African Vision and Eye Health
ISSN: (Online) 2410-1516, (Print) 2413-3183

Macular thicknesses and their associations with ocular and demographic variables in black South Africans

Authors:
Khathutshelo P. Mashige[1]
Olalekan A. Oduntan[1]

Affiliations:
[1]Discipline of Optometry, University of KwaZulu-Natal, South Africa

Corresponding author:
Khathutshelo Mashige,
mashigek@ukzn.ac.za

Dates:
Received: 31 Aug. 2016
Accepted: 04 Nov. 2016
Published: 30 Jan. 2017

How to cite this article:
Mashige KP, Oduntan OA. Macular thicknesses and their associations with ocular and demographic variables in black South Africans. Afr Vision Eye Health. 2017;76(1), a374. https://doi.org/10.4102/aveh.v76i1.374

Purpose: To determine normal macular thicknesses and their associations with demographic and ocular variables in healthy eyes of black South Africans.

Methods: Six hundred healthy subjects ($N = 600$) underwent height and weight measurements followed by a complete ophthalmic examination, which included auto-refraction, subjective refraction, slit-lamp biomicroscopy, ocular biometric measurements and tonometry. Intra-ocular pressure (IOP) was measured with the Nidek NT530P (Tonopachy™) and the axial length (AL) thickness with the Nidek Echoscan. The central corneal thickness (CCT) and macular thickness were measured using iVue-100 spectral-domain optical coherence tomography (Optovue, Inc.). The macular thickness map protocol that divides the macular area into nine regions of the Early Treatment Diabetic Retinopathy Study (ETDRS) fields was used. Variations in macular thickness measurements with body mass index (BMI), age, gender, refraction, AL, CCT and IOP were determined with partial correlation analysis.

Results: The 600 subjects had a mean age of 28.15 ± 13.09 years (range = 10–66 years), with 305 (50.83%) being males and 295 (49.17%) females. The thickness values of the central, inner and outer maculae were normally distributed, with means of 235.89 µm ± 20.04 µm, 303.56 µm ± 18.68 µm and 287.81 µm ± 14.61 µm, respectively. Mean total macular thickness for all subjects was 268.72 ± 15.04 µm. The temporal quadrant was markedly thinner than all other quadrants for both inner and outer macular regions. Macular thicknesses were greater in men than in women ($p < 0.05$). The thickness of mean central, mean inner and mean outer maculae increased significantly with increasing BMI ($p < 0.001$). Central, inner and outer maculae were significantly associated ($p < 0.001$) with a high hyperopic spherical equivalent refraction. AL was associated with a thin inner macula ($p < 0.05$) and an outer macula ($p < 0.001$), but not with a thinner central macula ($p > 0.05$). Age, CCT and IOP were not associated with macular thickness values in any quadrant ($p > 0.05$).

Conclusion: The macular values were thinner in women than in men and were related to BMI, gender, hyperopic spherical refraction and AL with regional variations. These differences should be considered when interpreting optical coherence tomography results for accurately diagnosing and managing retinal abnormalities.

Introduction

Measurement of macular thickness is essential for diagnosing and monitoring pathological changes in various ocular diseases such as glaucoma, macular hole and macular oedema.[1] In addition, knowledge of macular thickness in comparison with population or normal values and their associations with other parameters such as demographic and ocular variables is important for the treatment and follow-up of disease severity or progression.[1]

The introduction of optical coherence tomography (OCT) has allowed eye care professionals to quantitatively and qualitatively assess retinal parameters to detect small changes in these parameters and to evaluate the efficacy of different treatment modalities.[2] Previous studies[3,4] have shown that quantitative measurement of retinal parameters using OCT can distinguish between pathology and physiology, thus emphasising the importance of understanding normal variations in different populations, races and ethnicities using the OCT.

The iVue-100 (Optovue, Inc.) is a new-generation spectral-domain OCT (SD-OCT) instrument with high axial and lateral resolution compared with the previous generations of this technology such as time-domain OCT (TD-OCT).[5] As different types of OCTs have become more widely available and used, normative data have become important in interpreting pathological features affecting retinal structures, such as with glaucoma. Several OCT-based studies conducted on

macular thickness measurements and their variations with age, gender, race, refractive error and axial length (AL) in normal subjects have yielded conflicting results.[6,7,8,9,10] Some of the major sources of inconsistencies in these studies lie in the variability of age groups, techniques used and limited focus on ethnicities, such as in Africans. In addition, the effects of body mass index (BMI), spherical equivalent (SE) refractive error, AL, central corneal thickness (CCT), intra-ocular pressure (IOP) and other ocular biometric variables have not been taken into consideration in many of these studies. The purpose of this study was to determine the distribution of macular thicknesses and to assess any associations with demographic (BMI, age and gender) and ocular variables (SE, AL, CCT and IOP) in normal black South African subjects using iVue SD-OCT. To the best of our knowledge, this is the first report on the distribution of macular thicknesses and their associations with other ocular variables in a large sample of black South Africans.

