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Utilization of the excimer laser and a moving piezoelectric mirror to accomplish the customized contact lens ablation to correct high-order aberrations

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ABSTRACT

The use of the Hartman-Shack sensor in ophthalmology allowed the identification of higher-order aberrations, which make possible the search for methods to correct them. Customized refractive surgery is one of the most successful methods, although there are patients which cannot be submitted to this surgery due to a variety of abnormal limiting factors such as cornea thickness and quantity of higher-order aberrations. Being this an irreversible process, the alternative is to develop a non-surgical method. This work proposes a method to obtain personalized contact lenses to correct high-order aberrations via the development of a customized ablation system using an excimer laser and a moving piezoelectric mirror. The process to produce such lenses consists of four steps. 1) The map of total aberrations of the patient's eye is measured by using an aberrometer with a Hartman-Shack sensor. 2) The measured aberration map is used to determine the maps for correction and related distribution of laser pulses for the ablation process with the excimer laser. 3) The lens production is performed following the same principle as customized refractive surgery. 4) The quality control of the lens is evaluated by two tests. 4.1) The lens is measured by a non-commercial lensometer, which is assembled specially for this measurement, as the ones commercially available are not capable of measuring asymmetric and irregular surfaces. 4.2) The evaluation of the lens-eye system is made using the aberrometer of the first step in order to verify the residual aberrations. Here, the lenses are ablated with a customized refractive surgery system.

Keywords: Hartman-Shack sensor, aberrometer, high-order aberrations, customized contact lens, lensometer

1. INTRODUCTION

Nowadays, most of the types of conventional glasses and contact lenses only correct two basic types of aberrations, defocus and astigmatism. A conventional contact lens in an eye with high-order aberration can still allow some residual blurring of objects on the retina (Figure 1A). The use of Hartman-Shack sensor in ophthalmology allowed the identification of higher-order aberrations [1], which make possible the research for methods to correct them [2-6]. The most successful method is laser refractive surgery. But not everybody may benefit from this method due to a variety of abnormal limiting factors such as cornea thickness and quantity of higher-order aberrations. So, a more practical correction could be achieved with customized contact lenses (Figure 1B). This method is based on the idea that a contact lens of variable thickness could be fitted to the patient's eye so that the wavefront deviation may be corrected by the local lens thickness. Therefore, the aberrated wavefront produced by the lens would be transformed into a perfect wavefront yielding a perfect image on the retina.

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Then, the purpose of this work is the development of a method to obtain personalized contact lenses to correct high-order aberrations via the development of a customized ablation system. Such an experimental ablation system comprises an excimer laser and a moving piezoelectric mirror (Figure 2) imitating the features of typical personalized refractive surgery systems. The complete ablation of a lens (step 3 of Figure 2) requires implementing the automation of the experimental system, which is in the development stage (preliminary results are described in De Matos et al. [7] and De Matos [8]). Thus, the results of the complete ablation of lenses presented below were obtained by using a commercial refractive surgery system (see Figure 3).

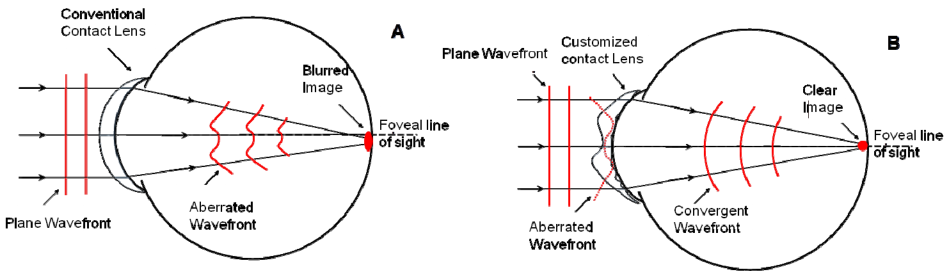

Figure 1: An eye with high-order aberration corrected by: (A) Conventional Contact lens, (B) Customized contact lens. It is noted that in case B the higher-order aberrations were corrected successfully.

