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Normal Macular Thickness Measurements in Healthy Eyes Using Stratus Optical Coherence Tomography

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Abstract

Objective— To report normal macular thickness measurements in healthy eyes using the latest commercially available optical coherence tomography (OCT) mapping software, version 3.0, from the Stratus OCT (OCT3).

Methods— Thirty-seven eyes from 37 healthy subjects underwent a complete ophthalmologic examination, including OCT. Six radial scans, 6 mm in length and centered on the fovea, were obtained using the OCT3. Retinal thickness was automatically calculated by OCT mapping software. Measurements were displayed as the mean and standard deviation for each of the 9 regions defined in the Early Treatment Diabetic Retinopathy Study.

Results— Foveal thickness (mean thickness in the central 1000-μm diameter area) and central foveal thickness (mean thickness at the point of intersection of 6 radial scans) on the OCT3 were 212 ± 20 and 182 ± 23 μm, respectively. Macular thickness measurements were thinnest at the center of the fovea, thickest within 3-mm diameter of the center, and diminished toward the periphery of the macula. The temporal quadrant was thinner than the nasal quadrant. Central foveal thickness was also manually determined as 170 ± 18 μm, approximately 12 μm less than the value automatically obtained from the OCT3 software. There was no correlation between age and foveal thickness ($P = .80$).

Conclusions— Mean foveal thickness measurements were 38 to 62 μm thicker than previously reported values, while mean central foveal thickness measurements were 20 to 49 μm thicker than previously published values. This discrepancy should be considered when interpreting OCT scans.

INTRODUCTION

Macular edema is a common cause of visual loss. Abnormal fluid accumulation within the retina and a concomitant increase in retinal thickness usually result from the breakdown of the blood-retinal barrier. This process can be found in those with diabetic retinopathy, retinal vein occlusion, uveitis, and other ocular disorders. However, it has been observed repeatedly in clinical practice that the presence of macular edema does not necessarily preclude good vision.^{1,2} Nussenblatt et al³ were able to demonstrate that the degree of macular thickening, rather than the presence of macular edema, is significantly correlated with visual acuity. Traditional

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methods for evaluating macular edema, such as slitlamp biomicroscopy, stereoscopic photography, and fluorescein angiography, are relatively insensitive to small changes in retinal thickness and are qualitative at best.⁴ The introduction of optical coherence tomography (OCT) has enabled clinicians to reliably detect and measure small changes in macular thickness and to quantitatively evaluate the efficacy of different therapeutic modalities.^{5–22}

The latest OCT model (Stratus OCT [OCT3]; Carl Zeiss Meditec, Dublin, Calif) was made commercially available in 2002. It provides a 4-fold increase in imaging speed and better resolution (axial resolution, <10 m) than earlier generations of the instrument. Based on our experience with the OCT3 and previous versions of the system, we observe that the macular thickness measurements for healthy eyes are higher than the values obtained using earlier versions of the instrument, including the prototype OCT. Recently, Frank et al²³ compared macular thickness measurements from 2 versions of OCT scanners: OCT1 and OCT3. Scans were acquired from both eyes of 8 consecutive patients with suspected macular edema. The measurements from the 2 instruments were statistically different. Therefore, as the OCT3 becomes more widely available and used, normative data will be important in interpreting pathological features of the macula.

This study measures and defines normal macular thickness values in healthy eyes using OCT3 mapping software. To our knowledge, this is the first study to provide normative macular thickness data for the OCT3 system.

METHODS

The study protocol was approved and monitored by the Human Investigation Review Committee at New England Medical Center. All participants engaged in an informed consent process and signed a written consent document before study procedures were carried out. Healthy subjects were examined at New England Eye Center between August 1, 2003, and February 27, 2004. All subjects underwent a complete ophthalmologic examination, including a medical and family history, best-corrected visual acuity testing with Early Treatment Diabetic Retinopathy Study charts, Humphrey SITA standard 24-2 visual field testing, applanation tonometry, slitlamp biomicroscopy, indirect ophthalmoscopy, and color fundus photography. Optical coherence tomograms were acquired through a dilated pupil by an experienced operator using the OCT3 (Carl Zeiss Ophthalmic Systems, Inc, Humphrey Division, Dublin).

Exclusion criteria for healthy eyes included any history or evidence of pathological features of the retina, diabetes mellitus or other systemic disease that could affect the eye, glaucoma or first-degree relative with glaucoma, intraocular pressure higher than 21 mm Hg, abnormal visual fields, intraocular surgery or laser therapy (although refractive surgery >1 year before enrollment was acceptable), best-corrected visual acuity worse than 20/32, and refractive error greater than 6.00 or less than -6.0 diopters.

