DOC 2023 – HH 2 Corneal Ectasia

Corneal biomechanics in vivo - from enhanced ectasia screening to assessment of Corneal crosslinking efficacy

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The in vivo assessment of corneal biomechanics plays a major role in screening for refractive surgery and keratoconus. It is expected that corneal biomechanics provide complementary information to corneal topography and tomography measurements, especially in cases where these measurements are still normal. It is assumed that focal biomechanical changes occur before corneal topographic and tomographic alterations are even detectable. Therefore, an early detection of corneal ectasia is desirable to prevent the reduction of vision using appropriate treatments or to avoid iatrogenic keratectasia after laser vision correction.

The mechanical properties of biomaterials are measured experimentally with the induction of a deformation by an external force. Air-puff tonometry provides an ideal in vivo method to assess the dynamic behavior of the cornea. The in vivo quantification of the corneal biomechanical properties was introduced to clinical practice by the commercialization of the ocular response analyzer (ORA; Reichert Ocular Instruments, Depew, NY, USA) and the more recent dynamic Scheimpflug analyzer (Corvis ST, Oculus, Wetzlar, Germany). Both techniques are based on an air-puff that is applied to the front surface of the cornea inducing a corneal deformation process. The resulting parameters represent corneal biomechanical response to a force that is applied to the tissue.

Main parameters of the ORA are corneal hysteresis (CH) and corneal resistance factor (CRF). Both CH and CRF are not associated with corneal stiffness because they reflect corneal visco-elastic properties due to the integration of pressure values of inward and outward movement in its calculations. In contrast, parameters of Corvis ST describe corneal behavior of inward and outward movement separately. Parameters of inward movement are associated with the elastic component and thus to corneal stiffness.

The measurement of biomechanical properties of the cornea are mainly influenced by IOP and corneal thickness. For instances, the higher the IOP of the eye is, the less deformable the cornea behaves against the applied air puff, even though the material properties are not altered. Corneal thickness is also an influencing factor on biomechanical parameters. A higher corneal thickness is associated with a stiffer biomechanical behavior, namely a lower DAR2 and IIR as well as a higher SP A1 (Corvis ST), than thinner corneas.

The investigations in healthy and keratoconic eyes have shown that the CBI is the best parameter separating between these cohorts. Furthermore, DAR2, IIR and SP A1 show higher values for sensitivity and specificity in differentiating healthy from keratoconus as CH and partly CRF. Regarding the severity of keratoconus, some DCR parameters are different between several stages. However, corneal biomechanics are also helpful in investigating very early ectasia. The CBI provides further information for ectasia screening in cases where corneal topography and tomography are clinically not suspicious.

Corneal biomechanical properties are also altered after corneal cross-linking. In an experimental setting, a higher IOP, a higher SP A1 and a lower IIR was observed by Corvis ST after CXL that is associated with an increased corneal stiffness. These observations correlated with stiffening changes using stress-strain measurements. In vivo, alterations in the same manner of bIOP and IIR were observed one months after CXL and partly up to one year postoperatively. In addition, the SSI is a potential parameter to asses biomechanically the efficacy of the CXL treatment. However, it is assumed that the biomechanical effect can be measured preferably in short-term follow-up.

Therefore, air-puff tonometry can be considered a useful method for measuring the biomechanical properties of the cornea in vivo. In particular, the Corvis ST improves early detection of ectasia, which is beneficial before refractive surgery and treatment of keratoconus. Furthermore, the evaluation of CXL efficacy is only possible with the Corvis ST, as it measures the elasticity components of the cornea.

Parameter	Abbreviation	Description
CH [mmHg]	CH	Corneal hysteresis
CRF [mmHg]	CRF	Corneal resistance factor
DA Ratio Max (2mm) [mm]	DAR2	Ratio of deformation amplitude and mean peripheral deformation at ± 2mm from apex
Integrated Radius [mm^{-1}]	IIR	integrated inverse radius between 1st and 2nd applanation
SP A1 [mmHg/mm]	SPA1	stiffness parameter at 1st applanation
CBI	CBI	Corvis Biomechanical Index
SSI	SSI	Stress-strain index