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The role of corneal biomechanical properties assessment in laser vision correction – the introduction

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HIGHLIGHTS

Laser refractive treatments might induce changes in the mechanical resistance of the cornea. The parameters derived from the current as well as new technologies may be helpful in assessing corneal biomechanical changes after laser refractive surgery.

ABSTRACT

The role of corneal biomechanical properties in patients referred to laser vision correction (LVC) is currently being raised. Understanding of corneal biomechanics may support the proper selection of refractive surgery candidates, improve the refractive outcomes and safety of refractive procedures. The Ocular Response Analyzer (ORA) and Corvis ST are commonly used devices to assess corneal biomechanical parameters in LVC. The vertical corneal incisions have a greater impact on corneal biomechanics weakening than horizontal incisions. Maintaining the high biomechanical strength of the cornea following LVC can decrease the potential risk of postoperative ectasia.

Key words: corneal biomechanics, corneal collagen, corneal stroma, laser vision correction, SMILE, LASIK, PRK

BACKGROUND

Laser vision correction (LVC) is a group of corneal refractive surgery procedures which are commonly used in refractive error management. The safety and efficiency of LVC as well as frequent postoperative visual rehabilitation has made these procedures the most common ophthalmic surgery today. In most cases LVC allows complete correction of refractive error, thus improving the patient's quality of life. The high safety profile of LVC procedures is conditioned by the precise patients qualification, including a detailed assessment of the corneal tomography, pachymetry, aberrometry and finally the corneal biomechanics the importance of which is now strongly emphasized in refractive surgery. Understanding of corneal biomechanical properties can reduce the risk of postoperative keratectasia as well as improve treatment results in difficult refractive cases [1]. Devices such as the Corneal Response Analyzer (ORA) or CORVIS-ST enable the clinical evaluation of corneal biomechanics in LVC candidates.

METHODS OF SELECTED CORNEAL REFRACTIVE SURGERY PROCEDURES

Many studies report that LVC compromise the biomechanical strength of the cornea [1–6]. However, the change in corneal biomechanics is strongly related to the refractive surgery technique and ablation profile. In brief, the corneal refractive procedures can be divided into:

- the superficial ones, such as photorefractive keratectomy (PRK)
- laser-assisted sub-epithelial keratectomy (LASEK) and stromal techniques that include: flap-related laser-assisted in situ keratomileusis (LASIK) and microinvasive lenticule extraction (small incision lenticule extraction, SMILE and minimal invasive lenticule extraction, SmartSight).

In PRK, the corneal epithelium is precisely removed by use of excimer laser (trans-PRK), alcohol, mechanical surgical devices or combination of the above techniques. After the epithelium debridement, the anterior stroma is ablated by the excimer laser. Corneal abrasion causes postoperative pain, prolonged healing process and visual recovery [1]. In LASEK procedure, the corneal epithelium is soaked with 20% ethanol and then carefully pushed aside just before anterior stroma ablation. At the end of the procedure, the epithelium is slid over the cornea again [1]. LASIK procedure requires formation of corneal flap with use of femtosecond laser (previously microkeratome knife). The surgeon lifts the corneal flap and the excimer laser ablates the exposed stroma [1]. In SMILE, the femtosecond laser cuts off the lenticule in the anterior corneal stroma. Then the micro-side cuts are performed to allow the surgeon mechanical removal of lenticule [1]. The advantages of LASIK and SMILE over surface procedures are: the painless healing process and almost immediate good visual acuity.

METHODS OF CORNEAL BIOMECHANICAL PROPERTIES ASSESSMENT

The devices used in clinical evaluation of corneal biomechanical parameters are: the Ocular Response Analyzer® (ORA; Reichert Ophthalmic Instruments, NJ, USA) and Corvis ST® (CST; Oculus Opticgerate, Inc. Wetzlar, Germany). To understand and assess the corneal biomechanics, the parameters such as: corneal viscosity, elasticity, stiffness, hysteresis, resistance factor were used by the ORA and CST manufacturers.

The corneal tissue is compared to the visco-elastic material. Viscosity is defined as the resistance against progressive deformation by the shear stress. Viscosity of the cornea is a result of stromal matrix hydration maintained by proteoglycans [7]. Elasticity of the material is the ability of return to the original shape after deformation by the applied force. It is considered that the collagen fibres of the corneal stroma are responsible for corneal elasticity [7]. Stiffness of the cornea describes its overall rigidity and resistance to the applied force. The corneal stiffness is dependent on both the elastic properties of the cornea and the amount of corneal tissue (corneal thickness) [7].

