Proposal for a new approach to corneal biomechanics: dynamic corneal topography

Proposta de uma nova abordagem da biomecânica corneana: topografia dinâmica de córnea

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ABSTRACT

Purpose: To establish the literature basis that could support the idea that it would be possible to analyze changes at the anterior surface of the cornea induced by an air jet applied onto the eye. **Methods:** The PUBMED/MEDLINE literature basis regarding the following subjects was searched: videokeratography, high-speed photography, ocular response analyzer (ORA). The information concerning the goal of this paper was selected. **Results:** The literature showed data that support the idea of gathering 3 nowadays available technologies that could result in a new concept of "dynamic corneal topography": the corneal topography, the air jet applied to histeresis measurement by the Ocular Response Analyzer® and the high-speed photography technique used to study the tear film and the anterior surface of the cornea. **Conclusion:** The literature basis supports the idea of gathering the existent technologies of corneal topography, the air jet of the corneal histeresis device and the high-speed photography to create a new concept in the analysis of the corneal surface: the dynamic corneal topography.

Keywords: Corneal topography/methods; Microscopy, video/methods; Biomechanics; Image processing, computer-assisted/methods; Diagnostic techniques, ophthalmological/methods; Refractive surgical procedures

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INTRODUCTION

What would result if, by gathering three different technologies, we could have a new way of assessing corneal biomechanics?

Today we have corneal topography as a static way of describing and measuring the curvatures of the anterior corneal surface. Despite being a good examination, it needs to be complemented by corneal tomography that also takes into account the corneal thickness and the evaluation of the anterior and posterior corneal elevations.

Another available examination today is corneal histeresis measurement done by the Ocular Response Analyzer® consisting of the measurement of the response of the cornea to an air jet, resulting in a graphic that can point out some pathologic corneal conditions like ectasias.

There is also a kind of high-speed photography technique used to study the tear film and the anterior surface of the cornea that can be associated with corneal topography.

However, these techniques together not evaluate corneal biomechanics.

If we had the possibility of assessing what happens to the anterior surface of the cornea when the eye is "kicked" with an air jet, we could theoretically have additional data that could contribute to a better understanding of the corneal biomechanics, possibly showing weak areas that could bulge on the corneal surface and would predict, for example, corneal ectasias.

The goal of this paper is to establish the literature basis that could support the idea that it would be possible with the current technology to analyze changes on the anterior surface of the cornea induced by an air jet applied onto the eye.

METHODS

The PUBMED literature basis was searched regarding videokeratography, high-speed photography and ocular response analyzer in the last five years, selecting the information concerning the goal of this paper.

After the choice of the main articles, their information was placed in the results section, with speculation about the possible associations that could be done between these current technologies aiming the goal of analyzing the changes of the anterior surface of the cornea induced by an air "kick" applied onto the eye.

RESULTS

Fifteen papers were found and twelve were selected because these were related to the goal of the present paper as shown below.

A high-speed videokeratoscope that can acquire data at the rate of 50 Hz was developed. There are two major applications of the technology. First, the analysis of tear film stability in the inter-blink interval and techniques for estimating the tear film build-up and break-up times. The second application involves the study of the dynamic response of the corneal anterior surface to mechanical forces exerted by the eyelids during horizontal eye movements in downward gaze[1].

The surface regularity and asymmetry indices, which are traditionally used to characterize the stability of precorneal tear film, have limitations in the context of high-speed videokeratoscopy because they are highly sensitive to natural ocular microfluctuations. To overcome this problem, a new microfluctuation-independent surface indicator was proposed. It is based on the root-mean-square (RMS) of the error of the parametric model fitting the surface. Further, techniques were developed for estimating the tear film build-up and break-up times. The tear film build-up time estimator is based on the proposed RMS fit surface indicator while the tear film break-up time estimator is derived directly from a set of consecutive HSV digital images, without the need for estimating the resulting corneal surface[2].