Methods

The study adhered to the tenets of the Helsinki Declaration, and ethical approval was obtained from the Biomedical Research and Ethics Committee of the University of KwaZulu-Natal. Informed consent to participate in the research study was obtained from all the participants. The study was conducted at the Eye Clinic of the Department of Optometry at the University of KwaZulu-Natal in Durban, South Africa. The Eye Clinic is situated inland of the central business district of Durban. Participants were selected through stratified random cluster sampling from geographically contiguous areas of Durban, South Africa, that consisted of urban, peri-urban and rural areas. Two fieldworkers were involved in the study. One fieldworker worked in advance of the other recruiting participants in the selected clusters and the other transporting participants to the examination site. The study took place after consulting with and approval from the local authorities (city councillors, key community figures and traditional leaders), school administrators and civil society. During the fieldwork, the head of the household was informed of the nature and details of the study, the date of the clinical examination as well as transportation arrangements.

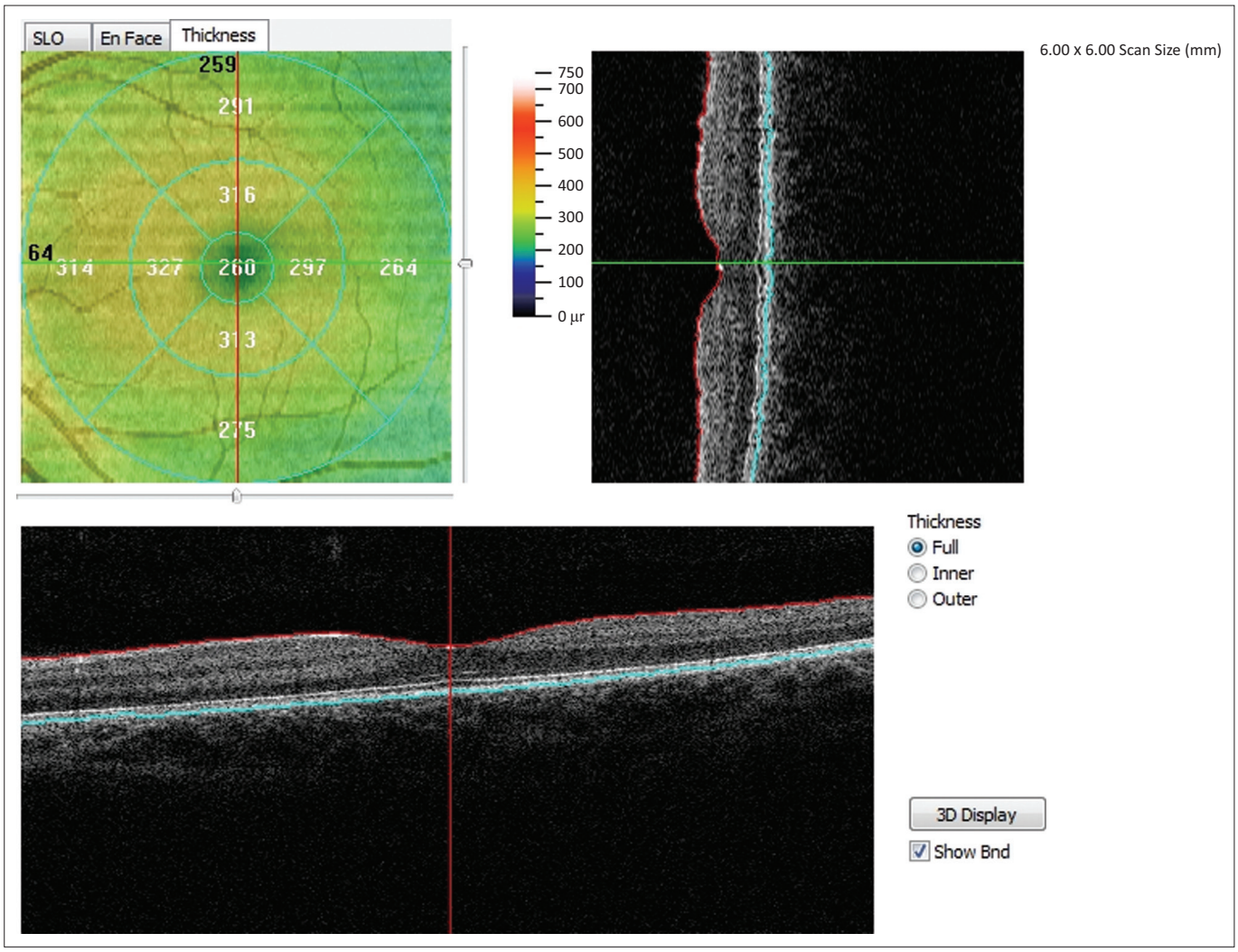
All subjects underwent a complete ocular examination, including non-cycloplegic refraction, assessment of IOP, slit-lamp biomicroscopic evaluation, fundus examination and ocular biometry. To eliminate inter-examiner variability that negatively impacts on validity, subjective refraction, AL, CCT, IOP and macular thickness measurements were performed by one optometrist experienced in performing these techniques. Other tests such as case history, visual acuity, height and weight measurements, auto-refraction, slit-lamp and fundus examinations were also performed by one optometrist. Inclusion criteria included a best-compensated visual acuity of 6/6 or better, and normal ocular findings on slit-lamp, perimetry and ophthalmoscopic examinations. Subjects with previous histories of ocular surgery, trauma, contact lens wear and those on medications that could affect the measured variables were excluded.