The macular thickness map scan protocol on the OCT3 was used to obtain 6 consecutive macular scans, 6 mm in length, centered on the fovea, at equally spaced angular orientations. The cross-sectional images were analyzed using OCT3 mapping software that used an edge detection technique to locate the strongest 2 edges in each tomogram, presumed to be at the vitreoretinal interface and the anterior surface of the retinal pigment epithelial-choriocapillaris region. Retinal thickness was measured as the distance between these 2 interfaces at each measurement point along the scan's x-axis. Bilinear interpolation in polar coordinates was used to estimate the thickness of the wedges between each consecutive OCT scan.

We selected the retinal map analysis protocol on the OCT3 to reconstruct a surface map as a false-color topographic image displayed with numeric averages of the measurements for each of the 9 map sectors as defined by the Early Treatment Diabetic Retinopathy Study.²⁴ The

inner and outer rings were segmented into 4 quadrants, with radii of 1.5 and 3 mm, respectively. *Foveal thickness* was defined as the average thickness in the central 1000- μ m diameter of the Early Treatment Diabetic Retinopathy Study layout (Figure 1A). *Central foveal thickness* was defined as the mean thickness at the point of intersection of the 6 radial scans (Figure 1B).

In addition, the OCT3 mapping software was used to manually locate the minimum value along each radial scan using the raw data. All 6 values were averaged to determine the mean central foveal thickness for each subject. The manually determined central foveal thickness measurements were compared with the values generated by the software, corresponding to the box labeled “Center” on the OCT3 patient printout.

The relationship between foveal thickness and age was investigated using linear regression analysis. Statistical analysis was performed with a commercially available software program (SPSS 11.0.1; SPSS Inc, Chicago, Ill).

RESULTS

Thirty-seven healthy eyes from 37 healthy subjects were examined clinically and by the OCT3. The patients were aged 22 to 71 years (median, 43 years). There were 26 women (70%) and 11 men (30%). The mean and standard deviation retinal thickness by sector are shown in Figure 2 and Table 1. The foveal thickness never exceeded 252 μ m in any of the healthy eyes. As expected, macular thickness was thinnest at the center, thickest within 3-mm diameter of the center, and diminished toward the periphery of the macula. The temporal quadrant was thinner than the nasal quadrant. The superior and nasal quadrants were thickest overall. In this study, the inner nasal sector was thickest in 29 patients (78%), the inner inferior sector was thickest in 6 patients (16%), the outer superior sector was thickest in 1 patient (3%), and the inner superior sector was thickest in 1 patient (3%).

The standard deviation of the mean thickness of each sector outside the central 1000- μ m diameter was consistently approximately 15 μ m, demonstrating little variability in thickness measurements by OCT3. The SDs of 20 and 23 μ m for mean foveal thickness and mean central foveal thickness, respectively, were slightly larger. The standard deviation of the 6 central macular measurements provided a simple estimate of the measurement reproducibility for a given patient. The average of this reproducibility was 11 μ m. The mean $\pm$ SD central foveal thickness was manually measured as 170 ± 18 μ m, approximately 12 μ m less than the value automatically obtained from the OCT3 software.

By using linear regression analysis, we found no relationship between age and foveal thickness within the central 1000- μ m diameter ($P = .80$) (Figure 3).

A summary of previous studies that have measured retinal thickness in healthy eyes using OCT is shown in Table 2 for comparison with this study.

COMMENT

Optical coherence tomography has emerged as a useful imaging technique by providing new high-resolution cross-sectional information about various pathological features of the macula.^{5–7} It allows clinicians to quantitatively measure retinal thickness in a reliable and highly reproducible manner.^{10,11,21, 25,26} The introduction of the commercial OCT3 in 2002 provided faster imaging speed and better visualization of intraretinal morphological features compared with earlier versions of the instrument. Although there are several articles^{8,9,11–20} that report normative data for the prototype OCT, OCT1, and OCT2, to our knowledge, such data for OCT3 have been published in only 1 other article.²¹ That study had a sample size of 10 and characterized the reproducibility of OCT3 measurements.