Aiming to investigate fluctuations in the ocular surface, high-speed videokeratoscopy (50 Hz) was used to measure the dynamics of the ocular surface topography. Ocular surface height difference maps were computed to illustrate the changes in the tear film in the inter-blink interval. Topography data were used to derive the ocular surface wavefront aberrations up to the fourth radial order of the Zernike polynomial expansion. The ocular surface dynamics and temporal changes in the ocular surface wavefront aberrations in the inter-blink interval were examined. It was observed that during the first 0.5 s following a blink, the ocular surface height at the upper edge of the topography map increased by about 2 µm and that temporal changes occurred for some ocular surface wavefront aberrations that could be related to changes in the distribution of the tear film. This is why in the clinical measurement of both ocular surface topography using videokeratoscopy and optics of the eye using wavefront sensors, care is necessary to avoid the initial tear film build-up phase following a blink in order to achieve more consistent results[3].

In healthy subjects the temporal changes in the optical quality of the air-tear film interface at the anterior cornea through corneal aberrations determinations were examined each second after a blink in the interval of 15 seconds. Total wavefront aberration decreased slightly with time after a blink reaching a minimum after approximately 6 seconds. Thereafter aberrations increased steadily, exceeding the immediate post-blink level after approximately 10 seconds. In normal subjects, the contribution of the anterior cornea to the overall ocular aberration remains reasonably stable over the normal inter-blink interval (approximately 4 seconds) but rises to levels which could perceptibly degrade retinal image quality under circumstances where the interblink interval is increased to exceed 10 seconds, as may occur during the use of visual display screens or when performing difficult tasks[4].

To achieve a brilliant beauty of the eye ("eye sparkling"), it is important that the tear film (aqueous layer) surface is smooth and stable with adequate tear volume and that the tear lipid layer is present in adequate thickness[5].

In physiologic conditions changes in intraocular pressure have no noticeable effect on image quality. This could be because the eye has a compensating mechanism to correct for any effect of ocular dynamics on corneal shape and refractive status. Such a mechanism may also affect the pattern of aberrations or it may be that aberrations alter in a way that offsets any potentially detrimental effects of intraocular pressure change on the retinal image. Variations in patterns of aberrations and how they may be related to ocular dynamics need to be investigated further before attempts at correction are made[6].

Optical aberrations and visual disturbances are associated with dry eye, although visual impairment is often not detected by conventional visual acuity testing. The newly developed functional visual acuity (FVA) device allows continuous dynamic evaluation of distance visual acuity and assessment of the effect of natural tear film status on dynamic visual function. Similarly, to detect corneal surface irregularities during sustained eye opening in dry eye subjects, a new tear stability analysis system (TSAS) has been developed. Both FVA and

72(2)13.pmd 265 14/4/2009, 11:39

TSAS measurement systems seem to be effective tools in the assessment of dynamic visual acuity changes in dry eye and normal subjects(7).

A system to measure the topography of the first optical surface of the human eye noninvasively by using a curvature sensor was described. The static corneal topography and the dynamic topography of the tear film can both be measured, and the topographies obtained are presented. The system makes possible the study of the dynamic aberrations introduced by the tear film to determine their contribution to the overall ocular aberrations in healthy eyes, eyes with corneal pathologies, and eyes wearing contact lenses(8).

The dynamic corneal imaging (DCI) method uses sagittal, stepwise, central indentation of the cornea with electronically controlled microprecision motors and sequential registration of videotopography images. The indentation steps are preselected and range from 50 to 800 µm. The computerized analysis of the videotopography images captured during the process uses Zernike polynomials to establish a newly defined flexing curve for normal eyes and eyes with abnormal findings. DCI was done in 187 eyes of 103 patients who had clinically healthy corneas, distinct keratoconus, or previous refractive surgery. The method rapidly evaluated artificially and reversibly induced changes in corneal topography in a clinical setting using a modified Placido disk-based computer-assisted videokeratography system with a small cone. In early analysis, the flexing curve showed a significant correlation with the applied indentation depth. Factors influencing the shape of the curve were central corneal thickness, intraocular pressure, and patient age. The DCI method also allowed easy examination of keratoconic corneas and corneas after refractive surgery(9).

The corneal hysteresis and corneal resistance factor values were significantly lower in keratoconic eyes than in post-LASIK eyes, when measured with the Reichert Ocular Response Analyzer (ORA). Future work is needed to determine whether these differences are useful in detecting keratoconus when other diagnostic tests are equivocal(10).

High-speed filming (100 frames per second) has been used to capture the natural blinking patterns of subjects(11).