Height was measured in metres with a tape measure, and weight was measured in kilograms with a digital Adam equipment scale, these being used to determine the BMI (BMI = weight/height^2), the internationally accepted measure of obesity. Refractive errors were assessed with the Nidek AR-310A auto-refractor followed by subjective refraction, which was defined as the SE (sphere power + cylinder power/2). The Nidek NT530P (Tonopachy™) device was used to measure IOP. AL was measured with the Nidek US-500 Echoscan, and CCT was measured with the iVue-100 OCT (Optovue, Inc.). The same OCT was used to take retinal thickness scans of the macula. Retinal thickness is defined as 'the distance between the vitreoretinal interface and the inner border of retinal pigment epithelium (RPE)'.[11] All OCT devices generally identify the vitreoretinal interface as the inner retinal border,[11] but the segmentation of the outer retinal border identified by different OCT devices varies significantly. The iVue-100 OCT considers the inner border of the RPE as the outer retinal border.[11,12] Retinal thickness was, therefore, automatically determined by the instrument software as the distance between the internal limiting membrane and the inner border of the RPE, with measurements being obtained for three concentric regions (Figure 1). The central disc (fovea), called the central macula, is a region with a radius of 1 mm, while the inner and the outer rings have an outer radius of 3 mm and 6 mm, respectively, and were each divided into four quadrants. Average retinal thickness was provided for each of the nine regions.

Three circular scans deemed to be of satisfactory quality were obtained for each eye, these being repeated in succession without any breaks. Three consecutive readings for macular thickness scans were taken and the averages computed. Satisfactory scan quality was defined as good centring on the disc and macula, and as per the manufacturer's recommendations, repeat scans were taken if the signal strength was less than 40.[12]

Statistical analysis

All analyses were conducted with the Stata: data analysis and statistical software (version 11.0, Stata Corp., TX, USA). The Kolmogorov–Smirnov test was used to test for normal distributions with macular thickness data. Variables such as percentages, means and standard deviations were generated using descriptive statistics. Independent two-sample *t*-tests were used to test for differences in the relevant variables between the two genders. Analysis of variance (ANOVA) enabled a comparison of the mean thicknesses across the regions and quadrants with respect to the demographic and ocular variables. Pearson partial correlation analysis was used to examine the associations between macular thickness and demographic and ocular variables. A 95% confidence interval and a 5% level of significance were adopted, the results with a $p \leq 0.05$ being considered significant.



The top left picture shows the macular map, automatically divided into nine Early Treatment Diabetic Retinopathy Study sectors.

FIGURE 1: Example of macular thickness measurements obtained using iVue-100 optical coherence tomography.

Results

A total of 600 healthy subjects (305 males and 295 females) with a mean age of 28.15 ± 13.09 years (range = 10–66 years) and a mean BMI of 21.90 kg/m^2 ± 2.85 kg/m^2 were included. The ages of males ranged from 10 to 59 years with a mean of 27.52 ± 12.42 years, and those of females ranged from 10 to 66 years with a mean of 28.79 ± 13.77 years. The mean BMI for males was 20.24 kg/m^2 ± 2.49 kg/m^2, with a range of 17.74 kg/m^2 – 26.82 kg/m^2. The mean BMI for females was 23.05 kg/m^2 ± 3.16 kg/m^2, with a range of 20.31 kg/m^2 – 29.66 kg/m^2. Preliminary statistical analysis showed that there was no difference in macular thicknesses between right and left eyes for every participant (Pearson correlation coefficient, r = 0.89; p = 0.02). Due to this, and to avoid possible lack of independence[13] and correlation effects, only the right eye data from each participant were used for further data analysis and presentation. The mean SE was -0.46 ± 1.54 D (range = -7 ± 3 D), and the mean AL was 23.05 mm ± 0.98 mm. The mean CCT and IOP measurements were 495.05 µm ± 32.40 µm and 14.22 mmHg ± 2.33 mmHg, respectively. Males had significantly greater ALs than their female counterparts (all p-values < 0.05). No significant differences were found between the genders for BMI, age, SE, CCT and IOP (independent samples t-tests: p = 0.19, 0.30, 0.26, 0.54 and 0.19, respectively). Independent two-sample t-tests also showed that the central, inner and outer macular thicknesses were significantly lower in women (all p-values < 0.05).

Macular thicknesses were normally distributed, according to the Kolmogorov–Smirnov tests. The mean thickness of the whole macular region was 268.72 µm ± 15.04 µm. The macula was thinnest at the centre or fovea (innermost 1-mm ring), with a mean value of 235.89 µm ± 20.04 µm. The mean for the inner macula was 303.56 µm ± 18.68 µm, whereas at the outer macula it was 287.81 µm ± 14.61 µm. There were variations across quadrants within the inner and outer macular regions. In the inner macular region, the superior quadrant was the thickest (308.47 µm ± 17.21 µm), followed by the nasal (306.28 µm ± 18.71 µm), inferior (302.12 µm ± 15.63 µm) and temporal (292.77 µm ± 21.55 µm) quadrants. In the outer macular region, the nasal quadrant was the thickest (296.58 µm ± 20.30 µm), followed by the superior (290.32 µm ± 18.44 µm), inferior (273.39 µm ± 15.04 µm) and temporal (270.77 µm ± 17.16 µm) quadrants. Macular thickness for both genders in each of the nine regions of the Early Treatment Diabetic Retinopathy Study (ETDRS) map is presented in Table 1, with the thicknesses

by ETDRS region in the 600 healthy eyes being stratified by age in Table 2.