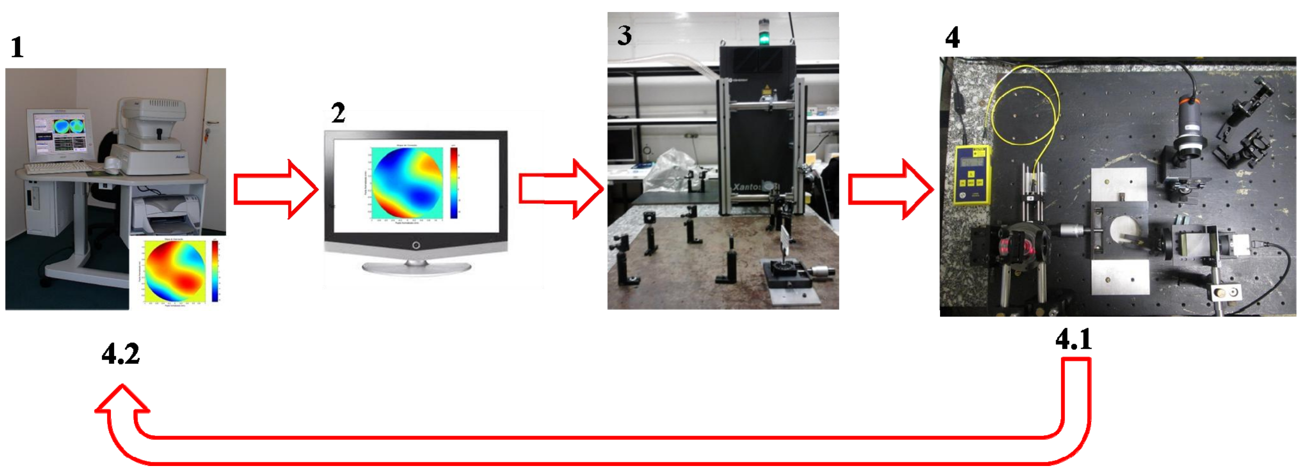

Figure 2: Flow chart of customized ablation of contact lenses. 1- Aberrometer, 2- The correction map related to the measured aberration data, 3- Experimental ablation process, 4.1- Lensometer to measure the ablated lens, 4.2- Measurement of the eye-lens system.

2. METHODOLOGY

The methodology employed in this study involved several steps (Figure 3). First, the eyes of a patient volunteer were examined by a keratometer (Table 1). Second, with these measurements, some soft contact lenses with special ticknesses were produced by Solótica (São Paulo, Brazil) using a Computer Numerical Control (CNC) machine (DAC Vision, USA). The characteristics of these contact lenses are in Table 2, and the prescription of lenses produced are in Table 3. In the third step, the lenses were measured in the pre-ablation stage using a non-commercial lensometer which was assembled specially for this experiment for later comparison with measures of the post-ablation stage. In the fourth step, the ablation of the contact lens was carried out with a commercial system that performs refractive surgery (Wavelight ®

EX500 Excimer Laser) at Refractive Surgery Clinic, School of Medicine, Federal University of Sao Paulo, Brazil. The lenses were fixed in a plastic holder and a ring of plastic material. During the ablation the system for remote monitoring of eye movement (eye tracker) was disabled. Ablation applied -1 D to all lenses in the anterior surface, except one that ablation was performed on the posterior surface of the lens. In this case, it was evaluated whether the tear film would act on the peaks and valleys of the ablated surface so polishing the lenses will not be needed. The fifth step is the post-ablation measurement of the lenses in the lensometer. Finally, in the sixth step the lenses were tested on the patient, and tests were performed to assess whether there was an improvement in visual quality.

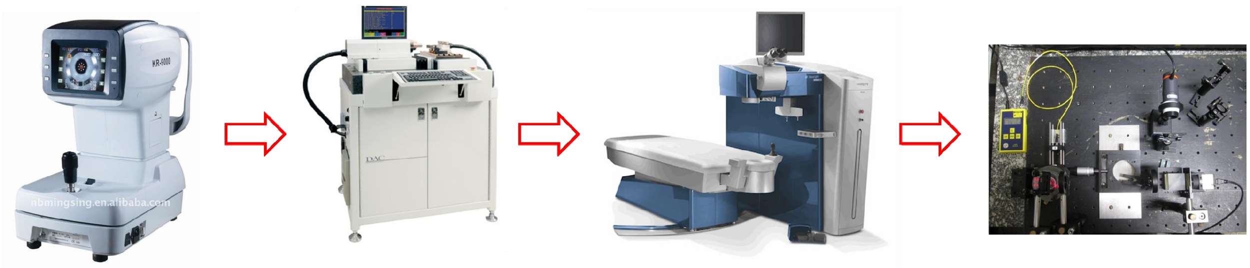

Figure 3: Flow chart to ablation of contact lenses via system of refractive surgery. 1- keratometer, 2- CNC Machine of DAC, 3 – commercial system of laser refractive surgery, 4 - lensometer.

