Effect of corneal surface ablation and flap creation on the eye's wavefront errors and visual quality

PhD thesis

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Introduction

Refractive error is an error when the eye cannot focus parallel rays of light (light from distant objects) on the retina after their interaction with the cornea and the lens. Refraction of the eye can be described approximately by using sphaerical (myop, hypermetrop) and cylindrical (astimatism) models, but real refraction is always multifocal. Lower (first, second) and higher (third, fourth …) order aberration can be distinguished and diagnosed nowadays by using several tools.

Zernike polynomials are used to characterize higher-order errors, while numerically they can be transformed into RMS (root mean square) values. The RMS value is the square root of the arithmetic mean of the squares of the difference from the perfect wavefront, or the square of the function that defines the continuous wavefront. These values allow us to follow and to compare our patients data.

These aberrations are responsible for decreased contrast sensitivity, glares, halos and several visual disturbances by night.

The most important higher order aberrations in connection with photorefractive keratectomies (PRK) are sphaerical aberrations (OSA 4;0, 6;0) and horisontal coma (OSA 3;1, 5;1). First one can be explained by the geometry of the treatment while the second type occurs if the treatment is a little bit off-axis.

LASIK (Laser In Situ Keratomileusis) was developed to avoid postoperative pain caused by epithelial cell loss and to reach faster regeneration after the surgery. Femtosecond assisted LASIK surgeries are the new generation of this type of refractive operations.

Femtosecond lasers were developed by Professor Tibor Juhász. First time it was used for creation of corneal flaps in 2001. This method is considered to result in much more precise and predictable corneal flaps and it is also able to cut flap edges askew which helps to prevent flap displacement.

First time in the world in 2008 by Professor Zoltán Zsolt Nagy femtosecond lasers were used to assist cataract surgeries by creating corneal wounds, capsulorrhexis and lens fragmentation.

A new, multifunctional femtosecond laser platform was introduced in 2011, which is able to assist both LASIK and cataract surgeries. Our purpose was to evaluate the predictability, safety, visual acuity and flap creation results, and higher order aberration induction effect of this new device.

Objectives

Our aim was to evaluate the eye's higher order aberrations and several refractive surgeries' effect on them.

1. to examine higher order aberration compensation mechanism of cornea's anterior and posterior surfaces and photorefractive keratectomies effect on wavefront error induction according to photoablation depth.

2. to evaluate femto-LASIK surgeries results assisted by a new, multifunctional femtosecond laser platform used first time in the world at our Department in connection of flap creation, refractive and higher order aberration induction effect.

3. to compare results of PRK and femto-LASIK surgeries

4. to evaluate visual acuity, flap creation results and iatrogenic induced ectasia risk of femto-LASIK surgeries in case of thinner (120 μm) corneal flaps.

5. Methods

Patients

Our patients underwent corneal refractive surgery between 2011 and 2014 at Ophthalmology Department, Semmelweis University. Exclusion criteria for being part of our study were consistent with ones used in case of eligibility for refractive surgeries.

The studies were conducted in compliance with the Declaration of Helsinki, applicable national and local requirements regarding the ethics committee and institutional review boards, and other statutes or regulations regarding the protection of the rights and welfare of human subjects participating in biomedical research. A written informed consent was obtained before the surgery from each patient.

1. **PRK group:** 89 eyes of 48 myopic and myop-astigmatic patients.
2. **Femto-LASIK group: 38 eyes of** 20 myopic and myop-astigmatic patients. Planned flap thickness and diameter were 140 μm and 8,5 mm.
3. **Comparing the two groups:** 30 eyes of 15 patients underwent femto-LASIK, and 30 eyes of 15 patients underwent PRK surgeries.
4. **Femto-LASIK group of thinner (120 μm) flaps:** 42 eyes of 21 patients underwent femto-LASIK surgeries by creation of 120 μm thick corneal flaps.

Surgical technique

Oxibuprocain-hydrochloride (Humacain; 4 mg/ml) drops were used three times every 10 minutes as part of the premedication preoperatively. Epithel cell layer was removed using a hockey knife in case of PRK suregeries, while

in case of femto-LASIK procedures corneal flaps were created by using Alcon LenSx multifunctional femtosecond laser (Alcon, Aliso Viejo, CA, USA). Refractive treatment was executed by using Wavelight Allegretto 400 (Alcon Inc., Forth Worth, TX, USA) excimer laser device except in case of the first PRK group where it was made by using Asclepion Meditec MEL 80G-scan excimer laser device.

After the operation, the ocular surface was irrigated with a chilled balanced saline solution (+4.0°C); topical tobramycin (3 mg/ml) and tropicamide (Mydrum, 5 mg/ml) eyedrops were also administered.

Levofloxacin (Oftaquix, 5 mg/mL) drops were used 4 times daily until the epithelium healed. For 5 days after reepithelialization occurred, fluorometholone (Flucon, 1 mg/mL) drops were administered 5 times daily, after which they were tapered to 0 over 4 months.

Measurements

Every patient had to attend screening prior to the surgeries which included a objective refraction (KR 8800, Topcon, Tokyo, Japan), visual acuity test for uncorrected and best spectacle corrected visual acuity (UDVA and BSCVA).

Intraocular pressure (IOP) and corneal topography were also executed by using non-contact tonometer (PT 100, Reichert, Inc., Depew., NY) and topography (Tomey, Tomey Corp, Nagoya, Japan). Corneal thickness was measured by Scheimpflug-camera (Pentacam, Oculus, Wetzlar, Germany).