Males had greater macular thicknesses than females in all nine regions of the ETDRS map, except for the temporal and inferior quadrants of outer regions, which did not show any significant differences. Partial correlation analysis was used to assess the relationship between macular thickness and BMI, age, SE, AL, CCT and IOP. As the participants' mean BMI increased, overall macula, central macula, average inner macula and average outer macular thickness increased significantly (partial correlation analysis adjusted by age, gender, SE, AL, CCT and IOP: $r = 0.29$, $p < 0.001$; $r = 0.32$, $p < 0.001$; $r = 0.21$, $p < 0.001$ and $r = 0.24$, $p < 0.001$, respectively; Table 3). No significant correlation was found between macular thickness and age (with adjustments for BMI, SE, AL, CCT and IOP), CCT (with adjustment for BMI, age, SE, AL and IOP) and IOP (with adjustments for BMI, age, SE, AL and CCT) for either gender. Macular thickness in all the quadrants showed a significant positive correlation with SE (with adjustments for BMI, age, gender, AL, CCT and IOP), being thinner in myopia and thicker in hyperopia. Apart from the central macula, and the superior, inferior and nasal quadrants of the inner macula, significant negative correlations were evident between macular measurements and AL in all other quadrants (Table 3).

Discussion

Accurate diagnosis and appropriate management of retinal abnormalities, such as glaucoma and macular degeneration, using the OCT depend on comparisons of the normative values.[14,15] This study is, therefore, relevant in that it reports the baseline normative data of macular thickness and their associations with demographic and ocular variables from healthy African individuals. Macular thicknesses were normally distributed according to the Kolmogorov–Smirnov test, this being an expected finding, as most biological variables are normally distributed.[1] There was a high degree of mirror image symmetry between the right and left eyes in the macular thickness measurements, a finding similar to a previous report.[16]

We found a mean macular thickness of 268.72 µm ± 15.04 µm and a mean central macular thickness of 235.89 µm ± 20.04 µm among all (N = 600) the study participants. The mean central macular thickness from our study is higher than the 181 µm ± 3.7 µm and 200.27 µm ± 2.7 µm reported by Kashani et al.[10] in African-Americans and white people,

TABLE 1: Macular thickness measurements in each Early Treatment Diabetic Retinopathy Study region by gender in 600 healthy eyes using the iVue-100 spectral-domain optical coherence tomography system.

Quadrant (µm)	Total (n = 600)	Males (n = 305)	Females (n = 295)	p
Inner macula (3-mm ring)				
Average	303.56 ± 18.68	307.98 ± 17.36	300.08 ± 17.34	< 0.05
Superior	308.47 ± 17.21	311.64 ± 18.78	305.47 ± 18.90	< 0.05
Inferior	302.12 ± 15.63	306.73 ± 16.48	298.06 ± 16.03	< 0.05
Nasal	306.28 ± 18.71	310.52 ± 17.12	301.63 ± 17.46	< 0.05
Temporal	292.77 ± 21.55	295.94 ± 20.18	287.48 ± 20.22	< 0.05
Outer macula (6-mm ring)				
Average	287.81 ± 14.61	289.36 ± 14.98	284.56 ± 15.22	< 0.05
Superior	290.32 ± 18.44	294.82 ± 16.66	273.07 ± 18.04	< 0.05
Inferior	273.39 ± 15.04	272.38 ± 14.96	274.53 ± 15.03	> 0.05
Nasal	296.58 ± 20.30	294.29 ± 18.69	288.09 ± 16.81	< 0.05
Temporal	270.77 ± 17.16	271.03 ± 15.60	273.35 ± 15.80	> 0.05
Total	**268.72 ± 15.04**	**273.34 ± 13.62**	**264.66 ± 11.46**	**< 0.05**
Central macula (1-mm ring)	**235.89 ± 20.04**	**238.14 ± 21.02**	**226.34 ± 17.82**	**< 0.05**

The p-values of the differences between the means for men and women are also shown. Ten of the 12 comparisons were significant at a 95% confidence level.

TABLE 2: Macular thickness measurements by Early Treatment Diabetic Retinopathy Study region in 600 healthy eyes stratified by age.

