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Influence of corneal refractive surgery on scanning laser polarimetry

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Abstract

In order to improve the accuracy of glaucoma diagnostics, the use of the modern imaging technologies in routine practice has become necessary. Scanning laser polarimetry (SLP) is one of the widely-used modern imaging technologies. It was developed to measure the thickness of the retinal nerve fibre layer (RNFLT) around the optic nerve head, and to automatically compare the results with the corresponding normative database reference values.

The method is based on retardation (slowing down) of the polarized illuminating laser light of the instrument along one axis ("slow axis") by the birefringent retinal ganglion cell axons.

Certain surgical interventions which involve the corneal tissue (such as LASIK) may have clinically significant influence on the corneal retardation, which may potentially lead to misinterpretation of the results. Since corneal refractive surgery has become a widely-used method to correct for ametropia, and many young people, who in future may develop glaucoma, undergo different types of refractive surgery, this issue gained great clinical significance.

Following the introduction of GDx-VCC, the next generation of the GDx devices, the influence of corneal retardation became easily manageable, which helped to confirm that the virtual decrease of the post-LASIK polarimetric RNFLT was an artifact, and was not the sign of true RNFLT damage.

Recently a new polarimetric software version (enhanced corneal compensation, GDx-ECC) was developed and investigated by different research groups for its ability to remove the LASIK-induced corneal retardation artifacts, proving the new method to be more accurate than GDx-VCC. It all led to a conclusion that since GDx-ECC is able to neutralize changes of corneal retardation induced by LASIK, this software may be even more suitable to long-term follow-up of eyes which undergo corneal refractive surgery.

KEYWORDS: scanning laser polarimetry, glaucoma, retardation, LASIK, GDx.

Влияние кераторефракционной хирургии на результаты сканирующей лазерной поляриметрии

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Резюме

На сегодняшний день использование современных методов медицинской визуализации является необходимым условием получения более точных результатов диагностики глаукомы.

Одним из таких методов является сканирующая лазерная поляриметрия (СЛП), разработанная для оценки одного из наиболее важных критериев диагностики глаукомного процесса — толщины слоя нервных волокон (СНВ) в перипапиллярной зоне сетчатки и автоматического сравнения результатов с показателями нормы.

Измерение толщины СНВ с помощью санирующей лазерной поляриметрии основано на так называемом эффекте ретардации — замедлении поляризованного пучка света. Параллельная структура микротрубочек

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в нервных волокнах обеспечивает эффект двойного лучепреломления — расщепления проходящей световой волны на две части, поляризованные в двух взаимно перпендикулярных плоскостях, проходящие СНВ с различной скоростью.

Величина световой задержки определяется детектором сканирующего лазерного поляриметра и преобразуется в толщину СНВ в микронах.

Согласно результатам исследований, хирургические вмешательства на роговице, такие как LASIK, могут клинически значимо изменять величину световой задержки. В таких случаях бывает необходимо применение методов нейтрализации погрешностей измерения во избежание неверного толкования результатов исследования. С увеличением частоты рефракционных хирургических вмешательств для коррекции аметропии, в том числе у молодых людей, у которых в будущем может развиться глаукома, эта проблема приобрела большую клиническую значимость.

Благодаря использованию нового поколения лазерных поляриметров GDx-VCC с переменным роговичным компенсатором (VCC — variable corneal compensator) было установлено, что изменение световой задержки после LASIK является артефактом, а не признаком повреждения нервных волокон.

Недавно было разработано новое оборудование GDx-ECC, оснащенное усиленным роговичным компенсатором (ECC — enhanced corneal compensation). Оно было протестировано несколькими исследовательскими группами и показало большую точность результатов, чем предшествующий ему поляриметр GDx-VCC.

Таким образом, можно предположить, что на сегодняшний день именно GDx-ECC лучше всего подходит для компенсации изменений в световой задержке после LASIK и долгосрочного наблюдения за пациентами после рефракционной хирургии.

КЛЮЧЕВЫЕ СЛОВА: сканирующая лазерная поляриметрия, глаукома, рефракционная хирургия, GDx-VCC, GDx-ECC.

Introduction

In order to improve the accuracy of glaucoma diagnostics, the use of the modern imaging technologies in routine practice has become necessary. Scanning laser polarimetry (SLP) is one of the widely-used modern imaging technologies. It was developed to measure the thickness of the retinal nerve fibre layer (RNFLT) around the optic nerve head, and to automatically compare the results with the corresponding normative database reference values. In clinical practice, scanning laser polarimetry has been made with the different members of one instrument family: the GDx (Glaucoma Diagnostics) instrument family (Carl Zeiss Meditec Inc., Dublin, CA, USA).