Corneal hysteresis decreases following LASIK and LASEK. A similar reduction occurs following both procedures, indicating that LASIK involving a thin 120 µm flap did not induce additional biomechanical change. Postoperative reduction in hysteresis did not correlate with the amount or percentage of corneal tissue removed, nor with optical zone or patient age(12).

Data that could support the idea that it would be possible with the current technology to analyze changes inthe anterior surface of the cornea induced by an air "kick" applied to the eye were found in the literature basis. The fast air jet ("kick") could be applied by the corneal hysteresis equipment onto the eye(10,12), pushing the air onto the sclera or even onto the cornea, depending on the convenience for the best results. The possible resulting deformation of the cornea (perhaps a bulging of the weakest area produced by nonphysiologic air pressure(6)) could be analyzed with the already existent high-speed videokeratography photography or filming equipment(1-4,7-9,11) even considering the lids action, corneal thickness, blinking and tear film effects that are already known(5), isolating them with appropriate software from the real corneal deformation caused by the applied air jet onto the eye. This corneal deformation could show patterns like normal, ectatic, post-refractive surgery, for instance. This method could be called "dynamic corneal topography" because the cornea would be topographically analyzed along the time as it responds to a force applied onto the eye.

DISCUSSION

High-speed videokeratoscopy is an emerging technology that has the potential to provide new information on dynamic changes of corneal topography and tear film behavior(1).

This concept could be extended to the analysis of the corneal biomechanics or even corneal resistance if, as considered in the results section, we could apply a force like an air jet onto the eye and analyze the resulting corneal deformation in terms of topographic changes along the time measured and graphically presented by the dynamic high-speed videokeratography, resulting in the new of concept "dynamic corneal topography".

If the air jet applied onto the eye is nonaggressive, like that one from the ORA equipment(10), or even that one from the air tonometer we would have another innocuous diagnostic method to assess corneal biomechanics that could show normal and ectatic corneas having diagnostic importance or even preventing a given eye from a refractive surgery.

This could be another method among the already existent ones, like standard corneal topography, elevations and pachimetry measurements by the optical corneal tomography and histeresis measurements as already shown. This new method would add information to a better diagnostic or therapeutic decision by the ophthalmologist resulting in less surgical risks to the patient.

The ophthalmic equipment manufacturers and researchers working together would certainly face a big challenge if they want to make this new concept a real product to be used routinely. This would occur because despite using currently available technologies, these are supplied separately needing to be gathered probably in a joint venture between these manufacturers.

CONCLUSION

The literature basis supports the idea of gathering the existent technologies of corneal topography, the air jet of the corneal histeresis device and the high-speed photography to create a new concept in the analysis of the corneal surface: the dynamic corneal topography.

72(2)13.pmd 266 14/4/2009, 11:39

RESUMO

Objetivo: Estabelecer a base de literatura para apoiar a idéia de que seria possível analisar mudanças da superfície anterior da córnea por um jato de ar aplicado sobre o olho. **Métodos:** Procurou-se na base de literatura PUBMED/MEDLINE os assuntos videoceratografia, fotografia de alta velocidade, analisador de resposta ocular (ORA), selecionando-se informação concernente ao objetivo deste trabalho. **Resultados:** A literatura mostrou dados que apoiam a ideia de juntar três tecnologias hoje existentes que poderiam resultar num novo conceito de "topografia dinâmica de córnea": a topografia corneana, o jato de ar aplicado sobre o olho na medida da histerese do aparelho de analisador de resposta ocular (ORA) e a técnica de fotografia de alta velocidade usada para estudar o filme lacrimal e a superfície anterior da córnea. **Conclusão:** A base de literatura apóia a idéia de juntarem-se as tecnologias hoje disponíveis de topografia corneana, o jato de ar do aparelho de medida de histerese corneana e a fotografia de alta velocidade para se criar um novo conceito na análise da superfície corneana: a topografia dinâmica da córnea.

Descritores: Topografia da córnea/métodos; Microscopia de vídeo/métodos; Biomecânica; Processamento de imagem assistida por computador/métodos; Técnicas de diagnóstico oftalmológico/métodos; Procedimentos cirúrgicos refrativos

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72(2)13.pmd 267 14/4/2009, 11:39