Quadrant (µm)	10–19 (n = 185)	20–29 (n = 177)	30–39 (n = 117)	40–49 (n = 71)	50–59 (n = 44)	60+ (n = 6)	p
Inner macula (3-mm ring)							
Average	305.26 ± 16.21	304.18 ± 17.04	305.06 ± 16.33	306.36 ± 17.53	305.15 ± 16.12	304.30 ± 15.84	0.51
Superior	309.74 ± 16.59	308.14 ± 16.92	310.04 ± 16.24	309.65 ± 16.09	308.18 ± 16.98	308.36 ± 17.61	0.44
Inferior	306.49 ± 15.86	304.77 ± 15.99	305.13 ± 16.52	304.49 ± 16.49	305.26 ± 16.88	306.43 ± 16.38	0.83
Nasal	308.85 ± 16.64	307.21 ± 17.88	308.43 ± 16.46	308.13 ± 17.46	307.70 ± 16.86	310.14 ± 16.34	0.61
Temporal	292.28 ± 20.04	290.46 ± 19.63	294.24 ± 19.36	292.25 ± 19.34	292.59 ± 19.76	292.15 ± 19.50	0.66
Outer macula (6-mm ring)							
Average	288.19 ± 14.31	286.62 ± 15.42	288.68 ± 14.37	289.81 ± 13.33	288.08 ± 13.75	289.16 ± 14.16	0.62
Superior	293.06 ± 17.53	291.12 ± 17.27	293.18 ± 17.92	295.45 ± 17.11	293.16 ± 17.26	292.53 ± 17.76	0.53
Inferior	275.73 ± 15.64	273.31 ± 15.82	274.21 ± 15.41	274.96 ± 15.74	275.63 ± 15.18	274.18 ± 15.08	0.71
Nasal	295.61 ± 16.26	293.96 ± 16.85	297.05 ± 6.58	296.13 ± 16.39	294.17 ± 16.43	295.62 ± 16.66	0.43
Temporal	272.26 ± 15.38	271.66 ± 15.48	272.29 ± 15.98	274.60 ± 15.22	273.01 ± 15.58	272.17 ± 15.29	0.48
Total	**270.31 ± 15.04**	**269 ± 14.83**	**270.06 ± 14.46**	**271.93 ± 16.04**	**270 ± 16.62**	**272 ± 15.46**	**0.49**
Central macula (1-mm ring)	**236.05 ± 19.95**	**234.99 ± 20.66**	**236.38 ± 19.86**	**236.58 ± 21.29**	**236.09 ± 24.53**	**238.67 ± 22.65**	**0.58**

All p-values were greater than 0.05 and so thicknesses did not differ with age group. Note that the 60+ age group only had six participants.

TABLE 3: Correlations between macular measurements and body mass index, age, spherical equivalent, axial length, central corneal thickness and intra-ocular pressure.

Quadrant	BMI		Age		SE		AL		CCT		IOP	
	r	*p*	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*
Inner macula (3-mm ring)												
Average	0.21	**< 0.001**	0.04	0.24	0.21	**< 0.001**	-0.17	**< 0.05**	-0.05	0.31	0.03	0.61
Superior	0.07	0.33	0.02	0.41	0.15	**< 0.05**	-0.04	0.34	-0.07	0.34	0.04	0.23
Inferior	0.15	0.04	0.05	0.55	0.12	**< 0.05**	-0.07	0.44	-0.01	0.14	0.02	0.43
Nasal	0.08	0.44	0.08	0.59	0.14	**< 0.05**	-0.08	0.26	-0.01	0.37	0.01	0.72
Temporal	0.22	**< 0.001**	0.02	0.35	0.18	**< 0.05**	-0.23	**< 0.001**	-0.03	0.19	0.00	0.56
Outer macula (6-mm ring)												
Average	0.24	**< 0.001**	-0.04	0.52	0.23	**< 0.001**	-0.29	**< 0.001**	-0.08	0.47	0.01	0.92
Superior	0.09	0.09	-0.00	0.16	0.16	**< 0.05**	-0.21	**< 0.001**	-0.08	0.71	0.02	0.64
Inferior	0.21	**< 0.001**	-0.07	0.34	0.28	**< 0.001**	-0.26	**< 0.001**	-0.06	0.33	0.02	0.53
Nasal	0.08	0.13	-0.06	0.41	0.29	**< 0.001**	-0.25	**< 0.001**	-0.06	0.59	0.02	0.44
Temporal	0.15	**< 0.05**	-0.01	0.67	0.28	**< 0.001**	-0.32	**< 0.001**	-0.04	0.25	0.01	0.69
Total macula	**0.29**	**< 0.001**	**0.01**	**0.58**	**0.34**	**< 0.001**	**-0.23**	**< 0.001**	**-0.05**	**0.27**	**0.03**	**0.34**
Central macula (1-mm ring)	**0.32**	**< 0.001**	**0.05**	**0.42**	**0.26**	**< 0.001**	**0.05**	**0.22**	**-0.02**	**0.39**	**-0.05**	**0.82**

Bold values indicate *p*-values with significant results.

BMI, body mass index; SE, spherical equivalent; AL, axial length; CCT, central corneal thickness; IOP, intra-ocular pressure.

respectively; higher than the 173.8 µm ± 18.16 µm reported by Gella et al.[11] in Indians; and lower than the 252.0 µm ± 20.1 µm reported by Harb et al.[17] in white people. Studies by Adhi et al.,[16] Sull et al.[18] and Giani et al.[19] reported mean central macular thicknesses of 229.01 µm ± 20.64 µm, 231 µm ± 16 µm and 229 µm ± 24 µm, respectively, which are comparable with our results. Interestingly, all the above-mentioned studies that reported results similar to ours used a SD-OCT. This could suggest that quantitative analysis of retinal thickness may depend on the OCT device used.