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Our results are different from previously published values obtained using earlier versions of the device. In our study, the mean $\pm$ SD foveal thickness (average thickness in the central 1000- μ m diameter area) was $212 \pm 20 \mu$ m, approximately 38 to 62 μ m thicker than previously reported values. The mean $\pm$ SD central foveal thickness (average thickness at the point of intersection of 6 radial scans) was automatically determined to be $182 \pm 23 \mu$ m, approximately 29 to 49 μ m thicker than previously published values. Clinicians should be aware of these discrepancies when interpreting OCT images from different OCT models. These discrepancies may be a direct result of the greater resolution achieved by the more recent OCT systems. Less movement by the patient because of faster scanning times and more refined algorithms have allowed better image quality. We found that the thickness measurements in the 4 peripheral outer quadrants on the OCT3 were thinner than those reported in the literature. This may reflect the difference in scan length between the OCT3 and previous versions of the instrument. The OCT3 uses a scan length of 6 mm, whereas the OCT1, which was based on the prototype, used a scan length of 4.5 mm. As a result, the OCT3 scans more peripheral regions of the retina that are anatomically thinner. The 4 outermost zones measured by the OCT3 are thinnest, as expected from histological examination of the eye. In previous reports,^{9,16} the superior and inferior quadrants were thickest, presumably from the superior and inferior arcuate bundling of the nerve fibers. Our findings show that the superior and nasal quadrants were thickest. We identified the nasal quadrant as the thickest region within the central 3-mm diameter. This is consistent with the anatomical relationship of the converging of nerve fibers with the optic disc.

Most of the OCT studies^{6,8,11–15,17–20} in the literature report central foveal thickness only. Investigators have shown that central foveal thickness is significantly correlated with best-corrected visual acuity in healthy and diabetic eyes. However, foveal thickness may be more indicative of changes in the macula than central foveal thickness for several reasons. Foveal thickness is determined from many more data points than central foveal thickness. For example, each radial scan on the OCT3 is composed of a sequence of 512 A-scans. The macular thickness map scan protocol uses 6 radial scans per individual. Within the central 1000- μ m diameter area, foveal thickness is determined from 512 data points, whereas central foveal thickness is determined from only 6 data points. In addition, we were able to manually measure the central foveal thickness from the raw data and compare this value with the computer output. We found the mean $\pm$ SD central foveal thickness to be $170 \pm 18 \mu$ m, approximately 12 μ m less than the value automatically obtained from the OCT3 software. This may reflect the difference in approach between the manual method and the automatic method of the OCT3 mapping software. The software automatically determined the mean and standard deviation thickness for the center point where all 6 scans intersected, whereas we manually located the minimum point on each separate radial scan and averaged those values. If the OCT scans were not perfectly centered on the patient's fixation point for all 6 scans, the point of intersection would not correspond to the center exactly (Figure 4). This may give falsely elevated values. Given that the awake human eye is in constant motion, the minimum point for each radial scan will virtually never converge at the center, despite faster OCT3 scanning speeds. Because the central point is the smallest area of measurement, it will be most affected by tiny eye movements, followed by the central foveal zone. As a result, the standard deviation for central foveal thickness is the largest. Consequently, foveal thickness may be a more practical and reliable indicator than central foveal thickness for changes in the macula. We believe future OCT studies should report foveal thickness, in addition to central foveal thickness, in the evaluation of the efficacy of different therapies for macular edema.

Recently, Brown et al²⁷ directly compared the clinical gold standard for the detection of macular edema (contact lens biomicroscopy) with the OCT3 for the detection of diabetic foveal edema. Because of the lack of normative data on the OCT3, the study suggested that the cutoff for the upper level of normal foveal thickness be 200 μ m, based on their analysis of the existing

literature. Our findings do not agree with their assessment. We use 2 SDs to define the cutoffs for the upper and lower levels of normal foveal thickness. Therefore, macular thickening can be suspected if foveal thickness is greater than 252 μ m and macular thinning can be suspected if foveal thickness is less than 172 μ m when measured with the OCT3. In the present study, the only 2 outliers were a young man who had a foveal thickness of 252 μ m and a middle-aged woman who had a foveal thickness of 154 μ m, both exceeding the normal value by more than 2 SDs. Such outlying values can occur and do arise in nearly all experimental data. Patients with subclinical macular thickening or thinning, and other risk factors, may require more frequent follow-up visits. Further OCT studies are needed to investigate whether diabetic patients with subclinical thickening are at higher risk for developing diabetic retinopathy.