Table 1: Refraction and keratometry in both eyes of the patient volunteer

Eyes	Refraction	keratometry
OD	-1.00 D	45.30 D @ 84.00^o 44.82 D @174.00^o
OE	-1.00 D	45.60 D @ 76.00^o 45.18 D @ 166.00^o

Table 2: Characteristics of contact lenses used in the study

Characteristics of lenses	Lens 1	Lenses: 2, 3, 4, 5
Water (%)	49	38
Dk (35^{o}C, Fatt)	15	9
Dry Refractive Index	1.507	1.520
Hydrated Refractive Index (35^{o}C)	1.425	1.442
Linear Expansion (mm)	1.300	1.205
Radial Expansion (mm)	1.300	1.205
Hardness (Shore D)	90	89
% Transmission (@600 nm)	>95	>95

Table 3: Prescription lenses made by the company

Lenses	Refractive Power	Base Curve (mm)	Diameter (mm)
1	-10.00	8.6	14.2
2	-00.00	8.5	15
3	-00.00	8.5	13.5
4	0.6;+2.25	-	-
5	0.6;+2.75	-	-

2.1 Quantitative measures via non-commercial lensometer

Quantitative measures of pre- and post-ablation lenses were made by an instrument assembled especially for this experiment (Figure 4) to assess higher-order aberrations generated by the irregular surface of soft contact lenses [8].

The instrument works as follows: the lens is placed in an acrylic cell with the concave side down and dipped in saline solution to keep it wet. A collimated beam from the laser diode ($\lambda = 635\ nm$, Oz Optics Limited) passes through the lens to reach the CCD camera with Hartmann-Shack sensor (WFS150-7AR, Thorlabs GmbH). A second CCD camera pupil (Celestron) is used to film the lens and thus verify the correct alignment and centering of the lens. The data measured by the sensor is processed by the software that calculates the Zernike coefficients. This software generates various graphs showing the map of aberration generated in the contact lens.

