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Effect of corneal refractive surgery on optical coherence tomography measurements

A.A. SHPAK, S.V. KOSTENEV, I.A. MUSHKOVA, M.V. KOROBKOVA

S. Fyodorov Eye Microsurgery Federal State Institution, 59A Beskudnikovsky Blvd., Moscow, Russian Federation, 127486

The effect of significant changes in corneal power after refractive surgery on the parameters of optical coherence tomography (OCT) has not been sufficiently studied. **Purpose** — to study effects of corneal refractive surgery on optical coherence tomography (OCT) measurements in patients with moderate and high myopia. **Material and methods.** OCT was performed in 62 patients (62 eyes) with myopia over 4 D before and one month after LASIK. The changes in 14 parameters of the thickness of the retina, ganglion cell-inner plexiform layer (GCIPL) and peripapillary retinal nerve fiber layer (pRNFL) were analyzed. **Results.** The mean refractive effect was 7.07±2.02 D (4.0 to 11.75 D). Postoperative changes in the parameters analyzed were insignificant, averaging not more than 1.3% of the baseline value with the exception of pRNFL thickness in the temporal quadrant (2.2%). Only six of the 14 parameters were statistically significant — retinal thickness in the central subfield and the inner nasal quadrant, average and minimum thickness of GCIPL, and pRNFL thickness (mean and in the temporal quadrant). Individual changes of the parameters in most patients did not exceed the error of method. **Conclusion.** In patients with moderate to high myopia, LASIK operation has only a slight effect on the OCT parameters of the retina and pRNFL. Only in patients with very high myopia, the decrease over 10 D in corneal refractive power creates an optical effect of increasing the average thickness of pRNFL and GCIPL by 2—3 μm. This should be taken into account when examining such patients for glaucoma.

Keywords: *optical coherence tomography, myopia, LASIK, optical effect.*

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Keratorefractive surgeries are widely used in current ophthalmological practice. They are most commonly performed in patients with myopia, even of very high degree. Such patients often have concomitant eye fundus pathology, which requires high-tech diagnostic methods, specifically the optical coherence tomography (OCT). A question has arisen whether significant changes in corneal refraction after a keratorefractive surgery can affect the results of OCT measurements.

Parameters of the ocular optical system, primarily eye's axial length, are well known to change the quantitative measurements of OCT significantly, especially in people with refractive anomalies of higher degrees [1–6]; the influence of other characteristics has not been studied that closely. Some studies looked at the influence of keratorefractive surgeries on OCT measurements – thickness of peripapillary retinal nerve fiber layer (pRNFL) [7–10], less often – other eye fundus structures [10]. However, the main purpose of the majority of those works was to evaluate the possible damage the short-term increase in intraocular pressure (IOP) during LASIK could cause, particularly in terms of the method of forming a corneal flap (using a microkeratome or a femtolaser). Additionally, changes in pRNFL were analyzed using scanning laser polarimetry [9, 11–14].

Some authors simulated the effect of a keratorefractive surgery by using soft contact lenses and measuring pRNFL thickness [15–17], but had diverging results.

In view of the above, the purpose of the present study was to evaluate the effects of keratorefractive surgery on measurements obtained by optical coherence tomography (OCT) in patients with moderate and high myopia.

Material and methods

The study included 62 patients (62 eyes) who sought to undergo a keratorefractive surgery to correct moderate or high myopia at either S. Fyodorov Eye Microsurgery Federal State Institution (Moscow) or Medical Centre "Svetoch" (Pushkino). Each patient had one eye examined: in anisometropic patients – the one with higher degree of myopia, in patients with equal refraction – an eye chosen randomly. Inclusion criteria were myopia of more than 4 Dioptre (sphere equivalent), astigmatism of no more than 3.0 Dioptre, visual acuity with correction not lower than 0.8, patient age 18 or older. The study excluded patients with unstable visual fixation, optical media opacity, and serious concomitant diseases of the eye or of somatic origin. Patients were chosen using continuous selection method limiting the percentage of moderate myopia to 25%.

