Corneal asphericity after myopic correction with excimer lasers

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Purpose:

The purpose of this work is studying a corneal asphericity change after a myopic refractive correction by mean of excimer lasers. As the ablation profile shape plays a key role in the post-op corneal asphericity, ablation profiles of recent lasers should be studied. The other task of this research was to analyze operation (LASIK) outcomes of one of the lasers with generic spherical ablation profile and to compare an asphericity change with theoretical predictions. The several correction methods, like custom generated aspherical profiles, may be utilized for mitigation of unwanted effects of asphericity change. Here we also present preliminary results of such correction for one of the excimer lasers.

Methods:

Generally the regularly shaped (without astigmatism and other imperfections) cornea can be represented as conicoid surface:

$$z = \frac{cr^2}{1+\sqrt{1-(1+k)c^2r^2}}$$

where z - is a sag of the surface, r - distance from the center and c-is a curvature (reciprocal radius of curvature- R) and k -is a conic constant. Conic constant is related to asphericity parameter p as $p=k+1$. In this notation sphere has $k=0$, and parabolic profile has $k=-1$. When two conic surfaces are added together the resulting curvature and conic will satisfy the following equations:

$$c_3 = c_1 + c_2$$

$$k_3 = -1 + \frac{(1+k_1)c_1^3 + (1+k_2)c_2^3}{c_3^3}$$

Let's suppose that the second surface is correction profile, than the power of correction (n=1.375):

$$F = \frac{1}{c_2(n-1)}$$

In the particular case of spherical correction profile:

$$k_3 = -1 + \frac{(1+k_1)c_1^3 + c_2^3}{c_3^3} \qquad (1)$$

The formulas are quite similar by ones obtained by Anera and co-workers [1]. The formulas give a prediction of the post-op corneal asphericity in the assumption of exact reproduction of the ablation profile. In practice there are several other factors like non-normal incidence of beam [2-3], biomechanical response of cornea and etc, which also influence on the resulting asphericity.

Since the ablation profiles are usually unknown their direct experimental measurement is necessary for quantifying the influence of different factors on post-op asphericity. For direct measurements of ablation profiles samples of PMMA were processed by the following lasers:

MEL80 (Zeiss), Nidek EC-5000 and Microscan-2000 (PIC, Russia). All lasers were programed to make -5D myopic correction. The plates were studied by the Zigo phase shift interferometer and obtained profiles were fitted by sphere and conicoids.

Microscan-2000 laser with spherical ablation profile was chosen for study post-op conic constant change. We study LASIK operation outcome of a group of 35 patients (70 eyes) with no significant astigmatizm (<0.5D) and absence of pos-op complications. Programmed correction was in the range of -1.5 to -10D.

The results were fitted by linear function and compared with prediction of theory (equations (1)).

We also study a possibility of asperical correction with the help of customized ablation software developed in Moscow State University for flying spot lasers. An interface to Microscan-2000 was utilized for direct transfer of ablation maps (scan-files) to laser. No aditional corrections we made in the laser operation software.

Results:

The example of the output of Zigo interferometer for Microscan-2000 laser is presented on Fig.1. The similar data were obtained for MEL80, Nidek EC-5000. Central sections were exported and fitted by spherical and conic profiles. Plots with superimposed fitted curves are presented on the Figures 2-4.