Although it has been suspected that macular thickness might decline slightly with age, no statistically significant relationship could be found from this study. These findings are consistent with studies by Hee et al.⁶ and Sanchez-Tocino et al.¹⁸ Our study also showed no significant difference in mean foveal thickness between men (204 μ m; range, 154–232 μ m) and women (207 μ m; range, 173–252 μ m). Future studies with larger sample sizes and a more even distribution of men and women may provide more useful information regarding differences by age, sex, and race.

In conclusion, normative values for macular thickness in a healthy population were obtained using commercially available OCT3 mapping software. Mean foveal thickness measurements were 38 to 62 μ m thicker than previously reported values, while mean central foveal thickness measurements were 20 to 49 μ m thicker than previously published values. This discrepancy should be considered when interpreting OCT scans.

References

1. Meredith TA, Kenyon KR, Singerman LJ, Fine SL. Perifoveal vascular leakage and macular oedema after intracapsular cataract extraction. *Br J Ophthalmol* 1976;60:765–769. [PubMed: 1009055]
2. Stark WJ, Maumenee AE, Fagadau W, et al. Cystoid macular edema in pseudophakia. *Surv Ophthalmol* 1984;28:442–451. [PubMed: 6463847]
3. Nussenblatt RB, Kaufman SC, Palestine AG, et al. Macular thickening and visual acuity: measurements in patients with cystoid macular edema. *Ophthalmology* 1987;94:1134–1139. [PubMed: 3684231]
4. Shahidi M, Ogura Y, Blair NP, et al. Retinal thickness analysis for quantitative assessment of diabetic macular edema. *Arch Ophthalmol* 1991;109:1115–1119. [PubMed: 1867554]
5. Huang D, Swanson EA, Lin CP, et al. Optical coherence tomography. *Science* 1991;254:1178–1181. [PubMed: 1957169]
6. Hee MR, Izatt JA, Swanson EA, et al. Optical coherence tomography of the human retina. *Arch Ophthalmol* 1995;113:325–332. [PubMed: 7887846]
7. Puliafito CA, Hee MR, Lin CP, et al. Imaging of macular diseases with optical coherence tomography. *Ophthalmology* 1995;102:217–229. [PubMed: 7862410]
8. Hee MR, Puliafito CA, Wong C, et al. Quantitative assessment of macular edema with optical coherence tomography. *Arch Ophthalmol* 1995;113:1019–1029. [PubMed: 7639652]
9. Hee MR, Puliafito CA, Duker JS, et al. Topography of macular edema with optical coherence tomography. *Ophthalmology* 1998;105:360–370. [PubMed: 9479300]
10. Massin P, Vicaud E, Haouchine B, et al. Reproducibility of retinal thickness measurements in healthy and diabetic eyes using optical coherence tomography. *Arch Ophthalmol* 2001;119:1135–1142. [PubMed: 11483079]
11. Baumann M, Gentile RC, Liebmann JM, Ritch R. Reproducibility of retinal thickness measurements in normal eyes using optical coherence tomography. *Ophthalmic Surg Lasers* 1998;29:280–285. [PubMed: 9571659]
12. Otani T, Kishi S, Maruyama Y. Patterns of diabetic macular edema with optical coherence tomography. *Am J Ophthalmol* 1999;127:688–693. [PubMed: 10372879]