Although direct comparisons are not easy to make due to differences in the age cohorts, methodologies, statistical estimation methods, segmentation algorithms of the OCT devices and scan protocols used, it does suggest that racial and ethnic variations in central macular thicknesses exist, as reported in previous studies.[10,17] The exact causes for racial and ethnic differences in central macular thickness remain obscure, with several reasons having been postulated. For example, it has been suggested that higher amounts of melanin in darkly pigmented populations 'weaken the OCT light signal', resulting in reduced thickness measurements.[20] This hypothesis contradicts with our findings because central macular thickness values were higher than the previously reported African and Indian population values, which have similar melanin levels. Another hypothesis is that the differences in the depth and diameter of the foveal pit may account for the central macular thickness differences observed in different races and ethnic groups.[21] Studies would be necessary to further explore these hypotheses.

Macular thickness decreased from the centre towards the periphery of the retina, due to the anatomical arrangement of retinal layers, with the thickness of the central macula (fovea) being devoid of the retinal nerve fibre layer. This decrease in thickness was consistent with findings reported elsewhere.[18,22] The temporal and nasal quadrants were thinnest and thickest, respectively, for the outer macular (perifoveal) region (Table 2), which is consistent with the arrangement of fibres in the papillo-macular region.[23] We found that the BMI was positively correlated with macular thicknesses (Table 3). The association between obesity and diabetes mellitus (DM), particularly type 2 (non-insulin-dependent) DM, has been known for several hundred years.[24] The BMI affects the measurement of macular thickness and should, therefore, be taken into consideration when comparing the macular thicknesses of diabetic and non-diabetic groups in future studies.[25]

Although it has been reported that macular thickness declines with age due to a decreasing density of photoreceptors, ganglion cells and retinal pigment epithelial cells,[18] no statistically significant relationship could be found in this regard from this study (Tables 2 and 3). There are several potential reasons for the findings from this study. Firstly, our study had only six participants above 60 years of age. Secondly, this was a cross-sectional study, which is not appropriate to accurately present the decrease in macular retinal thickness with age. Therefore, the results of the effect of age on the macular thickness should be interpreted with caution in relation to the outlined limitations. Our findings are, however, consistent with previous studies[16,26] that have shown no association between macular thickness and age. However, Sull et al.[18] reported a decrease in macular thickness with age. Our results showed gender-related differences in central macular thickness and all other eight ETDRS segments, with males showing significantly larger means (Table 1). These results are in agreement with reports from other studies.[2,10,16] Thus, gender-related variations should be considered when comparisons with macular thickness measurements are made, and when diagnosing and following-up macular diseases.[16] It is, however, noted that Grover et al.[26] reported no difference in macular thicknesses between male and female participants. Gender differences in this parameter may help to explain and understand the high prevalence of certain macular diseases in females. For example, the higher risk of macular holes (which begins with foveal thinning) in females may be due to their thinner macular thicknesses.[2,27]

This study found that macular thickness was significantly related to refractive error, with all macular regions being thicker with increasing hyperopia (Table 3). Previous investigations mainly explored the effect of myopia on macular thickness, with variable results.[28,29,30,31,32] Although these studies used various methods to measure macular thickness, they generally found that macular thinning was associated with increasing myopia, and that it mainly occurred in the inner and outer maculae rather than at the central macula.[28,32] It has been reported in several studies that the central macular thickness becomes thicker with increasing myopia[28,32] or that it did not change.[33] Wakinati et al.[33] also suggested that the thinning of the peripheral macula could be a compensatory mechanism to preserve the more essential central macular thickness, which is critical to vision. Chui et al.[34] proposed that retinal stretching unfortunately reduces peripheral visual acuity by decreasing the neural sampling density. The effect of central macular thickening on visual function in hyperopes is not yet known. A possible explanation was, however, provided by Hee et al.,[35] who suggested that it would reduce vision, as acuity has been found to worsen with increasing central macular thickness in otherwise normal adult eyes.

Previous studies on the associations between macular thickness and AL have yielded conflicting results.[2,17,36,37] We found a significant negative correlation between AL and overall macula (r = -0.23, p < 0.001), mean inner macula (r = -0.17, p < 0.001) and mean outer macula (r = -0.29, p < 0.001) thicknesses, but not with central macular thickness (r = 0.05, p = 0.22). Recent studies by Hwang and Kim[32] and Zhao et al.[28] have also shown that thinner inner and outer macular thicknesses are associated with longer ALs. However, these studies also showed that central macular thickness increased with AL. In contrast, Wakinati et al.[33] reported no difference in the thickness of the central, inner and outer macular regions between the three groups of axially myopic subjects and an emmetropic group. The discrepancies in these results are probably due to the differences in the algorithms used by OCT devices, subject age and definition of the size of various macular regions.

We did not find any significant association between macular thickness and IOP (Table 3). Our study included only healthy non-glaucomatous subjects, which may have accounted for the lack of relationship between IOP and macular thicknesses. Zhang et al.[38] suggested that macular thickness was affected only in the later stages of glaucoma, being less sensitive at the earlier stages and in healthy eyes. Similarly, macular thickness did not show any significant relationship with CCT. The limitations of the current study include normative data heavily weighted with younger patients, a limited number of eyes with high refractive errors and the small study sample of adults 60 years and above.

Conclusion

This study has presented normative data for macular thickness using the iVue-100 SD-OCT device in a black South African population with healthy eyes. These findings are comparable with some studies but vary from other reports using a similar OCT system. Macular thickness measurements varied with BMI, gender, hyperopic spherical equivalence, AL and retinal location. The data obtained here may enhance our ability to diagnose ocular disorders affecting the retina and optic nerve.