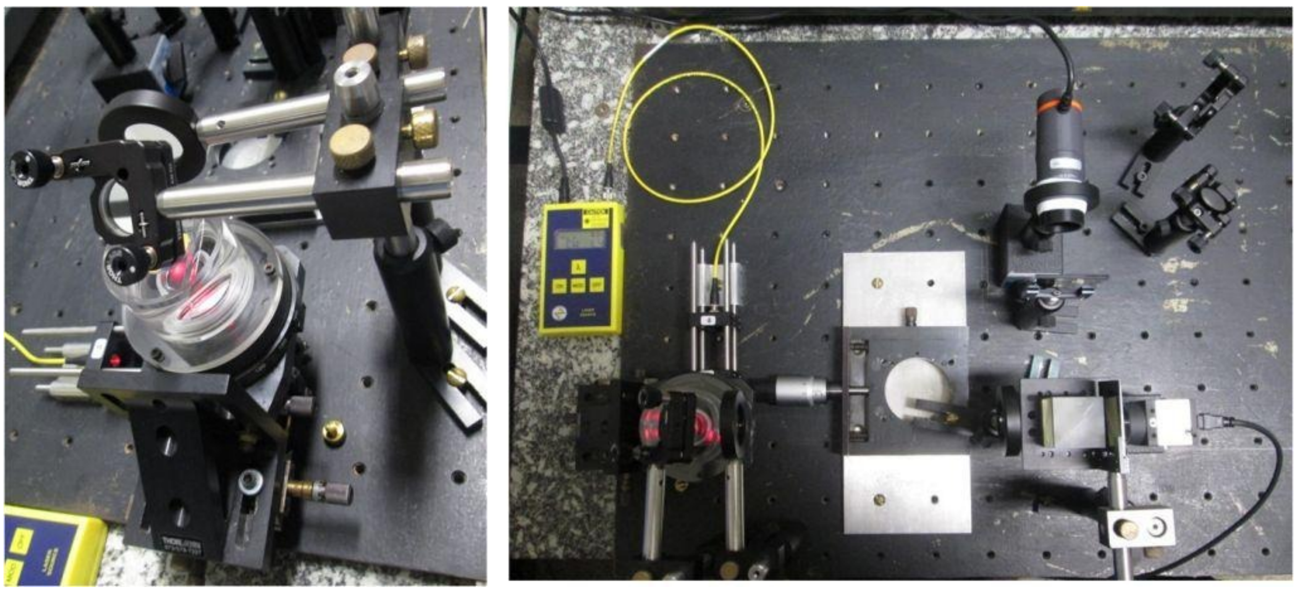

Figure 4: Lensometer built in bench. Left: View of the wet cell supporting the lens. The red spot is the diode laser that passes through the lens inside the cell immersed in saline solution, the laser beam reaches another mirror (on the cell) to direct it to the camera with the Hartmann-Shack sensor. Right: Top view of the complete lensometer.

3. RESULTS AND DISCUSSION

Soft contact lenses dry out easily in the absence of moisture, so it is necessary to measure them immersed in a solution to prevent dehydration and deformation of its surface. This ensures that the lens is in a state similar to that in the eye in its relaxed state and that it will not suffer surface irregularities. However, the wavefront aberration measurements of this lens immersed in solution are smaller than those taken on the air. This happens simply because of the difference in refractive index between the lens material and the solution (n_{medium}) being less than that between the lens material and air (n_{lens}). Thus, it is necessary to calculate a conversion factor (CF) to recalculate the measurements of contact lens aberrations. We used the equation 1, calculated by Jeong et al. [9]:

$$CF = \frac{n_{lens} - 1}{n_{lens} - n_{medium}} \quad (1)$$

With this expression, the wavefront aberrations of soft contact lenses in the air were recalculated using the measurements of aberrations carried out in a medium of sodium chloride 0.9%. The refractive indices used in the calculation are shown in Table 2. Conversion factor was 4,570 for lens 1 and 4.018 for the other lenses.

Each contact lens received a small mark on the rim to ensure the same position pre-and post-ablation. Five measures of each contact lens were taken and mean values and standard deviations were calculated. The CF of each lens was multiplied by the corresponding mean values. The maps and bar graphs pre-and post-ablation aberration are shown in Figures 5-9.

The lenses were tested on the patient and showed the following results: a lens that was ablated on the posterior surface (see Figure 5) completely corrected the aberration, while the lens ablated on the anterior surface did not corrected it and the patient complained of blurred vision. Thus, as we expected, the tear film nullified defects arising from ablation.

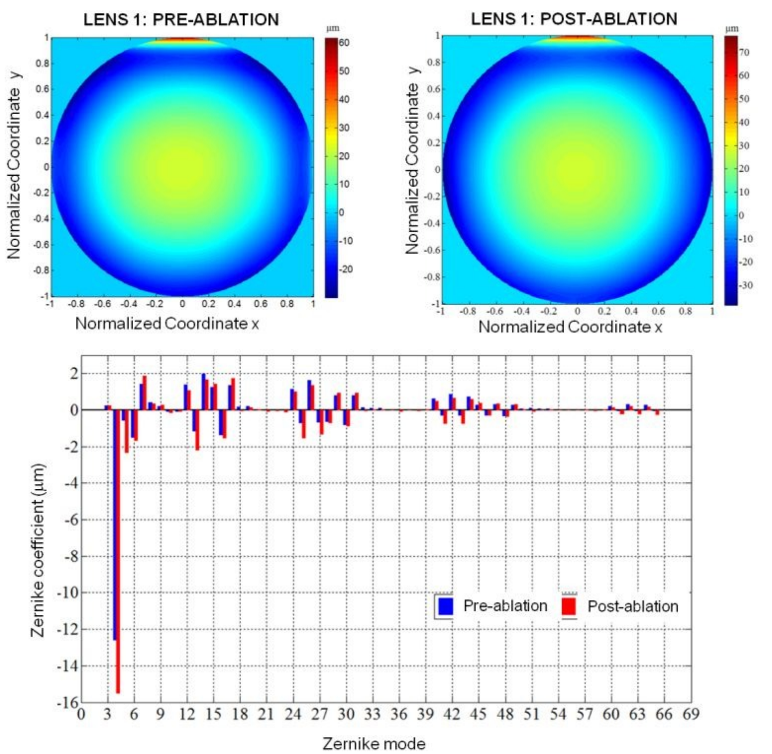

Figure 5: Maps of wavefronts of the lens 1, showing the measure pre-ablation (top left) and post-ablation (top right). Bar graphs (down) showing difference between the pre- and post-ablation.

