# Tissue-Saving Zernike Terms Selection in Customized Treatments for Refractive Surgery

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## ABSTRACT

**PURPOSE:** To study the possibility of performing customized refractive surgery minimising the amount of ablated tissue without compromising visual quality.

**METHODS:** A new algorithm for the selection of an optimized set of Zernike terms in customized treatments for laser corneal refractive surgery was developed. Its tissue saving attributes have been simulated on 100 different wave aberrations at 6mm diameter. Outcomes were evaluated in terms of how much depth and volume was saved for each condition (in micrometers and in percentage), whether the proposed correction consists of either a full wavefront correction or an aberration-free treatment, and whether the proposed depth or volume was less than the one required for the equivalent aberration-free treatment.

**RESULTS:** Simulated outcomes showed an average saved depth of 5µm (0-16µm), and an average saved volume of 95µl (0-127µl) or 11% saved tissue (0-66% saved tissue). Proposed corrections were always less deep than full wavefront corrections and in 59% of the cases were less deep than equivalent aberration-free treatments.

**CONCLUSIONS:** Even though Zernike modes decomposition is a mathematical description of the aberration, it is not the aberration itself. Not all Zernike modes affect the optical quality in the same way. The eye does not see through Zernike decomposition but with its own aberration pattern. However, it seems feasible to efficiently perform laser corneal refractive surgery in a customized form minimising the amount of ablated tissue without compromising the visual quality. Further clinical evaluations on human eyes are needed to confirm the preliminary simulated results presented herein.
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**KEY WORDS:** refractive surgery; visual quality; Zernike; tissue saving; wavefront; aberrations; depth; volume; time; aberration-free; free of aberrations; diffraction limited.


## RESUMEN

**OBJETIVO:** Estudiar la posibilidad de realizar tratamientos personalizados de cirugía refractiva donde se minimice la cantidad de tejido ablacionado sin que por ello se vea afectada la calidad visual.

**MÉTODOS:** Se ha desarrollado un nuevo algoritmo para seleccionar un conjunto optimizado de términos de Zernike para su aplicación en tratamientos personalizados de cirugía refractiva corneal. Para 100 mapas de aberración de onda corneal (para un tamaño de pupila de 6 mm de diámetro), se ha simulado la capacidad de dicho algoritmo para preservar tejido corneal. El resultado de dicha simulación se ha analizado en función de cuanto espesor (en micras) o de cuanto volumen (en %) se preserva en cada situación (respecto a otra situación de referencia): si la corrección propuesta logra corregir todo el frente de onda o sólo las aberraciones de segundo orden, y si el espesor o el volumen que hay que ablacionar con esta configuración es menor que para un tratamiento estándar equivalente, donde se traten de corregir únicamente las aberraciones de segundo orden.

**RESULTADOS:** Las simulaciones arrojaron un "ahorro" promedio de tejido ablacionado igual a 5 µm en términos de espesor máximo que se ha de ablacionar (rango: 0-16 µm), igual a 95 µl en términos de volumen (rango: 0-127 µl); esto es, se preserva un 11% del tejido (rango: 0-66%) respecto al tratamiento de referencia. Las correcciones propuestas siempre requerían espesores ablacionados menores que los patrones diseñados para corregir todo el frente de onda, y en el 59% de los casos requerían incluso un espesor menor que los tratamientos estándar (aquellos en los que se pretende corregir únicamente las aberraciones de segundo orden).

**CONCLUSIONES:** A pesar de que la descomposición en modos de Zernike es una descripción matemática de un patrón de aberración dado, no se corresponde exactamente con dicha aberración. No todos los modos de Zernike tienen el mismo efecto sobre la calidad óptica. El ojo no percibe su entorno "a través de" una descomposición en modos de Zernike de la aberración de onda, sino que se ve afectado por todo su propio patrón de aberración, de manera conjunta. Sin embargo, parece factible el llevar a cabo de manera eficiente tratamientos personalizados de cirugía refractiva corneal donde se minimice la cantidad de tejido ablacionado sin que por ello se vea afectada la calidad visual.
Es necesario hacer más estudios en ojos humanos reales para poder confirmar los resultados preliminares de las simulaciones que aquí se presentan.
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**PALABRAS CLAVE:** cirugía refractiva; calidad visual; Zernike; preservación de tejido; frente de onda, aberraciones; espesor; volumen; tiempo; sin aberraciones (de segundo orden); libre de aberraciones (de segundo orden); limitado por difracción.

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## INTRODUCTION

With the introduction of laser technology for refractive surgery, the procedure of changing the curvature of the cornea in a controlled manner[1] to compensate for refractive errors of the eye is nowadays more accurate than ever. However, the quality of vision still deteriorates significantly, especially under mesopic and low-contrast conditions.[2]

With the LASIK (laser in-situ keratomileusis)[3] treatment, we have an accepted method for correcting refractive errors such as myopia,[4] hyperopia,[5] and astigmatism.[6] One of the most significant side effects in myopic LASIK is the induction of spherical aberration,[7] which causes halos, and a reduction of contrast sensitivity.[2]

Although the optical quality of the eye can be described in terms of the aberration of its wavefront, it was observed that the subjects with minor aberrations in their wavefront did not always achieve the best scores in visual-quality tests.[8] Thus, the optical quality of the human eye does not determine in a one-to-one way its visual quality.