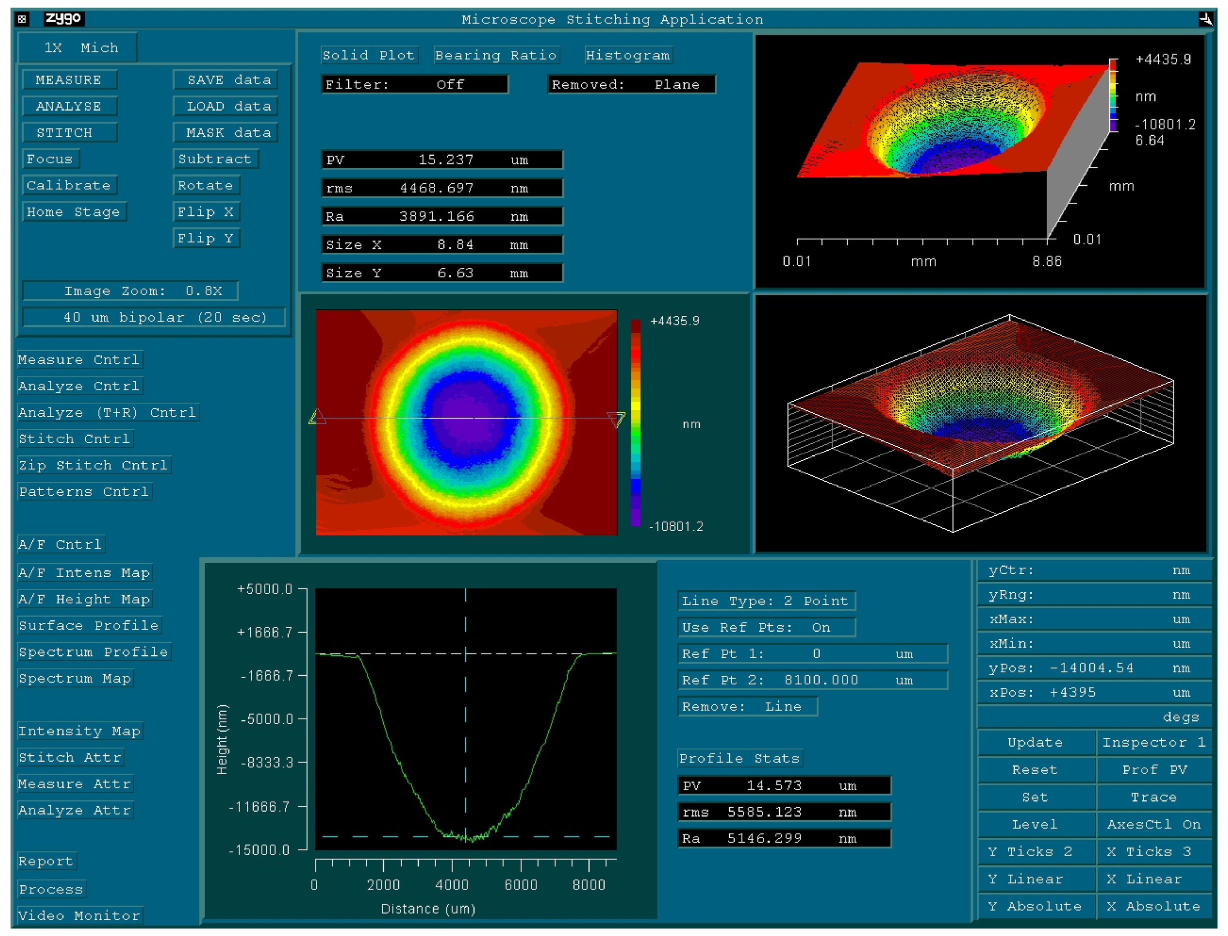

Fig.1 Output of Zigo interferometer for Microscan-2000

As it seen from the plots Nidek and Microscan has spherical ablation profiles, while an aspheric curve is best fitted to MEL80. The shape of aspheric for MEL80 indicates possible correction for non-normal incidence and may be for other factors.

For clinical study of the post-op asphericity described above group of patent from S.Fiodorov Eye Microsurgery Center was chosen. The refraction correction was performed with Microscan-2000 laser. All patients were examined prior and after surgery (1 and 3 month later) with a help of corneal topograph Tomey-3. The corneal height data from topograph were annualized for computation corneal power and conic constant. For this study a only patients with post-op visual acuity in the range of 0.8 to 1.0 were selected.

Figure 3 illustrates the obtained results (dots corresponds with the corneal power change, solid red line is linear approximation). The theoretical curve is also plotted as yellow curve.