Preoperative examination included measurement of the eye's axial length with AL-3000 biometer (Tomey, Japan). Additionally, before and 1 month after the surgery patients underwent standard spectral OCT without mydriasis on Cirrus HD-OCT (Carl Zeiss Meditec, U.S.A.; software version 10.0.0.14618). The macular area was scanned according to the "Macular Cube 512×128" protocol with following "Macular Thickness Analysis" and "Ganglion Cell Analysis"; the device measures the retinal ganglion cell and inner plexiform layers (RGCIPL)

Contact information:
Korobkova Maria Valerievna – post-graduate student, Ph.D. candidate.
e-mail: korobkova1@inbox.ru
https://orcid.org/0000-0002-6564-8743

together. Retinal thickness was analyzed in the central (foveal) area 1 mm in diameter and in the inner circle of ETDRS scheme divided into 4 quadrants – temporal, upper, nasal, and lower; peripheral parts of the macula were not included in the analysis due to large amount of artifacts seen in those areas in patients with high myopia. Examination of the optic disc area was performed according to the "Optic Disc Cube 200×200" protocol with data analysis on the "ONH and RNFL OU Analysis" software. At least two measurements of each type were done during each session. The scan data with the strongest signal and absence or minimal influence of artifacts caused by eye movements were considered final. Scans with signal strength of less than 6 (out of possible 10) were excluded. All measurements were carried out by the same specialist.

In 53 patients (85%), LASIK surgery (including personalized) was performed using WaveLight EX500 system (Alcon, U.S.A.), and corneal flap formation by femtosecond laser Femto LDV 6 (Ziemer, Switzerland); in 9 other patients (15%) – on excimer laser Nider EC-5000 (Nidek, Japan) with corneal flap formed by mechanical microkeratome Zyoptix XP (Baish&Lomb, U.S.A.).

Statistical analysis was done on a personal computer using Excel (Microsoft) and STATISTICA 6 (StatSoft) software. Outlying values were excluded when differing from arithmetical average by more than 3 standard deviations – M±3σ. Kolmogorov-Smirnov test was used to evaluate normalcy of distribution. The values distributed normally were put in M±σ format; they were compared before and after the surgery using paired Student t-test. When distribution varied from normal, the data was shown as a median with indication of interquartile range – *Me* (*IQR*). These values was compared using Wilcoxon test. Correlation of the parameters was assessed using linear regression method and Pearson correlation analysis. P values less than 0.05 were considered statistically significant.

Results

Fifteen patients (24%) had moderate myopia, 47 (76%) – high myopia. Mean age of the patients was 27.9±6.5 (18 to 47 years old), among them 39 (63%) were female and 23 (37%) were male. Axial eye length was between 25.21 and 28.04 mm (in average 26.42±0.54 mm).

Preoperative period went without any complications. Baseline refraction values and its changes after surgeries can be seen in **Table 1**.

In most cases, the intended effect was achieved successfully. Only one patient with high myopia (-13.0 Diopters in spherical equivalent) and astigmatism of 2.5 Diopters had remaining myopia of (-)3.38 Diopters (in spherical equivalent) due to insufficient initial thickness of the retina (555 μm).

The quality of macular scans was high: only in 7 scans performed before and 5 scans performed after the surgery the signal strength was less than 8. The quality was somewhat lower in optic disc scans: only in half of cases the signal strength was 8 or higher, in other eyes it was 6–7. Analysis of RGCIPL was performed in 54 patients – 8 were excluded due to program errors with segmentation (12 protocols). Furthermore, analysis of macular retinal volume and mean retinal thickness was performed in 55 patients: 7 were excluded due to incorrect measurements (9 protocols). Particularly high number of inaccuracies was seen in optic disc measurements; in a third of all cases (21 patient) significant discrepancies were observed with automatic assessment of optic disc borders before and after the surgery. In this respect, analysis of optic discs was excluded from the study.

Main parameters of the retina before and after LASIK can be seen in **Table 2**.

The changes before and after LASIK were essentially insignificant and in most cases did not exceed 1% from the baseline values, with only RGCIPL having an increase of 1.1 to 1.3%. Moreover, changes in 5 out of 9 parameters were not statistically reliable.

Thickness of pRNFL before and after the surgery can be seen in **Table 3**.

Changes in pRNFL thickness after refractive surgery were also insignificant. They were between 0.4 and 1.2% of the baseline value in all the sectors except the temporal quadrant with 2.2% change in thickness. Only the changes in this parameter and mean pRNFL thickness were reliable.

Correlation analysis and linear regression were used to assess the dependency of changes in each parameter on the amount of refractive effect. In all cases, correlation was weak and statistically unreliable: correlation coefficient was lower than 0.27 and for pRNFL parameters – lower than 0.11.

However, the patients with higher refractive effect showed unreliable tendency for slightly more prominent changes. For example, increase of mean pRNFL thickness in patients with better than average refractive effect

Table 1. **Refraction before and one month after LASIK (*n*=62)**

Refraction	Before surgery	After surgery	Change
Spherical equivalent, M±σ (Min; Max)	–7,50±2,13 (–4,0; –13,0)	–0,43±0,86 (–3,38; 1,25)	7,07±2,02* (4,0; 11,75)
Astigmatism, *Me* (*IQR*)	0,5 (0,25; 0,93)	0,5 (0; 0,69)	0,25** (–0,25; 0,5)

Note. * – p<0,001; ** – p<0,01.