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13. Schaudig UH, Glaefke C, Scholz F, Richard G. Optical coherence tomography for retinal thickness measurement in diabetic patients without clinically significant macular edema. *Ophthalmic Surg Lasers* 2000;31:182–186. [PubMed: 10847492]
14. Konno S, Akiba J, Yoshida A. Retinal thickness measurements with optical coherence tomography and the retinal thickness analyzer. *Retina* 2001;21:57–61. [PubMed: 11217931]
15. Neubauer AS, Priglinger S, Ullrich S, et al. Comparison of foveal thickness measured with the retinal thickness analyzer and optical coherence tomography. *Retina* 2001;21:596–601. [PubMed: 11756882]
16. Massin P, Erginay A, Haouchine B, Mehidi AB, Paques M, Gaudric A. Retinal thickness in healthy and diabetic subjects measured using optical coherence tomography mapping software. *Eur J Ophthalmol* 2002;12:102–108. [PubMed: 12022281]
17. Kanai K, Abe T, Murayama K, Yoneya S. Retinal thickness and changes with age. *Nippon Ganka Gakkai Zasshi* 2002;106:162–165. [PubMed: 11925953] in Japanese
18. Sanchez-Tocino H, Alvarez-Vidal A, Maldonado MJ, et al. Retinal thickness study with optical coherence tomography in patients with diabetes. *Invest Ophthalmol Vis Sci* 2002;43:1588–1594. [PubMed: 11980878]
19. Goebel W, Kretzchmar-Gross T. Retinal thickness in diabetic retinopathy: a study using optical coherence tomography (OCT). *Retina* 2002;22:759–767. [PubMed: 12476103]
20. Lattanzio R, Brancato R, Pierro L, et al. Macular thickness measured by optical coherence tomography (OCT) in diabetic patients. *Eur J Ophthalmol* 2002;12:482–487. [PubMed: 12510717]
21. Paunescu LA, Schuman JS, Price LL, et al. Reproducibility of nerve fiber thickness, macular thickness, and optic nerve head measurements using Stratus OCT. *Invest Ophthalmol Vis Sci* 2004;45:1716–1724. [PubMed: 15161831]
22. Jaffe GJ, Caprioli J. Optical coherence tomography to detect and manage retinal disease and glaucoma. *Am J Ophthalmol* 2004;137:156–169. [PubMed: 14700659]
23. Frank RN, Schulz L, Ave K, Iezzi R. Temporal variation in diabetic macular edema measured by optical coherence tomography. *Ophthalmology* 2004;111:211–217. [PubMed: 15019364]
24. Early Treatment Diabetic Retinopathy Study Research Group. ETDRS report number 7: Early Treatment Diabetic Retinopathy Study design and baseline patient characteristics. *Ophthalmology* 1991;98:741–756. [PubMed: 2062510]
25. Koozekanani D, Roberts C, Katz SE, Herderick EE. Intersession repeatability of macular thickness measurements with the Humphrey 2000 OCT. *Invest Ophthalmol Vis Sci* 2000;41:1486–1491. [PubMed: 10798667]
26. Muscat S, Parks S, Kemp E, Keating D. Repeatability and reproducibility of macular thickness measurements with the Humphrey OCT system. *Invest Ophthalmol Vis Sci* 2002;43:490–495. [PubMed: 11818395]
27. Brown JC, Solomon SD, Bressler SB, et al. Detection of diabetic foveal edema. *Arch Ophthalmol* 2004;122:330–335. [PubMed: 15006844]

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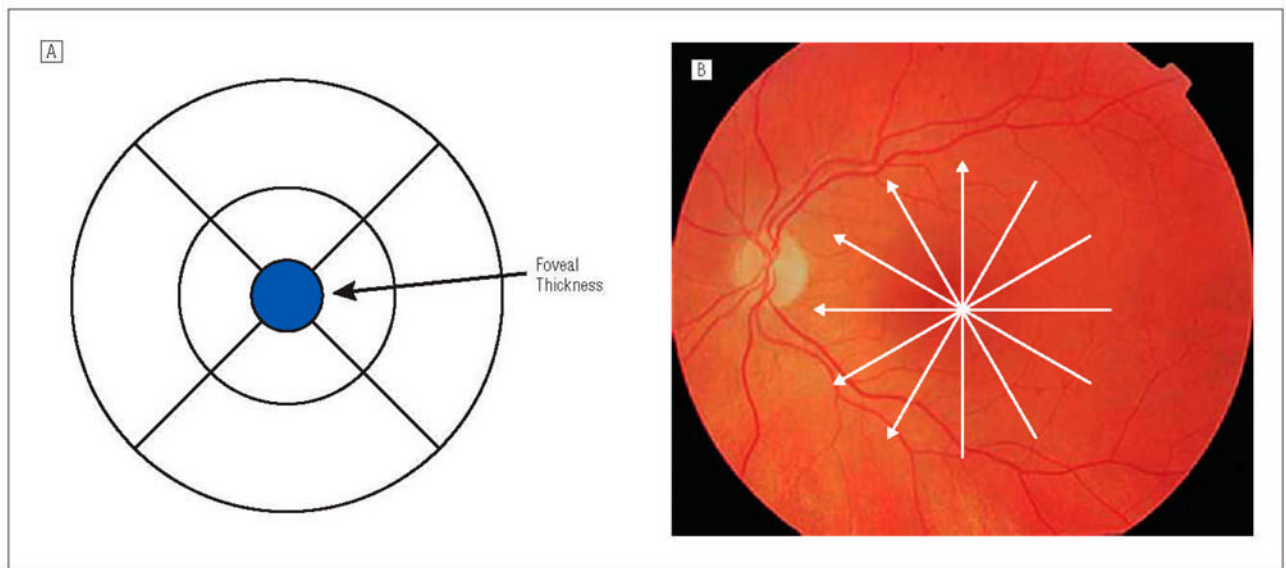


Figure 1.