The ORA tonometer measures the corneal hysteresis (CH) and the corneal resistance factor (CFR). CH is obtained by calculation of the difference between two applanation pressures P1 and P2 measured during corneal deflection by the air-impulse. The ORA measures CH by the reflection of the infrared laser beam to capture the deformation of the cornea. Clinically, CH reflects the viscoelasticity of the cornea. CRF defines the overall corneal stiffness taking into account both, the corneal elasticity and corneal thickness. CRF is mathematically described as $P1 - K \times P2$, where the constant $K = 0.7$ is derived from empirical analysis of the relation between P1 and P2 parameters and central corneal thickness (CCT). Lowering of CH and CRF parameters may suggest the risk of postoperative corneal ectasia, as it was reported in numerous studies [8–10]. In addition ORA provides 2 values of intraocular pressure (IOP): Goldmann-correlated IOP (IOPg) and corneal compensated IOP (IOPcc) [2].

Dynamic Scheimpflug Analyzer Corvis® ST is a second device commonly used for non-contact tonometry with the analysis of corneal thickness and biomechanics. Similarly to the ORA measurement principle, the assessment of corneal biomechanics in CST is based on the inward and outward corneal deformation by an air pulse and capturing the pass through two applanation phases. The device uses an ultra-high-speed Scheimpflug camera which that takes 140 horizontal 8 mm frames in 33 ms, allowing accurate evaluation of the corneal deflection in applanation points [11]. The deformation amplitude (DA) is defined as the greatest inward dislocation of the corneal apex measured at the highest concavity (HC) point [11]. DA ratio of central and peripheral deflection is assessed in a distance of 1 mm and 2 mm resulting in DAR-1 and DAR-2 parameters and stiffness parameter at the 1st applanation (SPA1) [12]. Applanation lengths (AL) and corneal velocities (CVel) are measured in inward and outward phases. The curvature radius at the highest concavity (curvature radius HC) integrated inverse radius (IntInverseR) and maximum inverse radius (InverseR) are also documented. The higher values of IR, the lower corneal resistance to deformation what indicate lower corneal stiffness [12]. Corneal pachymetry (Pachy) and parameters essential in potential keratoconus detection such as Ambrosio Rational Thickness horizontal (ARTh) and Pachyslope are measured before the air-puff generation [12]. Moreover, Corvis biomechanical index (CBI) and tomographic and biomechanical index (TBI) parameters are combined Dynamic Corneal Response (DCR) parameters that indicate the difference between healthy and subclinical ectasia or keratoconic eyes [12]. The result of Corvis tonometry is biomechanical corrected intraocular pressure (bIOP) [3].

Other methods that measure biomechanical corneal properties *in vivo* include Brillouin optical microscopy, surface wave elastometry, optical interferometric techniques, quantitative ultrasonic spectroscopy and optical coherence tomographic elastography, but these technologies are not commercially available [13, 14].

THE CORNEAL STROMA MORPHOLOGY AND BIOMECHANICS CHANGE AFTER LASER VISION CORRECTION

The corneal tissue is composed of precisely oriented layers of collagen fibers, which determines the transparency and strength of the cornea. Stromal collagen fibers are surrounded by proteoglycan molecules responsible for the proper distribution of collagen and hydration of the stroma. The flap formation and ablation of the stromal tissue during LASIK surgery cuts the anterior collagen bundles of the cornea, which means that the peripheral anterior fibers are no longer taut and therefore relax, resulting in a thickening of the peripheral stroma and increased water accumulation [15]. The consequence of anterior peripheral stromal fibers intersection is the exertion of tension on the posterior bundles, which results in a central flattening of the cornea. Additionally, the posterior stromal lamellae also have to cope with the force exerted by intraocular pressure [15]. The redistribution of forces triggered by the change of corneal shape after laser vision correction may weaken the corneal biomechanics over time [15]. Vertical lateral incisions (side cuts) of corneal lamellae have a greater impact on weakening of the corneal biomechanics than horizontal incisions (cap, lenticule, flap cuts) [1, 4]. This can theoretically explain the greater lowering of corneal stiffness and overall biomechanics after flap related procedures (LASIK) rather than after SMILE [1, 4]. What is interesting, the experimental studies reported that posterior corneal stroma is weaker than anterior stroma [15–19]. This fact is explained by the specific structure of collagen layers in different parts of the corneal stroma as well as the stronger anterior cross-linking [15]. Furthermore, some authors raise the role of the corneal ablation profile as an important factor influencing postoperative corneal biomechanics [20, 21]. The peripheral hyperopic ablation profile in thicker paracentral cornea results in lower risk and incidence of corneal ectasia after LASIK and SMILE in hyperopia correction in contrast to the myopia correction [21].

CONCLUSIONS

Keratectasia after corneal refractive surgery procedures is rare but severe complication, the risk of which must be excluded in LVC candidates. The corneal biomechanics assessment by ORA or CST is useful to determine the corneal strength and diminish the risk of postoperative corneal ectasia. Although the biomechanical properties alone cannot guarantee that the ectasia will not occur, the understanding of corneal stiffness and biomechanical structure can improve the surgical planning, support the choice of surgical method and help in postoperative ectasia-suspected eyes exclusion.

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