Table 2. **Parameters of the cornea measured by OCT before and one months after LASIK**

Parameter	*n*	Before surgery	After surgery	Change	% increase
Retinal thickness, µm, *M*±σ (Min; Max)					
Central area	59	258,6±21,1 (200; 311)	256,1±21,2 (198; 311)	–2,5±2,4 (–8; 3)*	–1,0±1,0 (–3,2; 1,3)
Inner temporal quadrant	61	302,2±14,1 (269; 331)	302,2±13,9 (268; 334)	0,0±3,0 (–7; 7)	0,0±1,0 (–2,1; 2,1)
Inner upper quadrant	60	313,7±12,7 (280; 341)	313,5±11,9 (277; 335)	–0,2±3,0 (–8; 8)	–0,1±1,0 (–2,3; 2,7)
Inner nasal quadrant	61	316,8±14,6 (273; 362)	315,5±14,0 (271; 354)	–1,2±2,8 (–8; 4)*	–0,4±0,9 (–2,2; 1,4)
Inner lower quadrant	59	309,5±13,2 (278; 344)	309,6±12,9 (278; 342)	0,1±2,7 (–6; 6)	0,0±0,9 (–1.8; 2,0)
Mean	51	269,6±10,5 (247; 293)	270,0±10,3 (247; 293)	0,3±1,9 (–4; 4)	0,1±0,7 (–2,0; 2,3)
Retinal macular volume, mm^3, *Me* (*IQR*)	52	9,7 (9,5; 9,93)	9,7 (9,5; 9,9)	0 (–0,1; 0,1)	0 (–0,9;1,04)
Thickness of retinal ganglion cell layer (including inner plexiform layer), µm					
Mean, *Me* (*IQR*)	52	75 (73; 78)	76 (74; 79)	1 (0; 2) *	1,3 (0; 2,6)
Minimal, *M*±σ (Min; Max)	52	75,7±4,7 (66; 85)	76,4±4,3 (66; 85)	0,8±1,4 (–2; 3) *	1,1±1,9 (–2,5; 4,5)

Note. * – $p<0.001$; patients with incorrectly taken measurements and outlying values were excluded.

Table 3. **Parameters of pRNFL thickness measured by OCT before and one month after LASIK, *M*±σ (Min; Max)**

pRNFL thickness, µm	*n*	Before surgery	After surgery	change	% increase
Mean	62	84,2±5,5 (69; 102)	85,2±5,8 (72; 103)	1,0±2,3 (–5; 7)*	1,2±2,9 (–5,9; 9,5)
Temporal quadrant	59	73,1±15,4 (40; 119)	74,6±15,8 (40; 125)	1,5±3,3 (–6; 8)*	2,2±4,7 (–6,5; 10,8)
Upper quadrant	59	103,5±13,4 (75; 155)	103,8±13,7 (76; 158)	0,3±3,9 (–8; 8)	0,4±3,8 (–7,3; 7,8)
Nasal quadrant	58	58,1±8,6 (46; 90)	58,4±9,4 (43; 96)	0,3±3,1 (–7; 6)	0,4±5,5 (–12,7; 13,0)
Lower quadrant	62	103,5±12,6 (78; 136)	103,9±12,8 (78; 133)	0,4±5,6 (–14; 11)	0,5±5,5 (–13,6; 10,0)

Note. * – $p<0.002$; outlying values were excluded.

(>7.0 Diopters) was 1.44±2.72 µm (1.78±3.37%) as compared with 0.69±2.07 µm (0.80±2.56%) in patients with lower effect. Actual changes even in best refractive effect (11.75 Diopters) were 3 µm, while calculated value was 1.8 µm. In this specific case, for instance, mean GCIPL only increased by 1 µm (calculated value 1.75 µm), and retinal thickness in the foveal area did not change (was calculated to decrease by 2.5 µm).

Discussion

The changes of the parameters measured with OCT, primarily pRNFL and GCIPL, are considered important criteria in early detection and assessment of primary open-angle glaucoma progression [18–22]. The patients with high myopia, however, can prove challenging in terms of diagnosing glaucoma with OCT due to pathological changes in those patients and the way optical system of a myopic eye can influence OCT results [3, 4, 6, 23, 24]. The only question in this regard that has been relatively well studied is influence of axial eye length on the parameters measured with OCT in patients with refractive anomalies [1–6]. The impact of optic changes after keratorefractive surgeries on OCT measurements has not been studied sufficiently yet.

