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Corneal Biomechanical Assessment with Dynamic Scheimpflug Analyzer following Corneal Collagen Crosslinking

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ABSTRACT

Corneal biomechanics has been heavily investigated by researchers due to its potential applications in the diagnosis, management, and treatment of several pathologies such as corneal ectasia, refractive surgery, and glaucoma. In the case of corneal ectasia, crosslinking is an effective method to slow or halt the progression of the disease. In 2016, the U.S. Food and Drug Administration (FDA) gave clearance for the crosslinking system to treat patients with progressive keratoconus and post-LASIK (laser-assisted in situ keratomileuses). This review discusses the latest development of Scheimpflug corneal tomography to assess the efficacy of crosslinking and to detect the progressivity of keratoconus in patients post-crosslinking. Corvis-ST is a non-contact tonometry system that allows the assessment of corneal biomechanical properties. The integration of these data into artificial intelligence has demonstrated to improve the accuracy to assess crosslinking efficacy.

1. Introduction

Cornea and tear film is the first optical interface of the visual system. They are responsible for most of the refractive power of the eye. Generally, the cornea is thicker in the periphery and it gets thinner as it approaches the apex [1]. The previous study reported a normal distribution of central corneal thickness in healthy eyes was 544.6±30.5 µm [2]. Ninety percent of the corneal thickness is made up of stroma. Keratocytes in stroma produce collagen, ground substance, and collagen lamellae. Collagen fibrils have the same size and distance from each other. This regularity helps to keep the cornea clear [3], [4].

2. Clinical applications of corneal biomechanics

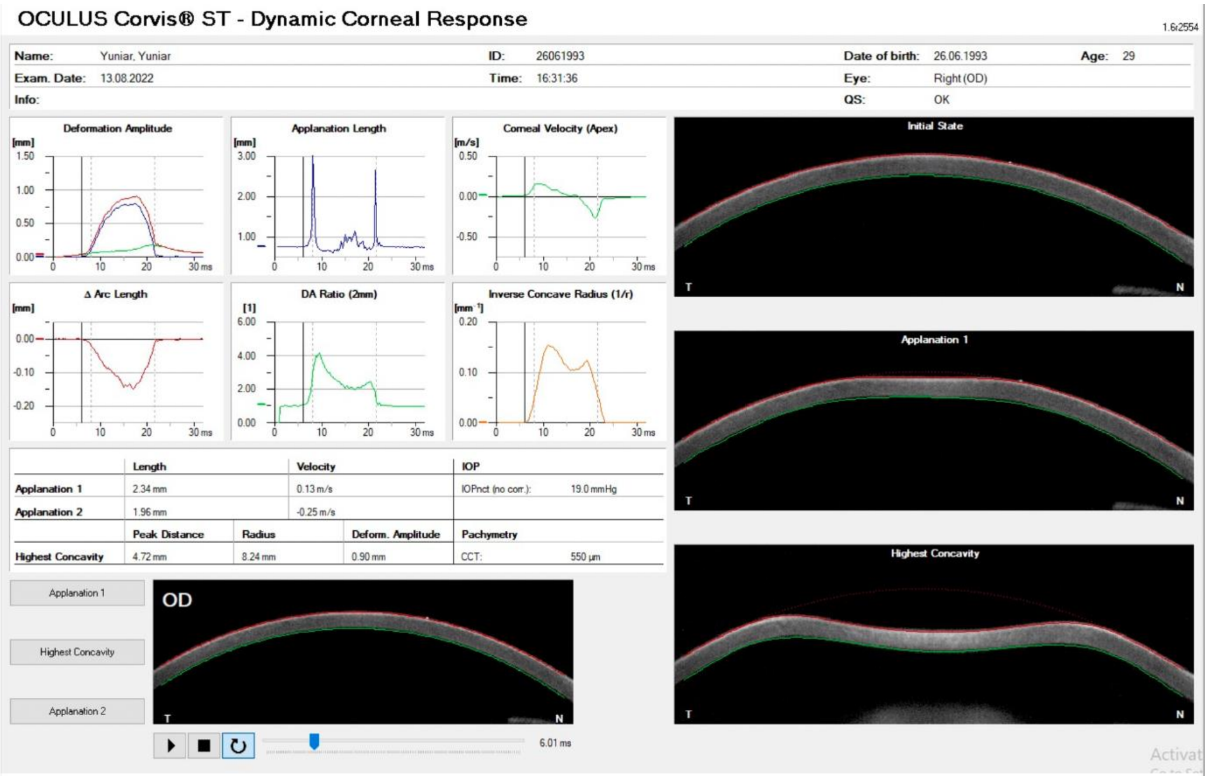
The cornea is a complex biomechanics composite whose properties depend on the subcomponent structure and arrangement. Cornea has the ability to maintain the complex and delicate balance between rigidity, strength, and extensibility to bear the continuous internal and external force that may present stress, deform, or threaten the integrity of the cornea [5], [6].

