Analysis of Wavefront and Corneal Topography Changes Caused by Laser Refractive Surgery

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Purpose

Laser ablation of the cornea has proven successful in most refractive treatments.

However, the technique still produces some unintended side effects, including induced low- and high-order aberrations. To analyze induced aberrations it is necessary to compare the intended ablation to the actual corneal changes. To perform this analysis, corneal topography measurements have to be taken before and after the surgery. In this study we compared the measured changes in corneal topography with measured changes in the wavefront of the eye. The goal was to find out to what degree changes in corneal topography were responsible for changes in aberrations of the eye following LASIK treatment.

Methods

We performed a statistical analysis based on the following two sets of clinical data, which included pre- and post-operative wavefront and topography measurements:

1. USIDE low-to-moderate myopia data from the CustomVue clinical study: topography data were measured with a Humphrey Atlas Corneal Topography System Model 991.
2. Data set from a commercial site: corneal topography data were measured with a Pentacam topographer.

The data set from the commercial site was smaller, but the measurements were better quality. The Pentacam topographer provided full coverage of the measured area, whereas pieces are missing from the Humphrey topographer's measured fields. Also, the treatments performed at the commercial site employed eye registration, which made the results more accurate.

All topography measurements were exported in text files for loading into Matlab data processing software for subsequent data analysis.

Methods *(continued)*

Pre-operative wavefront and corneal topography measurements for each eye were mandatory for inclusion.

Post-operative measurements were performed for each eye on one or more of the following time points: 1 day, 1 week, 1 month, 3 months, 6 months, 9 months, and 12 months.

In most cases the wavefront measurement was repeated several times for each eye and time point. We used average Zernike coefficients for our analysis.

In our analysis we used only records with wavefront diameter ≥ 6mm.

The distribution of available usable records is shown in Table 1.

USIDE	WF	Topo
Pre-op	271	126
1D	100	1
1W	121	3
1M	212	86
3M	237	75
6M	174	81
9M	63	50
12M	67	36
Total	1245	458

Dr. Stevens	WF	Topo
Pre-op	73	132
1D	0	0
1W	0	0
1M	18	14
3M	23	34
6M	21	15
9M	4	4
12M	2	2
Total	141	201

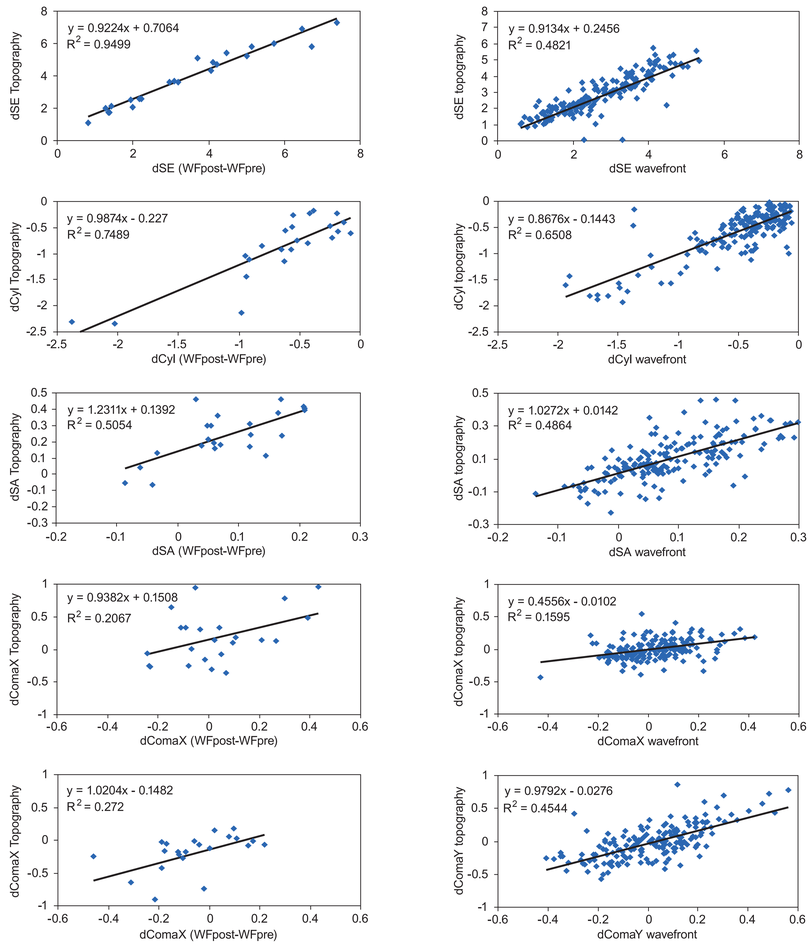
Table 1. Distribution of available records with wavefront diameter ≥ 6mm.

Actual ablation measurements were obtained using paired pre- and post-operative corneal topography. The actual ablations were compared with the intended ablations, which were computed from pre-operative wavefront measurements of the same eye. They were also compared with the paired pre- and post-operative wavefronts.

The most noticeable post-operative induced aberrations are spherical aberration (SA) and coma (x component, CMX; and y component, CMY). Therefore, we decomposed both wavefront and topography measurements into Zernike series and used the values of SE, cylinder, SA, CMX, and CMY for comparison metrics.

Results

The topography and wavefront changes in SE, cylinder, spherical aberration, and coma appeared to be well correlated (see Fig. 1). From these correlations we can conclude that changes in the anterior corneal surface are the primary source of post-operative aberrations.



A – data from a commercial site (23 records)

B – USIDE clinical trial data (173 records)

Figure 1. Changes in SE, cylinder, spherical aberration (dSA) and X,Y components of coma (dCMX, dCMY) for the corneal anterior surface (Topography) vs. wavefront (WFpost–WFpre) for a 6mm diameter optical zone and time points from 1M to 9M.

Discussion

A solid correlation appears to exist between aberration changes on the anterior surface of the cornea and the wavefront change caused by laser ablation.

A less pronounced correlation, and a trend slope just about 0.5 for USIDE X-coma, might be caused by the different centering of the wavefront and topography measurements. Wavefront is measured relative to the center of the pupil; corneal topography measurements are centered relative to the vertex of the eye, which is positioned nasally to the center of the pupil.

Another cause for the different trend slope of the X-coma could be the absence of eye registration in the USIDE studies. The commercial site data, where eye registration was applied, show a trend slope much closer to 1.

There may be other reasons for post-operative changes in the optical properties of these eyes, including bio-mechanical effects, the healing process, etc. However, these results show that changes in the anterior corneal surface have the greatest effect both on refraction (SE and cylinder) and on the largest high-order aberrations—spherical aberration and coma. Post-operative changes in the interior structure of the eye (if any) do not affect these optical properties.

Conclusions

Post-operative induced aberrations arise mostly from the changes in the anterior corneal surface.

References

1. Anatoly Fabrikant: Polynomial Approximation of Corneal Topography for LASIK Patients, Presented at the Eighth International Wavefront Congress, Vancouver, Canada, February, 2011.

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