Working principle of scanning laser polarimetry

Retinal nerve fibre layer thickness measurement with scanning laser polarimetry is based on retardation (slowing down) of the polarized illuminating laser light of the instrument along one axis ("slow axis") by the birefringent retinal ganglion cell axons, i.e. the retinal nerve fiber layer [4, 10]. The birefringent property of the axons is caused by the parallel organized intracellular organelles. When a retinal ganglion cell dies, the axon of the cell also disappears. Thus, ganglion cell loss means loss of birefringence. The automatic conversion of retardation to RNLFT data (expressed in μm) is based on the linear relationship between retardation caused by the measured RNFLT and the histological thickness of this layer. However, since other tissues (mainly the cornea) also cause retardation of the illuminating light, the influence of these structures on the measurement (measurement noise) needs neutralization. This issue gained special clinical importance in the last decade, and led to the development of the different GDx instrument generations.

Influence of corneal refractive surgery on polarimetric retardation

It has been also shown that certain surgical interventions which involve the corneal tissue may have clinically significant influence on the corneal retardation, which, in several cases, requires special neutralization techniques in order to prevent measurement artifacts and misinterpretation of the results. Since corneal refractive surgery has become a widely-used method to correct for ametropia, and many young people, who in future may develop glaucoma, undergo different types of refractive surgery, this issue gained great clinical significance.

It became clear already in the early studies that photorefractive keratectomy, which does not interfere with the cornea stroma, has no influence on corneal and global retardation [1, 6]. In contrast, during LASIK the corneal stroma tissue is manipulated [7, 8]. Since flap preparation is an essential part of both myopic and hypermetropic treatments, and the hinge area undergoes mechanical stress in all LASIK procedures, the parallel-organized corneal stromal fibres (which are considered as the structure responsible for corneal birefringence) are unavoidably disturbed even if the central cornea remains untreated (hypermetropic treatments). It is probable that flap preparation, corneal cut, mechanical manipulation and the appearance of microscopic metal debris of the LASIK-knife are more important causes of the LASIK induced retardation changes than the laser ablation of the corneal tissue itself [7, 8].

A decade ago, when built-in fixed-angle compensation was used to neutralize corneal retardation, a decrease of polarimetric RNFLT was observed after LASIK, as compared to the correspondent pre-LASIK value [5, 13]. Since at that time eye-fixation both during flap preparation and tissue evaporation was achieved with a suction ring at approximately 60 mmHg pressure, a decrease of polarimetric RNFLT after LASIK was considered a potential sign of suction-induced (pressure-induced) RNFLT damage. These early studies got wide publicity, even if the authors did not consider the role of corneal healing in their publications. Later, others extended the length of the post-LASIK follow-up, and proved that retardation after LASIK changes with time and the change is parallel with the histologically described corneal healing process [8, 9]. In brief, polarimetric retardation decreases immediately after LASIK, and then it increases during the first three post-LASIK months parallel with the early corneal healing. Later, the values become stable as the corneal healing process slows down and stabilizes.

Success of new GDX developments in neutralization of the LASIK-induced retardation noise

Following the introduction of GDx-VCC, the next generation of the GDx devices, the influence of corneal retardation became easily manageable. The individualized compensation of retardation caused by the anterior segment tissues enabled the clinicians to re-establish the corneal retardation after LASIK. When the pre-LASIK cornea retardation was used to correct for peripapillary retardation in images obtained before LASIK, and the post-LASIK corneal retardation to correct for the peripapillary retardation after LASIK, the polarimetric thickness remained stable [2, 8]. However, when only the pre-LASIK values were used for the pre- and post-LASIK time-points, the thickness values showed a virtual decrease [3]. These studies confirmed that the virtual decrease of the post-LASIK polarimetric RNFLT was an artifact, and was not the sign of true RNFLT damage. For clinical purposes, however, due to the relatively long-lasting corneal healing process after LASIK, using new corneal retardation images at each GDx-VCC measurement session, for at least one year after LASIK, is recommendable.

Recently a new polarimetric software version (enhanced corneal compensation, GDx-ECC) was developed and tested by different research groups [10, 11]. In the ECC mode the compensator is adjusted so that it combines with the corneal retardation to produce a bias retardation of approximately 55 nm and a slow axis to be close to vertical. The instrument then measures a higher total retardation than the RNFL retardation alone, and the signal-to-noise ratio is improved as a result. The actual bias retardation and axis in each image are measured from the macular region, in a similar way to corneal birefringence measurement. The actual retinal nerve fiber layer retardation is derived mathematically. The actual bias is determined from each image, and removed from the final RNFL image. Though the GDx-ECC software was developed to neutralize measurement noise caused by posterior ocular tissues around the retinal nerve fiber layer (atypical retardation pattern), and not to improve neutralization of corneal birefringence, this technique was also investigated for its ability to remove the LASIK-induced corneal retardation artifacts [12]. It was found that in contrast to GDx-VCC, which produced unchanged RNFLT if the corneal image was re-taken after LASIK but showed significant RNFLT changes if the pre-LASIK corneal retardation was used both for the pre- and post-LASIK measurements, RNFLT as measured with GDx-ECC, remained unchanged even when the original, pre-LASIK corneal retardation images were used for all measurements [12]. This showed that GDx-ECC is able to neutralize changes of corneal retardation induced by LASIK, thus this software may be even more suitable to long-term follow-up of eyes which undergo corneal refractive surgery.

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