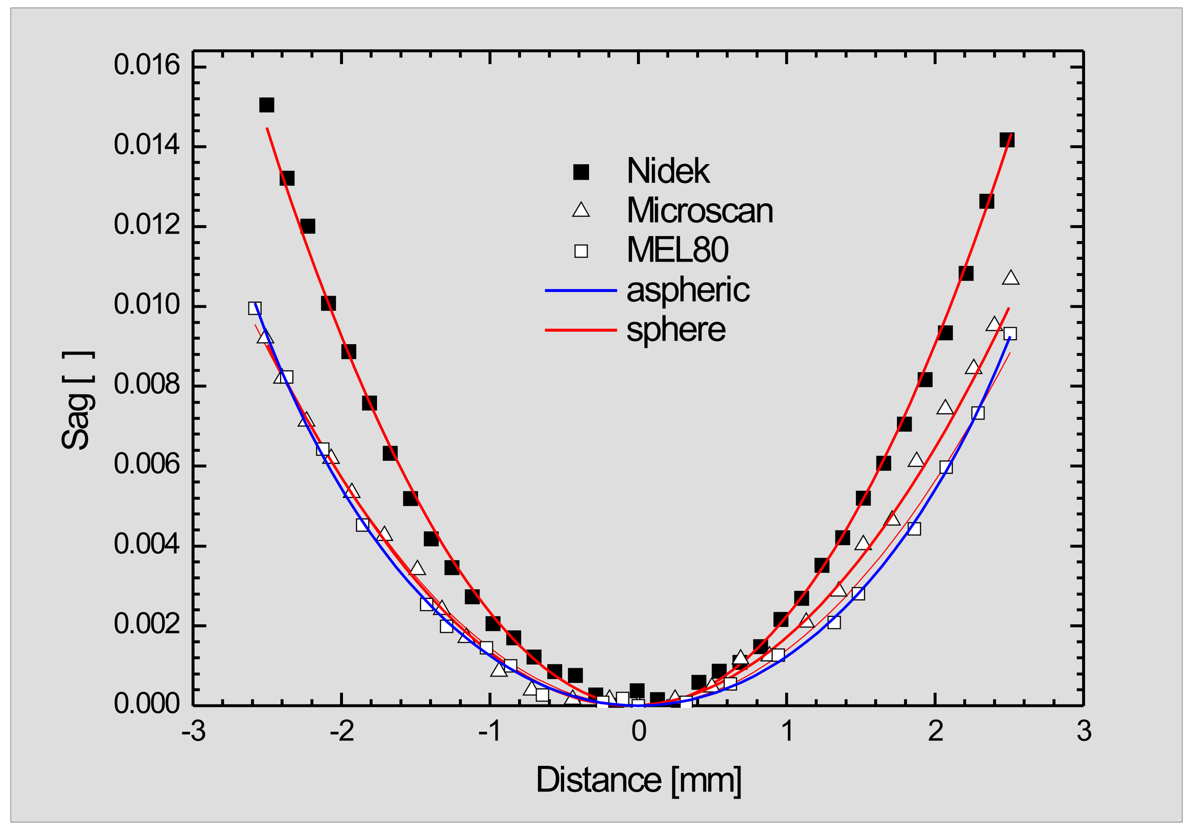

Fig.2 Ablation profile for MEL80, Microscan2000 and Nidek Ec5000

The curve is calculated in assumption of initial spherical profile of the cornea and its radius of 7.8mm.