However, the induction of aberrations, such as spherical aberrations and coma, has been related to a loss of visual acuity.[9] Finally, the concept of neural compensation suggests that the neural visual system is adapted to the eye's own aberration pattern. A study by Artal et al.[10] on the effects that this neural compensation causes on the visual function indicates that the visual quality we have is somewhat superior to the optical quality that our eye provides.

To avoid inducing aberrations, as well as to eliminate the existing aberrations, "customized" treatments were developed. Customization of the ablation procedure is possible, either using wavefront measurements of the whole eye[11] (obtained, e.g., by means of Hartman-Shack wavefront sensors) or by using corneal topography-derived wavefront analyses.[12,13] Topography-guided,[14] wavefront-guided,[15] wavefront-optimized,[16] asphericity-preserving, and Q-factor profiles[17] have all been put forward as solutions. Considerations such as the duration of the treatment, removal[18] and remodelling of tissue, and, in general, the overall surgical outcome have made it difficult to establish a universal optimum profile. These considerations are interrelated in a multifactorial way, and may lead to clinical problems as corneal dehydration, ectasia or regression.

The development of new algorithms or ablation strategies for performing laser corneal refractive surgery in a customized form minimising the amount of ablated tissue without compromising the visual quality becomes an important challenge.

The availability of such profiles, potentially maximising visual performance without increasing the risk factors, would be of great value for the refractive surgery community and, ultimately, for the patients' health and safety. Therefore, the topic "Optimized Zernike Term Selection in customized treatments for laser corneal refractive surgery" (OZTS) is worth to be analysed, because its clinical implications are not yet deeply explored.

The real impact of tissue-saving algorithms in customized treatments is still discussed in a controversial way. The problem of minimising the amount of tissue that is removed is that it must be done in such a way that: a) does not compromise the refractive correction; b) does not compromise visual performance; c) is safe, reliable and reproducible.

The goal of this study is to describe in detail the theoretical framework, explaining a possible method of tissue-saving optimisation and exploring its tissue-saving capabilities.

## Patients and Materials

To simulate the tissue-saving capabilities of such methods for minimising the required amount of ablated tissue, the complete records (together with their clinical data) corresponding to one-hundred eyes of fifty-five patients (39 (71%) male and 16 (29%) female) from the Augenzentrum Recklinghausen (Germany) were selected to be included in our simulation experiment. Fifty-five were right eyes (55%), and forty-five were left eyes (45%).

The mean age was 32±8 years (ranging from 19 to 54). The spherical equivalent (SE) was  1.60 D with a standard deviation (SD) of 3.44 D (range  9.75 to +7.50 D), with a mean sphere of -0.85±3.08 D (SD) (range  8.25 to +7.50 D), the mean cylinder was  1.51±1.42 D (SD) (range 5.75 to 0.00 D).

Using the Keratron-Scout videokeratoscope[19] (Optikon 2000, Rome, Italy), corneal wave aberrations were analysed up to the 7th Zernike order. Optical errors are described by means of the weight coefficients of the Zernike polynomials,[20] following the standards of the Optical society of America (OSA).[21]

For the purpose of the present work, SciLab™ was used for performing calculations and running the simulations, Microsoft™ Excel for plotting graphs, and Delphi's programming language was used for implementing the modules in the Optimized Refractive Keratectomy (ORK) and the Custom Ablation Manager (CAM). To simulate the tissue-saving capabilities of such algorithms for minimising the required amount of ablated tissue, the CAM module with a newly implemented Optimized Zernike Terms Selection (OZTS) was used.

## Methods

In our study, the quadratic equivalent of a wave-aberration map was used as a relationship between wavefront-error magnitudes and classical ametropias *(Appendix 1).*That quadratic is a sphero-cylindrical surface, which approximates the wave aberration map. The idea of approximating an arbitrary surface with a quadratic equivalent is a simple extension of the ophthalmic technique of approximating a sphero-cylindrical surface with an equivalent sphere.

For this study, a variation of the objective wavefront refraction from low-order Zernike modes at a fixed subpupil diameter of 4 mm was chosen as starting point to objectively include the measured subjective manifest refraction in the wave aberration *(Appendix 2).*

The expected optical impact of high-order aberrations in the refraction is calculated and modified from the input manifest refraction. The same wave aberration is analysed for two different diameters: for the full wavefront area (6 mm in this study) and for a fixed subpupil diameter of 4 mm. The difference in refraction obtained for each of the two diameters corresponds to the manifest refraction associated to the high-order aberrations.

The condition is to re-obtain the input manifest refraction for the subpupil diameter of 4 mm. This way, the low-order parabolic terms of the modified wave aberration for the full wavefront area can be determined. An explanation of this Automatic Refraction Balance concept is provided in *figure 1.*

*Figures 2* and *3* show examples of how the automatic manifest refraction balance algorithm works.