Based on material science terminology, the cornea is a complex anisotropic composite that has elastic and viscoelastic properties [5], [6]. Due to its viscoelastic behavior, the cornea response is dependent on the strain rate, which influences the deformation in the cycle of the loading and unloading [1].

The knowledge of corneal biomechanics has a significant contribution to understanding corneal ectasia diseases, such as keratoconus, pellucid marginal degeneration, and post-LASIK ectasia. Corneal biomechanics allow for better diagnosis, staging, and prognosis of the disease [7- 9]. In the case of subclinical keratoconus where topography is insufficient to provide conclusive evidence, corneal biomechanics data have a role. Furthermore, corneal biomechanics can provide information to identify patients at higher risk of developing ectasia post-LASIK [10]. Corneal biomechanics can also be utilized to understand cornea behavior post-crosslinking to determine whether the disease has stopped or still progressing [11- 13].

3. Dynamic scheimpflug analyzer

The Corvis ST (Oculus, Wetzlar, Germany) utilized an ultra-highspeed Scheimpflug camera which is able to take 140 horizontal 8 mm frames over a period of 33 ms. This system is approved by the US FDA for non-contact tonometry (NCT) and pachymetry. Internationally, this is also utilized for corneal biomechanical assessment. The Corvis ST assesses corneal deformation based on dynamic inspection of the corneal response. Air puff with certain pressure coming from the air nozzle will deflect the cornea backward. This air puff not only deforms cornea but also causes whole-eye motion. Thus, dynamic corneal response (DCR) either includes or compensates for the whole-eye motion. There are several parameters under DCR (Figure 1) including AL1 is corneal length in the first applanation (mm), AL2 is corneal length in the second applanation, AV1 is corneal velocity in the first applanation (m/s), AV2 is corneal velocity in the second applanation, peak distance is the distance between two apexes of the cornea at the time of maximum velocity, radius (mm) of curvature of the cornea at the time of maximum concavity, deformation amplitude (DA) is the amplitude of highest concavity of the central cornea [6].


OCULUS Corvis® ST - Dynamic Corneal Response

Name: Yuniar, Yuniar
ID: 26061993
Date of birth: 26.06.1993
Age: 29
Exam. Date: 13.08.2022
Time: 16:31:36
Eye: Right (OD)
Info:
QS: OK