Acknowledgements

This work is part of the PhD vision science project of the first author supported by the South African Medical Research Council (SAMRC). The authors thank Ms Carrin Martin for reviewing this article and giving valuable comments.

Competing interests

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

Authors' contributions

K.P.M. and O.A.O. made equal contributions in writing this article.

References

1. Huynh SC, Wang XY, Rochtchima E, Mitchell P. Distribution of macular thickness by optical coherence tomography: Findings from a population-based study of 6-year-old children. Invest Ophthalmol Vis Sci. 2006;47:2351–2357. https://doi.org/10.1167/iovs.05-1396
2. Song WK, Lee SC, Lee ES, Kim CY, Kim SS. Macular thickness variations with sex, age, and axial length in healthy subjects: A spectral domain–optical coherence tomography study. Invest Ophthalmol Vis Sci. 2010;51:3913–3918. https://doi.org/10.1167/iovs.09-4189
3. Hood DC, Harizman N, Kanadani FN, et al. Retinal nerve fibre thickness measured with optical coherence tomography accurately detects confirmed glaucomatous damage. Br J Ophthalmol. 2007;91:905–907. https://doi.org/10.1136/bjo.2006.111252
4. Lee EJ, Kim TW, Park KH, Seong M, Kim H, Kim DM. Ability of Stratus OCT to detect progressive retinal nerve fiber layer atrophy in glaucoma. Invest Ophthalmol Vis Sci. 2009;50:662–668. https://doi.org/10.1167/iovs.08-1682
5. Mansouri K, Liu JH, Tafreshi A, Medeiros FA, Weinreb RN. Positional independence of optic nerve head and retinal nerve fiber layer thickness measurements with spectral-domain optical coherence tomography. Am J Ophthalmol. 2012;154:712–721. https://doi.org/10.1016/j.ajo.2012.03.049
6. Eriksson U, Alm A. Macular thickness decreases with age in normal eyes: A study on the macular thickness map protocol in the Stratus OCT. Br J Ophthalmol. 2009;93:1448–1452. https://doi.org/10.1136/bjo.2007.131094
7. Gobel W, Hartmann F, Haigis W. Determination of retinal thickness in relation to the age and axial length using optical coherence tomography. Ophthalmologe. 2001;98:157–162.
8. Duan XR, Liang YB, Friedman DS, et al. Normal macular thickness measurements using optical coherence tomography in healthy eyes of adult Chinese persons: The Handan Eye Study. Ophthalmology. 2010;117:1585–1594. https://doi.org/10.1016/j.ophtha.2009.12.036
9. Ooto S, Hangai M, Tomidokoro A, et al. Effects of age, sex, and axial length on the three-dimensional profile of normal macular layer structures. Invest Ophthalmol Vis Sci. 2011;52:8769–8779. https://doi.org/10.1167/iovs.11-8388
10. Kashani AH, Zimmer-Galler IE, Shah SM, et al. Retinal thickness analysis by race, gender, and age using Stratus OCT. Am J Ophthalmol. 2010;149:496–502. https://doi.org/10.1016/j.ajo.2009.09.025
11. Gella L, Raman R, Sharma T. Macular thickness measurements using Copernicus spectral domain optical coherence tomography. Saudi J Ophthalmol. 2015;29:121–125. https://doi.org/10.1016/j.sjopt.2014.10.003
12. Optovue Inc. iVue-100 user's manual version 2.6 [homepage on the Internet]. c2011 [cited 2012 Mar 01]. Available from: http://license.optovue.com/CommonFolder/3360/Optovue/58044218-008_A.pdf
13. Ciolin JB, Khachikian SS, Belin MW. Comparison of corneal thickness measurements by ultrasound and Scheimpflug photography in eyes that have undergone laser in situ keratomileusis. Am J Ophthalmol. 2008;145:75–80. https://doi.org/10.1016/j.ajo.2007.08.026
14. Hood DC, Raza AS, de Moraes CGV, Liebman JM, Ritch R. Glaucomatous damage of the macula. Prog Retin Eye Res. 2013;32C:1–21. https://doi.org/10.1016/j.preteyeres.2012.08.003

