Journal of Optometry (2017) xxx, xxx–xxx

Journal of Optometry

www.journalofoptometry.org

ORIGINAL ARTICLE

Relationship between vessel diameter and depth measurements within the limbus using ultra-high resolution optical coherence tomography

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Received 11 October 2016; accepted 4 February 2017

KEYWORDS
Limbal vasculature;
Optical coherence tomography;
Repeatability;
Optical imaging;
Corneal imaging

Abstract
Purpose: To establish a relationship between the diameter and depth position of vessels in the superior and inferior corneo-scleral limbus using ultra-high resolution optical coherence tomography (UHR-OCT).
Methods: Volumetric OCT images of the superior and inferior limbus were acquired from 14 healthy subjects with a research-grade UHR-OCT system. Differences in vessel diameter and depth between superior and inferior limbus were analyzed using repeated measured ANOVA in SPSS and R.
Results: The mean (± SD) superior and inferior diameters were $29 \pm 18\,\mu m$ and $24 \pm 18\,\mu m$ respectively, and the mean (± SD) superior and inferior depths were $177 \pm 109\,\mu m$ and $207 \pm 132\,\mu m$ respectively. The superior limbal vessels were larger than the inferior ones (RM-ANOVA, $p = 0.004$), and the inferior limbal vessels were deeper than the superior vessels (RM-ANOVA, $p = 0.041$). There was a positive linear association between limbal vessel depth and size within the superior and inferior limbus with Pearson correlation coefficients of 0.803 and 0.754, respectively.
Conclusion: This study demonstrated that the UHR-OCT was capable of imaging morphometric characteristics such as the size and depth of vessels in the limbus. The results of this study suggest a difference in the size and depth of vessels across different positions of the limbus, which may be indicative of adaptations to chronic hypoxia caused by the covering of the superior limbus by the upper eyelid. UHR-OCT may be a useful tool to evaluate the effect of contact lenses on the microvascular properties within the limbus.

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http://dx.doi.org/10.1016/j.optom.2017.02.003

PALABRAS CLAVE
Vasculatura del limbo;
Tomografía de coherencia óptica;
Córnea;
Repetición;
Imagen óptica;
Imagen de la córnea

Relación entre las mediciones del diámetro y la profundidad de vasos sanguíneos en el limbo obtenidas mediante tomografía de coherencia óptica de ultra-alta resolución

Resumen
Objetivo: Establecer la relación entre el diámetro y la profundidad de los vasos del limbo esclerocorneal superior e inferior mediante tomografía de coherencia óptica de ultra-alta resolución (UHR-OCT).
Métodos: Se adquirieron 256 conjuntos de imágenes del limbo superior e inferior en 14 sujetos, mediante UHR-OCT. Se analizaron las diferencias en cuanto a diámetro y profundidad del vaso entre el limbo superior e inferior utilizando ANOVA de medidas repetidas en SPSS y R.
Resultados: Los diámetros medios (± DE) superior e inferior fueron de 29 μm ± 18 μm y 24 μm ± 18 μm respectivamente, y las profundidades medias (± DE) superior e inferior fueron de 177 μm ± 109 μm y 207 μm ± 132 μm respectivamente. Los vasos del limbo superior fueron de mayor tamaño que los del limbo inferior (RM-ANOVA, p = 0,004), y los vasos del limbo inferior fueron más profundos que los del limbo superior (RM-ANOVA, p = 0,041). Se produjo una asociación lineal positiva entre la profundidad y el tamaño del vaso dentro del limbo superior e inferior, con coeficientes de correlación de Pearson de 0,803 y 0,754, respectivamente.
Conclusión: Este estudio demuestra que UHR-OCT fue capaz de obtener imágenes de las características morfométricas tales como tamaño y profundidad de los vasos del limbo. Los resultados de este estudio sugieren una diferencia de tamaño y profundidad de los vasos en las diferentes posiciones del limbo, que puede ser indicativa de adaptaciones a la hipoxia crónica causada por el cubrimiento del limbo superior por parte del párpado superior. UHR-OCT puede ser una herramienta de utilidad para evaluar el efecto de las lentes de contacto sobre las propiedades microvasculares del limbo esclerocorneal.

Introduction

The limbus is the zone that separates the opaque sclera (overlaid by transparent conjunctiva) from the transparent cornea. It is a region of interest because it is a site of numerous biological activities ranging from supplying blood to the peripheral cornea, to housing the aqueous outflow apparatus.[1] The vascular properties of the limbus is important for many physiological responses such as nutrition, waste removal, and microvascular changes in response to corneal injury, inflammation or contact lens wear.[2] For most people, during both awake and asleep conditions, the superior limbus is covered by the upper eyelid; roughly two millimeters of the superior corneal region (the total area of the superior limbus) is obscured while the eye is in the open-eye primary-gaze position.[3] The lid is a barrier to atmospheric oxygen within the limbal zone and immediately after the retraction of the upper eyelid, superior corneal oxygen uptake is much higher than other parts of the cornea.[4–6] When equilibrated (after longer upper lid retraction) there is no difference in oxygen uptake of the various corneal regions.[7] When oxygen delivery to the limbus is reduced, limbal hyperemia occurs as blood flow is increased to the region.[8] Since limbal hyperemia is not the norm,[3] it can be deduced that anatomical and physiological alterations within the tissue might occur as a response to overcome the possible inadequate exposure to atmospheric oxygen that the superior limbus experiences as a result of it being constantly covered by the upper eyelid. Such adjustments in response to this chronic hypoxia might include but are not limited to, changes in vessel size, density and depth, as well as changes in epithelial thickness.

There are a number of other differences in the structures of the upper limbus: The density of endothelial cells is greater in the superior limbus,[9] the diameters and spacing of collagen fibrils[10] and stem cell size[11] differ, and the superior cornea is thicker.[12,13] Because of these structural differences and the coverage of the superior limbus by the upper eyelid, we examined some aspects of the vessel characteristics within the superior limbus and other limbal regions: Our working hypothesis was that there would be morphometric adaptations of the vessels that would provide some physiological accounting for the upper limbus not showing manifestations of chronic hypoxia.

Visualization of the limbus

Many methods exist for the visualization and morphometric analysis of structures within the limbus. Ex vivo technology such as serial histologic sections[14,15] and ultrathin sections[16,17] have been used to visualize ocular vessels, trabecular meshwork and aqueous outflow in the limbus. Some shortcomings associated with this type of histological sectioning are that the curvature of the eye provides a barrier to the reconstruction of anatomical structures including vasculature, from sectioned materials, and the process cannot be carried out in vivo.[18]

Please cite this article in press as: Alabi E, et al. Relationship between vessel diameter and depth measurements within the limbus using ultra-high resolution optical coherence tomography. *J Optom.* (2017), http://dx.doi.org/10.1016/j.optom.2017.02.003