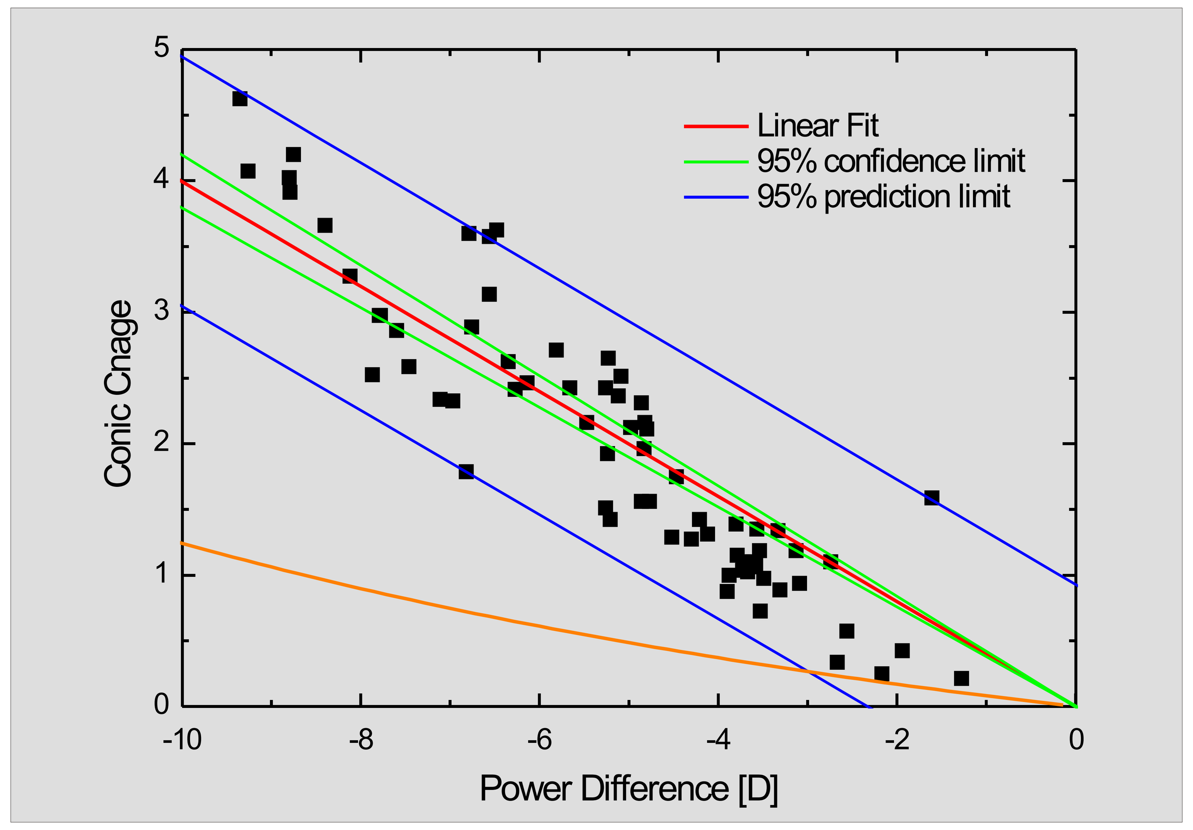

Fig.3 Conic change vs corneal power difference.

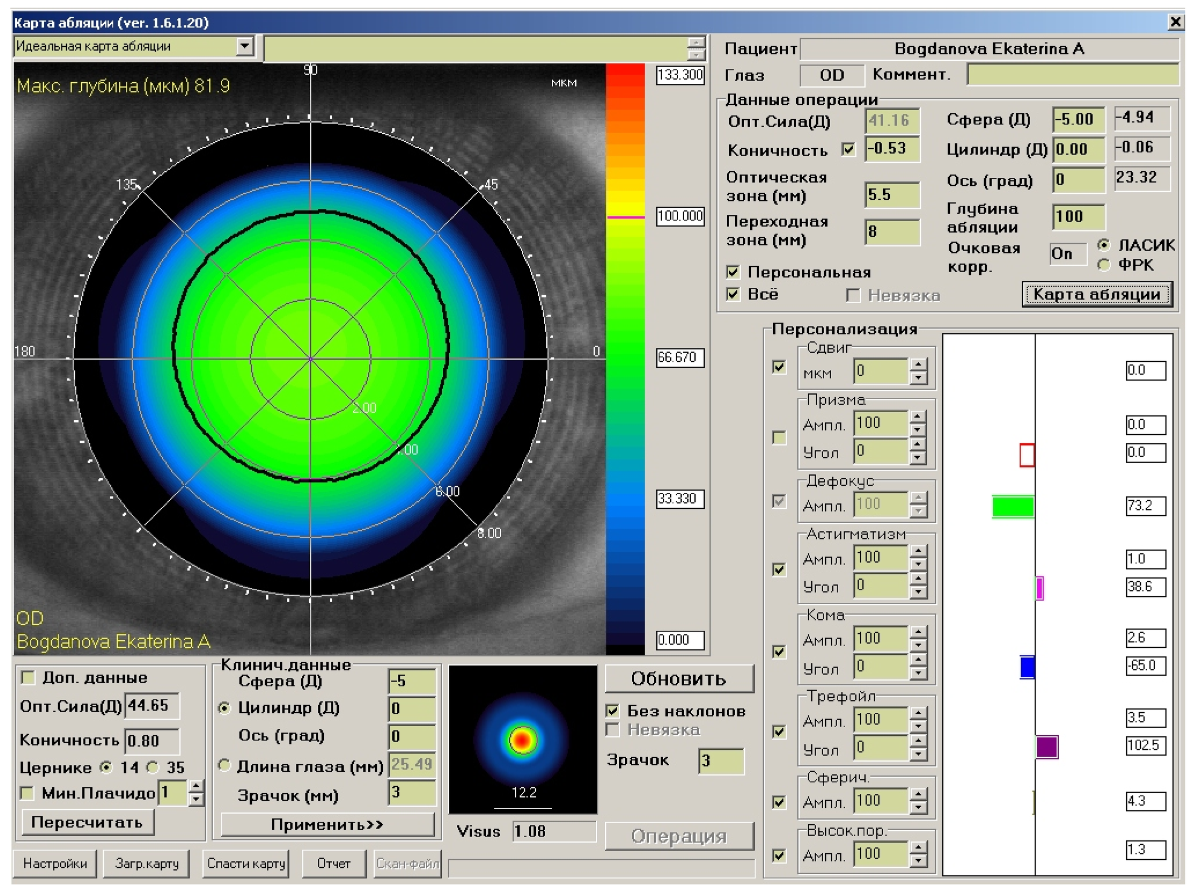

Fig.4. Screen shot of the custom ablation software

As it can be seen from the Fig. 3 there is a noticeable increase in conic constant after myopic correction. Though a certain improvement may be gathered with application of angle-of-incidence correction the results still will be too far from the desired conics (0 to -1 range). In some cases, there are a possibility to improve the conic correction with the help of custom ablation software. One example of such software is a custom ablation program from MSU, adopted for control of Microscan-2000 laser. In this software there is a possibility to vary independently several Zernike terms including one for spherical aberration (the screen shot of the program is shown on Fig.4). Converting the conic change to induced spherical aberration and entering the corresponding correction into Zernike term it's possible to achieve a conic correction. The results of application of such a procedure are illustrated on Fig.5. 10 patients (20 eyes) participated in this study. The selection criteria and data processing technique were the similar to described above.