Another matter requiring evaluation is a theoretical possibility of increased IOP during eye fundus surgeries causing injury, primarily to pRNFL. To assess the possibility, some authors employed scanning laser polarimetry performed on GDx VCC (Carl Zeiss Meditec, U.S.A.) device [9, 11–14]. In most cases, there were no changes detected, but P. Hlavácová et al. found minimal significant thinning of pRNFL [13], while E. Hoffman et al. also used Retinal Thickness Analyzer (Talia Technology, Israel) device, on which they detected slight thinning of pRNFL [14] not seen on GDx VCC.

Time-domain OCT on a previous generation device Stratus OCT 3000 (Carl Zeiss Meditec, U.S.A.), known as "classic" OCT, did not reveal changes in pRNFL [8, 9]. It was confirmed with spectral OCT – a modern OCT method with improved accuracy, higher measurement repeatability and lower variability of the results [25–27]. In the studies comparing methods of corneal flap formation (microkeratome or femtolaser) in LASIK surgeries, it did not reveal changes in pRNFL [7, 10]. Only short-term thinning of pRNFL and thickening of fovea were observed directly after the surgery (in 30 minutes) and disappeared by the next day [10].

The mentioned studies allowed ruling out the damaging effect of the IOP increase that happens during the surgery. Degree of myopia did not play any role in this because it does not affect the magnitude of intraoperative IOP increase.

Another concern about possible effect of corneal refraction change on pRNFL parameters could not be solved to a sufficient degree due to patients having mean myopia of (–)3 to (–)5 Diopters, with only two studies having patients with myopia reaching (-)5.46 to (-)6.43 Diopters [10, 13]. Relatively low refraction change seem to have almost no effect on OCT measurements. In the present study, mean myopia was significantly higher – (–)7.5 Diopters, while maximum refractive effect amounted to 11.75 Diopters; it seems to have allowed to reveal, although small, statistically relevant changes in pRNFL and some other parameters.

Experiments with soft contact lenses of different power, in which negative-refraction lenses essentially simulate the effect of a surgery, pose additional data on the role of corneal refraction change [15–17]. Significant effect of the contact lenses on mean pRNFL thickness was absent in the results of only one study that utilized "classic" OCT [17]. It's worth noting that there was statistically irrelevant thickening of pRNFL by 2.5 µm with a lens of (-)10.0 Diopters (0.25 µm/dptr). Studies that utilized spectral OCT showed pRNFL thickening for 0.5 µm [16] or 0.4 µm in average while contact lens power decreased for 1 Diopter, which amounted to 0.25 µm increase of pRNFL thickness when adjusted for signal strength. Similar effect, but of lower magnitude (about 0.11 µm/dptr) was observed in the present study when patient's ocular refraction weakened by 1 Diopter. Obviously, changes in pRNFL after LASIK are low in most patients, and do not exceed 1–1.5 µm. Only in very high myopia (more than 10 Diopters) changes in corneal refraction can produce the effect of pRNFL "thickening" by 2–3 µm.

Mean changes in the parameters were relatively small, but in some patients of the present study, they were more prominent. For example, while pRNFL thickness after LASIK has increased only by 1 µm in average, in 5 patients it changed by as much as 5–7 µm. Such changes, in most cases, were obviously the result of method error, which can be associated with e.g. the difference in patient's head position (or head tilt) [28]. Method error can be quantitatively characterized by repeatability limit (or just repeatability) – "value not exceeding the modulus of difference between two measurements with 95% level of confidence – [29]. In the restudies conducted at different times or by different operators the value is called reproducibility. Our own observations, as well as literature data [25–27], say that mean pRNFL thickness has a repeatability limit of 5–7 µm, i.e. individual changes in the parameters after LASIK did not exceed the repeatability limit, and so were considered regular method errors.

The present study only included patients with moderate or high myopia, but looking at the results of individuals with hypermetropia could also prove interesting. Taking into account the data on simulations with contact lenses, the effect of refractive surgeries on OCT measurements in patients with high hypermetropia can be as insignificant as in patients with myopia, although it needs further research.

Conclusion

In patients with moderate or high myopia, the effect of LASIK on retinal OCT measurements and pRNFL is insignificant (no more than 1.3% from baseline in average, with an exception of pRNFL thickness in the temporal quadrant). In patients with very high myopia, weakening of corneal refraction for more than 10 Diopters produces an optical effect of 2–3 µm increased mean thickness of pRNFL and GCIPL, which should be considered when evaluating such patients for glaucoma.

Author contributions:
Study conception and design: A.Sh., S.K., I.M., M.K.
Acquisition and processing of data: S.K., I.M., M.K.
Statistical analysis: A.Sh., M.K.
Drafting of manuscript: A.Sh., M.K.
Critical revision: A.Sh., S.K., I.M.

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