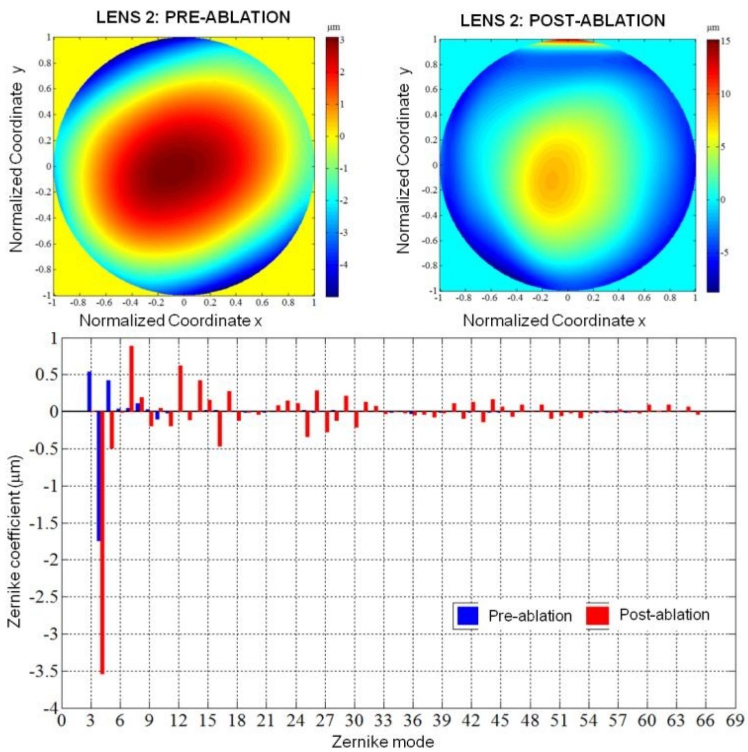

Figure 6: Maps of wavefronts of the lens 2 (ablation realized in back surface of lens), showing the measure pre-ablation (top left) and post-ablation (top right). Bar graphs (down) showing difference between the pre- and post-ablation.

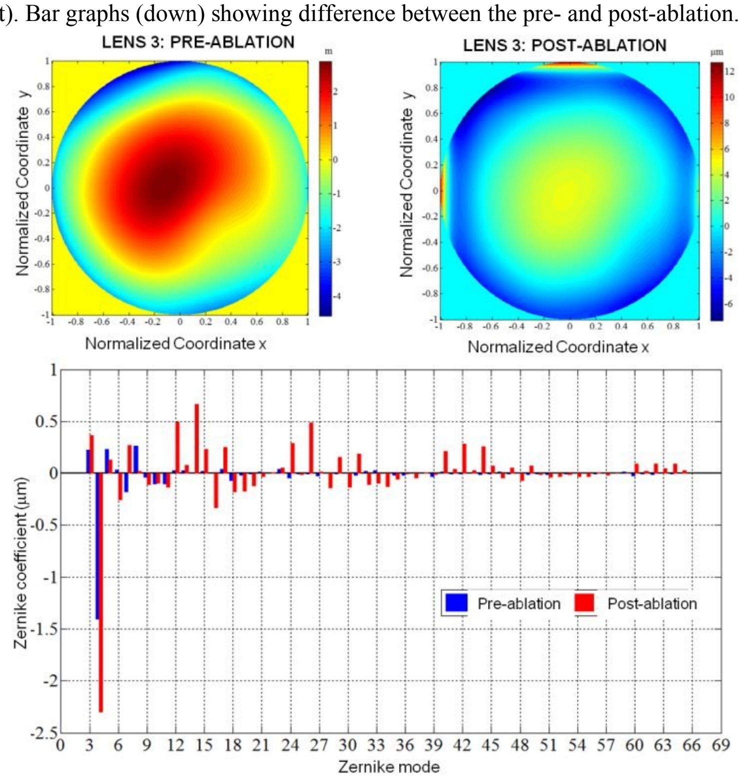

Figure 7: Maps of wavefronts of the lens 3 (ablation realized in anterior surface of lens), showing the measure pre-ablation (top left) and post-ablation (top right). Bar graphs (down) showing difference between the pre- and post-ablation.