Foveal thickness (A) and central foveal thickness (B). In A, foveal thickness is defined as the mean thickness within the central 1000- μ m diameter area (the central blue circle on the Early Treatment Diabetic Retinopathy Study map). In B, central foveal thickness is defined as the mean thickness measured at the point of intersection of the 6 radial scans on optical coherence tomography. The mean foveal thickness is approximately 30 μ m greater than the mean central foveal thickness.

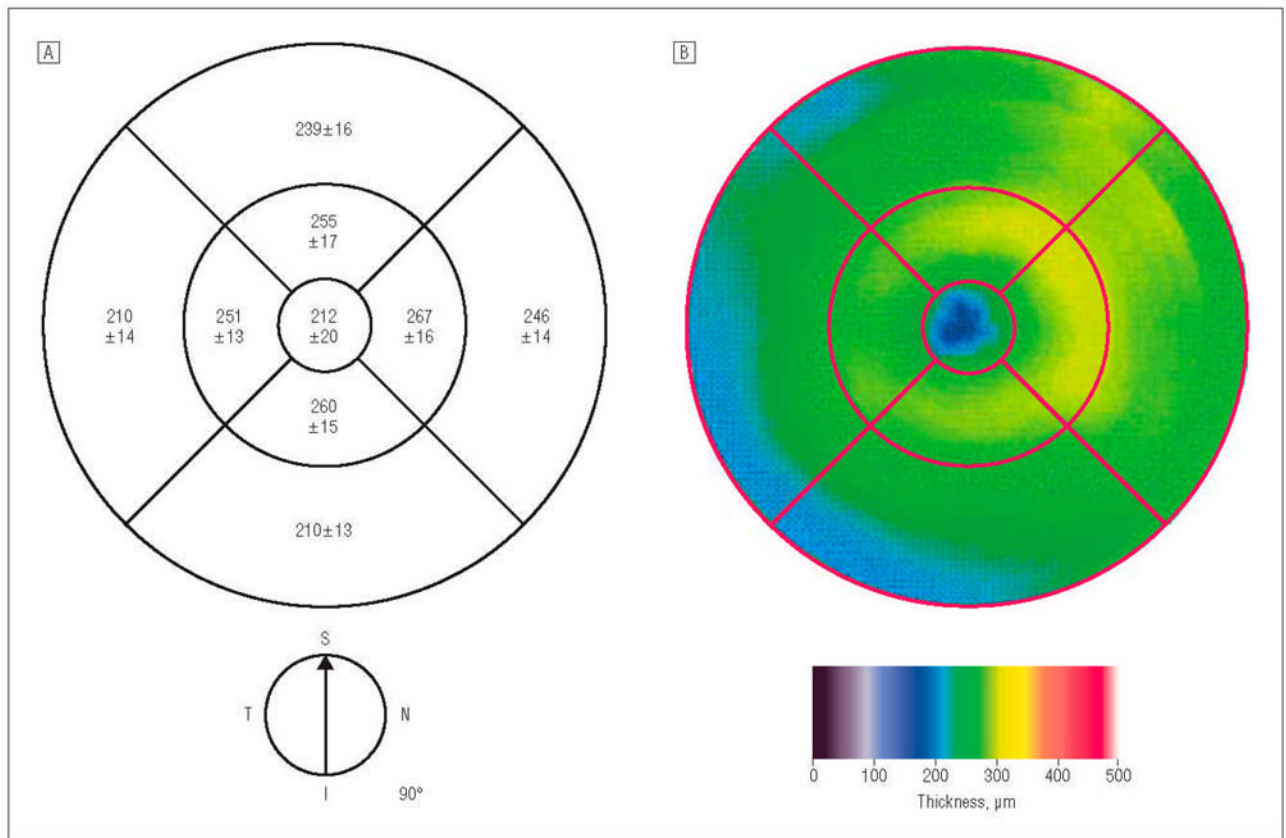


Figure 2.

Macular thickness measurements for a healthy eye population in this study, displayed as the mean and standard deviation in 9 regions, as defined in the Early Treatment Diabetic Retinopathy Study (A) and a false-color map for a prototypical healthy eye (B). I indicates inferior; N, nasal; S, superior; and T, temporal.