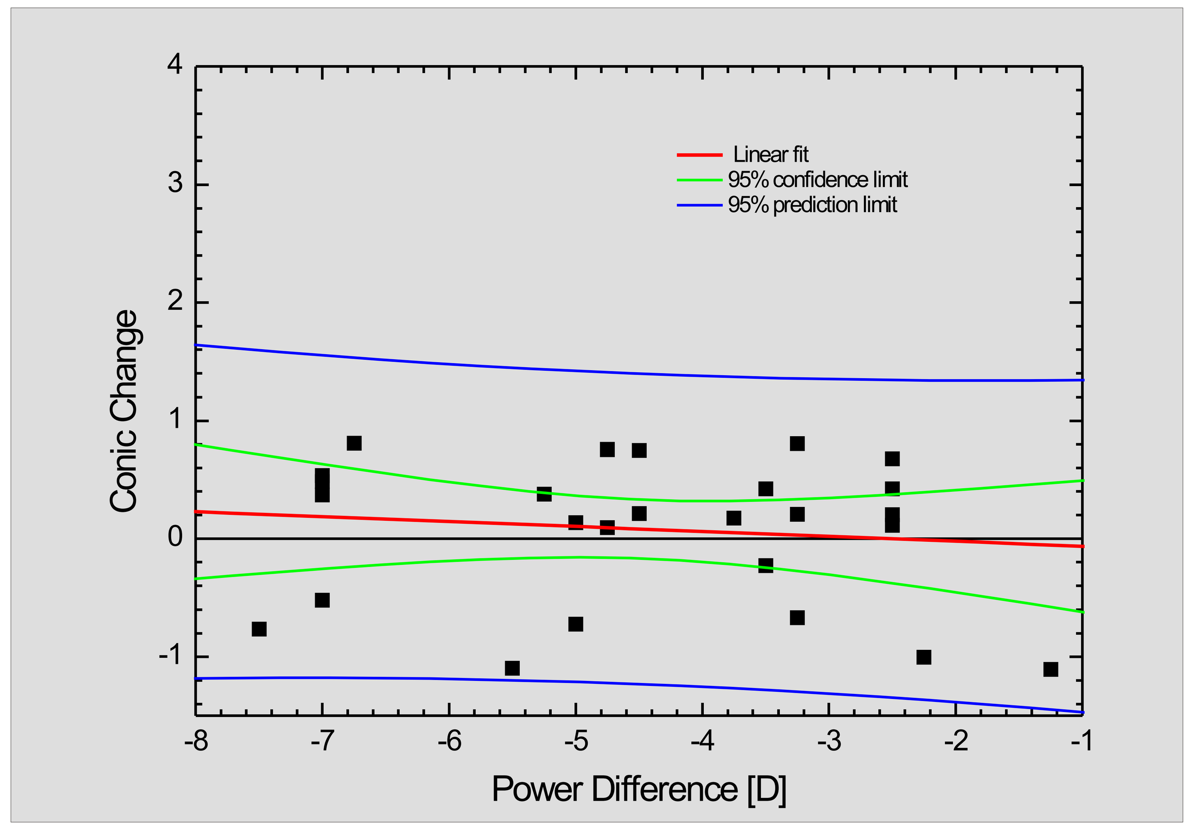

Fig.5 Conic change vs corneal power difference.

Discussion:

On the basics of the carried out research the following conclusions can be formulated:

- Resent ablation algorithms perform spherical or aspherical ablation, not parabolic approximation of Mynnerlin formula;
- With spherical ablation profile there is a significant conic change for myopic correction. This change is higher than theoretical prediction;
- Custom ablation software may improve conic correction by varying spherical aberration content in ablation profile;
- Respectively high variations in experimental data may indicate a necessity of multi- parametric analyzes of the data.

Literature:

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3.J. R. Jime´nez, R. G. Anera, L. Jime´nez del Barco, and E.Hita, "Effect on laser-ablation algorithms of reflection losses and nonnormal incidence on the anterior cornea," Appl. Phys. Lett. 81, 1521–1523 (2002).