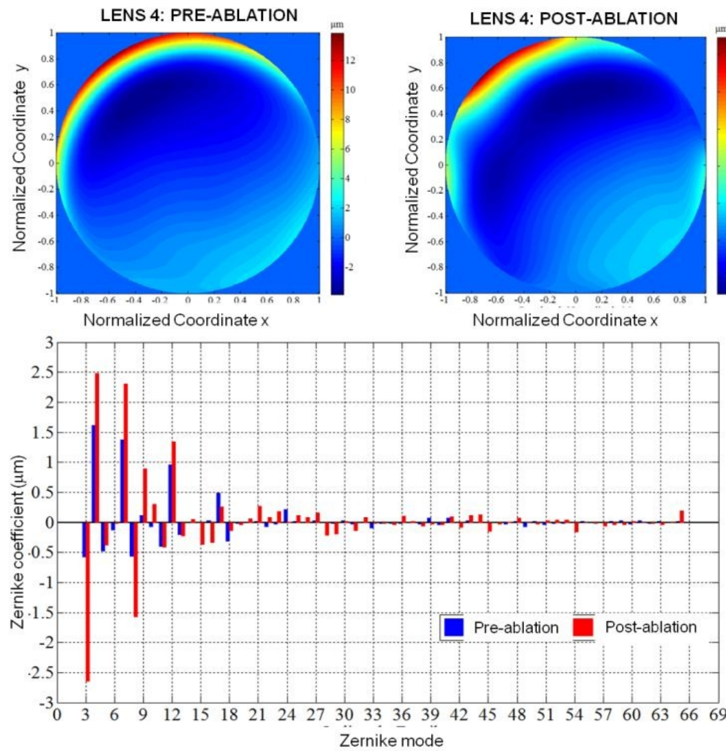

Figure 8: Maps of wavefronts of the lens 4, showing the measure pre-ablation (top left) and post-ablation (top right). Bar graphs (down) showing difference between the pre- and post-ablation.

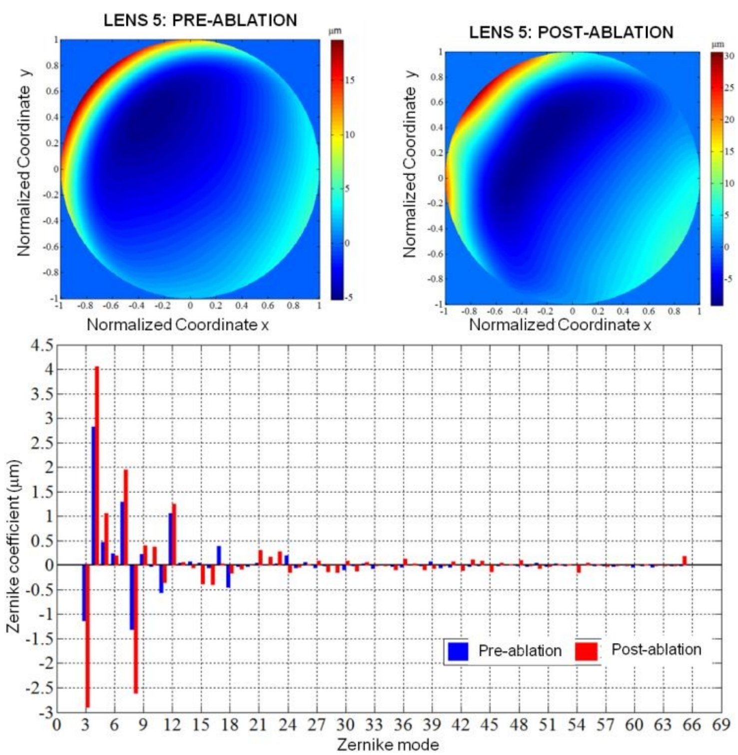

Figure 9: Maps of wavefronts of the lens 5, showing the measure pre-ablation (top left) and post-ablation (top right). Bar graphs (down) showing difference between the pre- and post-ablation.

4. CONCLUSIONS

This paper presents results of production of customized contact lens by commercial system laser refractive surgery. Four lenses (1, 3, 4 and 5) were ablated in the anterior surface and one was ablated in the back surface of lens 2. The results showed that the lenses ablated in the anterior surface corrected the refractive errors, but the patient complained of blurred vision partially. Whereas the lens ablated in the back surface corrected all the refractive error of the patient and there were no complaints of blurred vision. One explanation for this is that the tear film would solve the problem of the need for polishing.

The results obtained in this study are very important for the implementation of the automation of the experimental system.

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