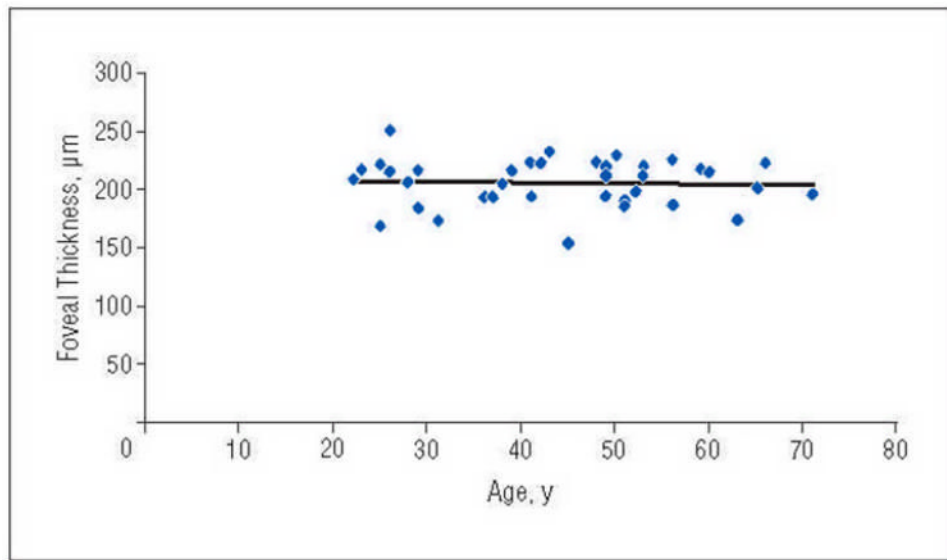


Figure 3. Regression plot of foveal thickness vs age. There is no relationship between foveal thickness and age ($P = .80$).