15. Yanni SE, Wang J, Cheng CS, et al. Normative reference ranges for the retinal nerve fiber layer, macula, and retinal layer thicknesses in children. Am J Ophthalmol. 2013;155:354–360. https://doi.org/10.1016/j.ajo.2012.08.010
16. Adhi M, Aziz S, Muhammad K, Adhi MI. Macular thickness by age and gender in healthy eyes using spectral domain optical coherence tomography. PLoS One. 2012;7:1–6. https://doi.org/10.1371/journal.pone.0037638
17. Harb E, Hyman L, Fazzari M, Gwiazda J, Marsh-Tootle W, The COMET study group. Factors associated with macular thickness in the COMET myopic cohort. Optom Vis Sci. 2012;89:620–631. https://doi.org/10.1097/OPX.0b013e318251293a
18. Sull AC, Vuong LN, Price LL, et al. Comparison of spectral/Fourier domain optical coherence tomography instruments for assessment of normal macular thickness. Retina. 2010;30:235–245. https://doi.org/10.1097/IAE.0b013e3181bd2c3b
19. Giani A, Cigada M, Choudhry N, et al. Reproducibility of retinal thickness measurements on normal and pathologic eyes by different optical coherence tomography instruments. Am J Ophthalmol. 2010;150:815–824. https://doi.org/10.1016/j.ajo.2010.06.025
20. Chauhan DS, Marshall J. The interpretation of optical coherence tomography images of the retina. Invest Ophthalmol Vis Sci. 1999;40:2332–2342.
21. Wagner-Schuman M, Dubis AM, Nordgren RN, et al. Race- and sex-related differences in retinal thickness and foveal pit morphology. Invest Ophthalmol Vis Sci. 2011;52:625–634. https://doi.org/10.1167/iovs.10-5886
22. Huang J, Liu X, Wu Z, et al. Macular and retinal nerve fiber layer thickness measurements in normal eyes with the Stratus OCT, the Cirrus HD-OCT, and the Topcon 3D OCT-1000. J Glaucoma. 2011;20:118–125. https://doi.org/10.1097/IJG.0b013e3181d786f8
23. Mitkova-Hristova VT, Konareva-Kostyaneva MI. Macular thickness measurements in healthy eyes using spectral optical coherence tomography. Folia Med. 2011;53:28–53: https://doi.org/10.2478/v10153-011-0064-z
24. Nayaran KMV. Type 2 diabetes: Why are we winning the battle but losing the war? Kelly West Award Lecture. Diabetes Care. 2016;39:653–663. https://doi.org/10.2337/dc16-0205
25. Wong ACM, Chan CWN, Hui SP. Relationship of gender, body mass index, and axial length with central retinal thickness using optical coherence tomography. Eye. 2005;19:292–297. https://doi.org/10.1038/sj.eye.6701466
26. Grover S, Murthy RK, Brar VS, Chalam KV. Normative data for macular thickness by high-definition spectral-domain optical coherence tomography (Spectralis). Am J Ophthalmol. 2009;148:266–267. https://doi.org/10.1016/j.ajo.2009.03.006
27. McCannel CA, Ensminger JL, Diehl NN, David N, Hodge MS. Population based incidence of macular holes. Ophthalmology. 2009;116:1366–1369. https://doi.org/10.1016/j.ophtha.2009.01.052
28. Zhao M, Wu Q, Hu P, Jia L. Macular thickness assessed with optical coherence tomography in young Chinese myopic patients. J Ophthalmol. 2015; Article ID 715798, 1–7. http://dx.doi.org/10.1155/2015/715798
29. Ziylan S, Kiziloglu OY, Yenerel NM, Gokce B, Ciftci F. Macular thickness in highly myopic children aged 3 to 7 years. J Pediatric Ophthalmol Strab. 2015;52:282–286. https://doi.org/10.3928/01913913-20150526-01
30. Barrio-Barrio J, Noval S, Galdos M, et al. Multicenter Spanish study of spectral-domain optical coherence tomography in normal children. Acta Ophthalmol. 2013;91:e56–e63. https://doi.org/10.1111/j.1755-3768.2012.02562.x
31. Al-Haddad C, Antonios R, Tamim H, Noureddin B. Interocular symmetry in retinal and optic nerve parameters in children as measured by spectral domain optical coherence tomography. Br J Ophthalmol. 2014;98:502–506. https://doi.org/10.1136/bjophthalmol-2013-304345
32. Hwang YH, Kim YY. Macular thickness and volume of myopic eyes measured using spectral-domain optical coherence tomography. Clin Exp Optom. 2012;95:492–498. https://doi.org/10.1111/j.1444-0938.2012.00749.x
33. Wakinati Y, Sasoh M, Sugimoto M, Ito Y, Ido M, Uji Y. Macular thickness measurements in healthy subjects with different axial lengths using optical coherence tomography. Retina. 2003;23:177–182. https://doi.org/10.1097/00006982-200304000-00007
34. Chui TY, Yap MK, Chan HH, Thibos LN, Retinal stretching limits peripheral visual acuity in myopia. Vis Res. 2005;45:593–605. https://doi.org/10.1016/j.visres.2004.09.016
35. Hee MR, Puliafito CA, Duker JS, et al. Topography of diabetic macular edema with optical coherence tomography. Ophthalmology. 1998;105:360–370. https://doi.org/10.1016/S0161-6420(98)93601-6
36. El-Ashry M, Hegde V, James P, Pagliarini S. Analysis of macular thickness in British population using optical coherence tomography (OCT): An emphasis on interocular symmetry. Curr Eye Res. 2008;33:693–699. https://doi.org/10.1080/02713680802323140
37. Turk A, Ceylan OM, Arici C, et al. Evaluation of the nerve fiber layer and macula in the eyes of healthy children using spectral-domain optical coherence tomography. Am J Ophthalmol. 2012;153:552–559. https://doi.org/10.1016/j.ajo.2011.08.026
38. Zhang Z, He X, Zhu J, Jiang K, Zheng W, Ke B. Macular measurements using optical coherence tomography in healthy Chinese school age children. Invest Ophthalmol Vis Sci. 2011;52:6377–6383. https://doi.org/10.1167/iovs.11-7477