Measurements mentioned above and in case of femto-LASIK surgeries anterior segment-OCT (RTVue; Optovue, Inc., Fremont, CA) were also performed postoperatively.

Statistical analysis:

Statistical analysis was performed using SPSS 17.0 (SPSS Inc, IBM, Chicago, IL). The Shapiro–Wilk Test was used to evaluate the normality of our sample. Differences with $P < 0.05$ were considered statistically significant. For between group comparison non dependent paired t-test was used in case of normal distribution and Mann-Whitney U-test was used in case of non normal distribution. Because of nonnormal distribution, the Wilcoxon Test was performed for the analysis of dependent data, while because of normal distribution dependent paired t-test was used. Linear piecewise regression analysis models were used to identify potentially meaningful trends in connection with photoablation depth. As a subgroup analysis, Receiver Operating Characteristics (ROC)-curve was used to caracterize significant difference in higher order aberration types between groups above and under 77 μm photoablation depth.

Friedman-test was used to compare the nine points of each cornea measured by anterior-OCT to prove the planar shape of the flaps.

Results

1. PRK group:

- The UCVA increased in a statistically signficant manner (0.13±0.102, 0.98±0.106, p<0.001).
- There were statistically signficant differences between the preoperative values of RMS-HOA anterior and RMS-HOA total: RMS-HOA anterior values proved to be signficantly higher compared with the RMS-HOA values of the total cornea (0.108±0.028 μm, 0.097±0.028 μm, p<0.001), which suggests a compensatory mechanism of the posterior.
- One year postoperatively there were no significant changes in the RMS-HOA posterior values (0.059±0.01 μm, 0.056±0.013 μm, p=0.12); however, the RMS-HOA anterior (0.108±0.028 μm, 0.206±0.054 μm, p<0.001) and RMS-HOA total values (0.097±0.028 μm, 0.207±0.063 μm, p<0.001) increased in a statistically signficant manner.
- Correlation between the ablation depth and anterior corneal aberrations was found között [r (fitting index) $_{\text{linear regression}}\approx 0.42$, r $_{\text{linear piecewise regression}}\approx 0.84$]. Above an ablation depth of 77 μm (the breakpoint is at 76.77 μm), the amount of HOAs of the anterior corneal surface increased 2.4-fold between the first and second segments of the curve.
- Comparison of eyes above and under 77 μm a statistically significant difference was found: above 77 μm amount of sphaerical aberrations (OSA 6;0 és OSA 4;0) and horizontal comas (OSA 3;1 és OSA 5;1) were increased caused by the geometry of the procedure and the subclinical decentration.

2. Femto-LASIK group:

- UDVA improved statistically significantly compared to the preoperative values at every control examination (0.1 (±0.07), 1.0 (±0.00), p<0.001).
- Lifting the corneas was easy with the special Slede's blunt spatula and subjectively there were no significant tissue bridges. No flap movement or dislocation was experienced during follow-up. All cases were included, no patients were lost, and there was no need for re-treatment during the follow-up period.
- The mean value of the postoperatively measured flap thickness was 141.95 (± 7.59) μm, so there was no statistically significant difference between planned and postoperatively measured flap thickness (p = 0.4067).
- Flaps had a planar shape and there was no significant difference between the thickness of the nine points in each cornea (p = 0.058).

3. Comparing the two groups:

- At baseline there were no statistically significant difference between the two groups regarding age, gender, refractive error, pachymetryphotoablation depth and uncorrected visual acuity.
- Uncorrected visual acuity showed significant increase in case of each group [PRK: 0.1 (±0.02), 1.0 (±0.00); p<0.001, Femto-LASIK: 0.1 (±0.07), 1.0 (±0.00); p<0.001].
- In the PRK group higher order aberrations' RMS values of the anterior corneal surface and the total cornea showed a statistically significant increase in all analyzed diameters (p<0,001), while posterior surface's RMS-HOA stayed stable (4.5 mm: p=0.142; 6.0 mm: p=0.052; 8.0 mm: p=0.65).

- In femto-LASIK group both anterior, posterior and total cornea higher order aberrations increased significantly in the 4.5 mm, 6.0 mm and 8.0 mm diameter ($p<0.001$).
- Comparing the two groups this difference didn't proved to be significant in case of anterior and total corneal surfaces regarding analysis diameter of 4.5 mm. However, changes of anterior and total corneal surfaces of PRK group regarding analysis diameter of 6.0 and 8.0 mm proved to be significantly greater than same parameters of femt-LASIK group.

4. **Femto-LASIK group of thinner (120 µm) flaps**:

- There was no significant difference between the planned and postoperatively measured flap thickness according to data of anterior segment OCT [planned: 120 µm, postoperatively: 120.33 (±6.55) µm, $p<0.05$]).
- Total corneal higher order aberrations showed significant increase in all analysis diameter.
- Mean PTA value was 35% in the group [PTA: 0,35 (±0,048)].

Conclusion

Both after PRK and femto-LASIK surgeries results regarding visual acuity and safety proved to be excellent.

1. According to our knowledge, this is the first study that proved compensation mechanism of posterior corneal surface to the anterior surface's higher order aberrations in healthy corneas.
2. We were also the first ones who published correlation between photoablation depth and induced higher aberrations by PRK, which showed that the amount of HOAs of the anterior corneal surface increased 2.4-fold above 77 μm.
3. Morphology of these induced HOAs are suggested to be related to the geometry of the procedure and the subclinical decentration.
4. This is also the first study that examined the results of LASIK performed with the LenSx femtosecond laser with intraocular application. Safety and efficacy were proved both in case of thicker (140 μm) and thinner (120 μm) flaps.

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