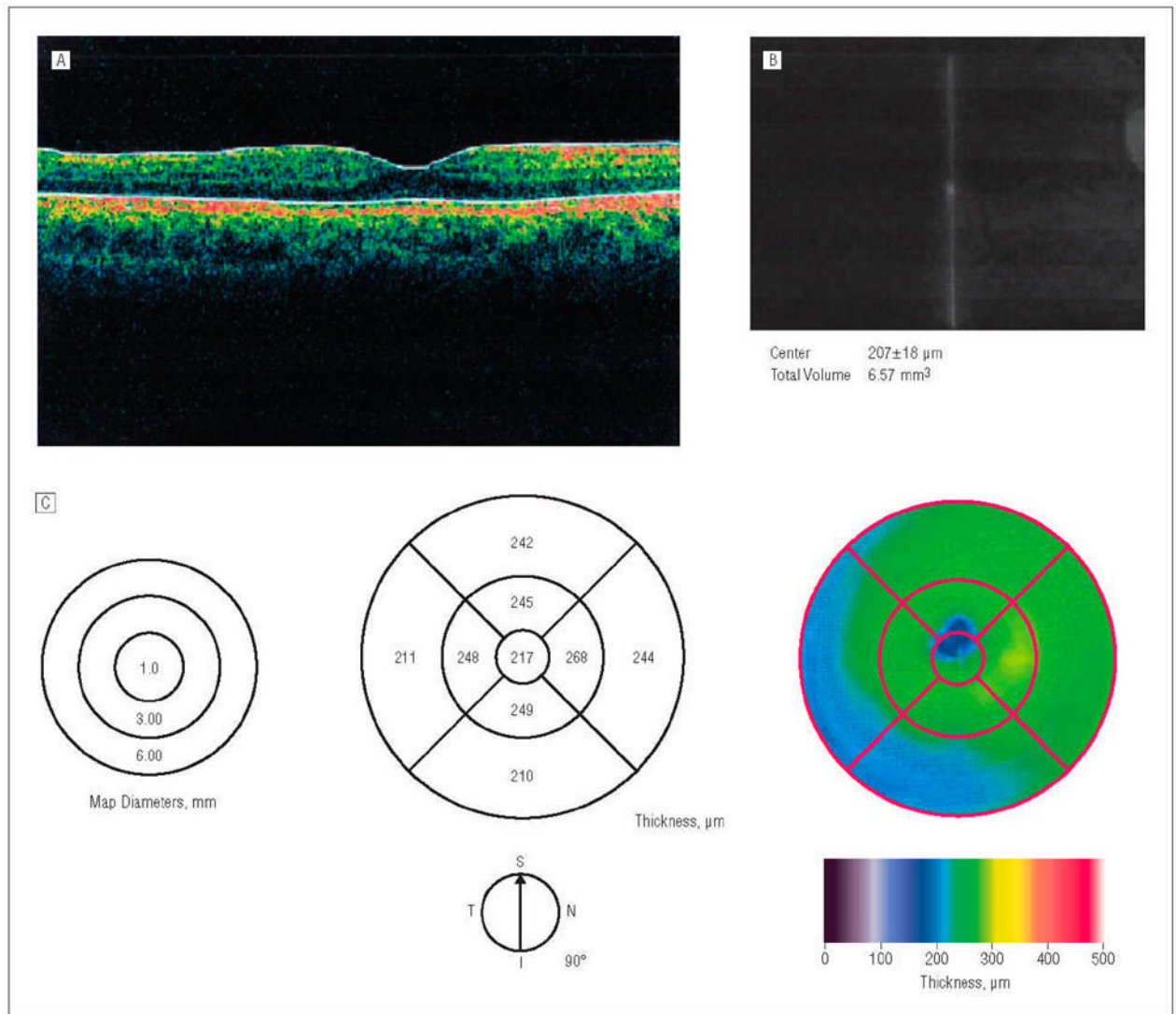


Figure 4.

The optical coherence tomographic (OCT) image (A), the fundus image (B), and the false-color map and numeric printout (C) for the right eye of a healthy patient who did not have well-aligned scans. In C, the central blue area corresponding to the fovea is off center superiorly. The OCT software determined the center (mean $\pm$ SD central foveal thickness) to be $207 \pm 18 \text{ m}$. Misaligned scans may give falsely elevated values. I indicates inferior; N, nasal; S, superior; and T, temporal.

Table 1
Macular Thickness Measurements in 37 Healthy Eyes Using the OCT3

Region	Retinal Thickness in the Healthy Eyes, Mean $\pm$ SD
Fovea (500- μ m radius)	212 $\pm$ 20
Center	
Automatically determined	182 $\pm$ 23
Manually determined	170 $\pm$ 18
Inner ring (1.5-mm radius)	
Superior	255 $\pm$ 17
Inferior	260 $\pm$ 15
Temporal	251 $\pm$ 13
Nasal	267 $\pm$ 16
Outer ring (3-mm radius)	
Superior	239 $\pm$ 16
Inferior	210 $\pm$ 13
Temporal	210 $\pm$ 14
Nasal	246 $\pm$ 14

Abbreviation: OCT3, Straus optical coherence tomograph.

Table 2
Macular Thickness Measurements in Healthy Eyes Reported in Previous Studies Using OCT

Source	No. of Eyes Studied	Type of OCT Device	Protocol No. of Scans	Foveal Thickness (1000- μ m Diameter)*	Central Foveal Thickness, μ m*
Hee et al. ⁸ 1995	20	Prototype	6	NS	147 $\pm$ 17
Hee et al. ⁹ 1998	73	Prototype	6	174 $\pm$ 18	152 $\pm$ 21
Baumann et al. ¹¹ 1998	18	Prototype	1	NS	154 $\pm$ 13
Orani et al. ¹² 1999	10	Commercial	1	NS	133 $\pm$ 9
Schaudig et al. ¹³ 2000	25	Commercial	6	NS	152 $\pm$ 17
Konno et al. ¹⁴ 2001	24	Commercial	2	NS	155 $\pm$ 20
Neubauer et al. ¹⁵ 2001	21	Commercial	6	NS	154 $\pm$ 26
Massin et al. ¹⁶ 2002	60	Commercial	6	170 $\pm$ 18	146 $\pm$ 20
Kanal et al. ¹⁷ 2002	47	NS	NS	NS	142 $\pm$ 15
Sanchez-Tocino et al. ¹⁸ 2002	44	Commercial	6	NS	145 $\pm$ 16
Goebel and Kretzschmar-Gross, ¹⁹ 2002	30	OCT2	4	NS	153 $\pm$ 15
Latanzio et al. ²⁰ 2002	50	NS	3	NS	162 $\pm$ 13
Paunescu et al. ²¹ 2004	10	OCT3	6	204 $\pm$ 20	164 $\pm$ 21
Present study	37	OCT3	6	212 $\pm$ 20	182 $\pm$ 23

Abbreviations: NS, data not specified; OCT, optical coherence tomography.

* Data are given as mean $\pm$ SD.