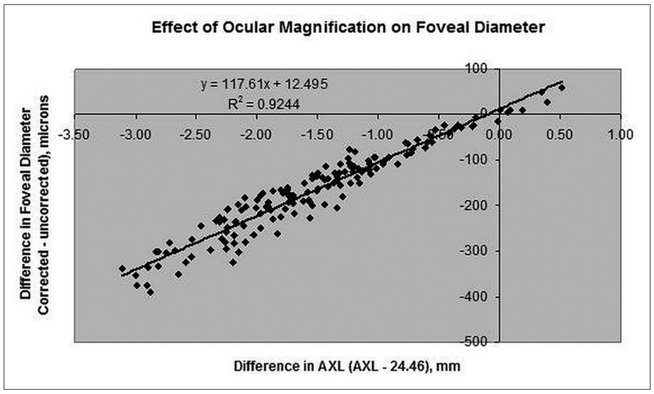

Figure 3: Scatter plot showing error in foveal diameter with increasing difference in axial length (AXL) from optical coherence tomography calibrated AXL of 24.46 mm. Error of about 118 μm occurred for every 1 mm difference in AXL

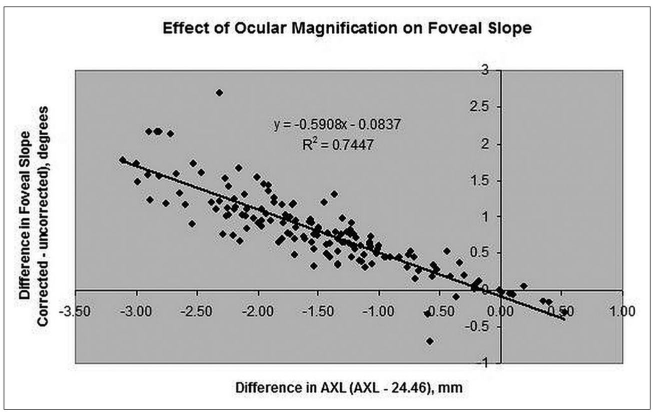

Figure 4: Scatter plot showing error in foveal slope with increasing difference in axial length (AXL) from optical coherence tomography calibrated AXL of 24.46 mm. Error of about 0.6° occurred for every 1 mm difference in AXL

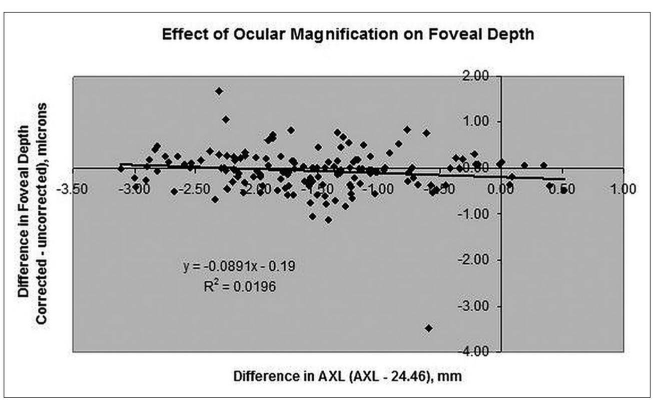

Figure 5: Scatter plot showing no correlation between error in foveal depth and difference in subjects' axial length (AXL) from calibrated AXL of 24.46 mm

and a maximum error of 7.86 μm in central subfield have been reported.[5]

Several methods have been proposed to correct for ocular magnification by incorporating the spectacle refraction, keratometry, or AXL, each method yielding different values.[8,11,12] We used the AXL method to correct for ocular magnification as described by Bennett *et al*. who introduced modifications in Littmann's formula.[8] Although correcting ocular magnification using AXL is reliable, keratometry value or refractive error can be used to get an approximate of the corrected measurements.[11] There can be a combined effect of AXL and keratometry values on OCT measurements which have not been evaluated in this study. Kuo *et al*. observed that the curvature of the retina seen in OCT is not the true curvature of the eye and proposed a correction technique for ocular shape which also corrects for ocular magnification.[24] Since our measurements were performed in the central macula, this smaller field may not be affected by ocular shape.

Conclusion

We assessed the effect of ocular magnification on measurements made on OCT and found that the lateral measurements tend to be erroneous for AXL different from the OCT calibrated value of 24.46 mm. Therefore, to estimate the actual dimension of a retinal lesion using OCT, especially lateral dimension, the measurement should be corrected for ocular magnification factor.

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