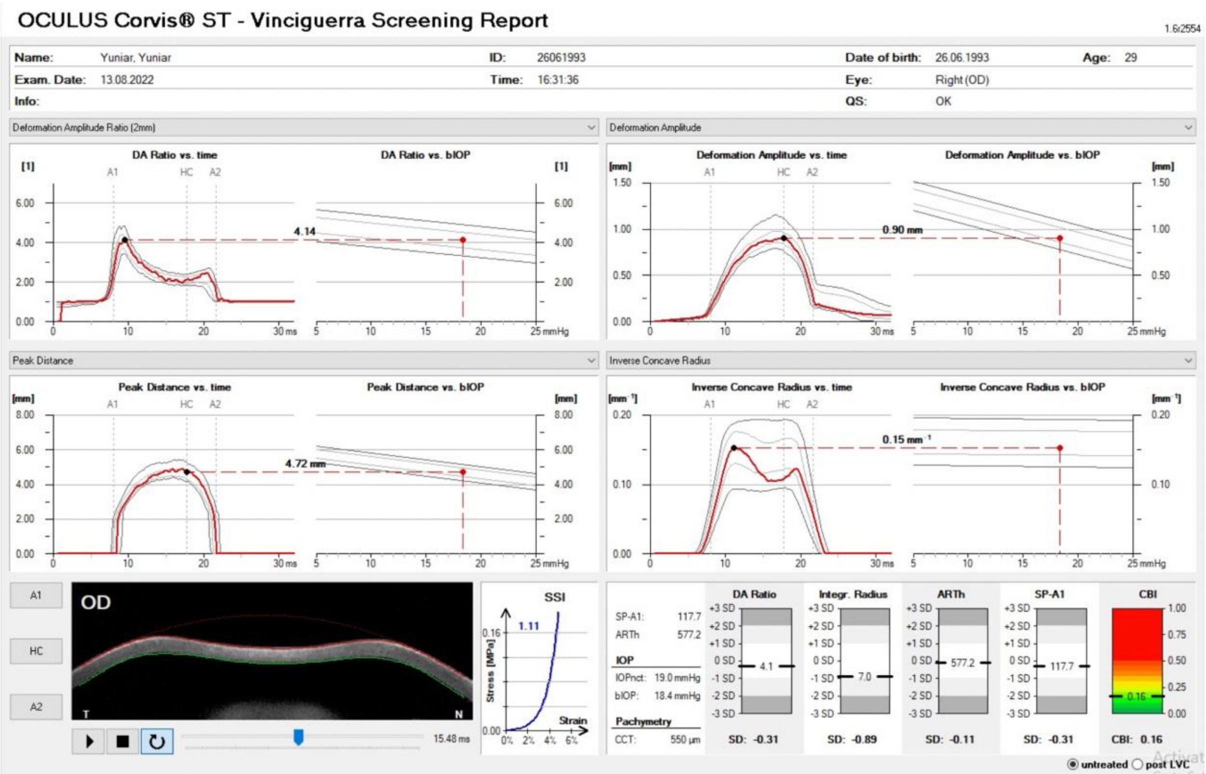
	Length	Velocity	IOP	
Applanation 1	2.34 mm	0.13 m/s	IOPnct (no corr.):	19.0 mmHg
Applanation 2	1.96 mm	-0.25 m/s		

	Peak Distance	Radius	Deform. Amplitude	Pachymetry	
Highest Concavity	4.72 mm	8.24 mm	0.90 mm	CCT:	550 µm

Figure 1 Corvis ST Dynamic Corneal Response parameters. The above figure showed the result of the

examination showing deformation amplitude (DA), applanation length (AL), corneal velocity (AV), peak distance, radius at highest concavity, deformation amplitude, intraocular pressure (IOP), and corneal thickness. Personal archive.

There are relatively newer parameters of Corvis ST under Vinciguerra Screening Report (Figure 2) that may help assess the efficacy of crosslinking procedure, including SPA-1 the stiffness parameters at first applanation (mmHg/mm), integrated radius (mm^{-1}; IR) is the area under the inverse concave radius curve, deformation amplitude ratio (DAR) is the ratio between DA and the average deformation amplitude at 2 mm around the center, and stress-strain index (SSI) as an approximation of the entire stress-strain behavior or the stiffness of the cornea [6].


OCULUS Corvis® ST - Vinciguerra Screening Report

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Time: 16:31:36
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SP-A1: 117.7
ARTh: 577.2
IOP
IOPnct: 19.0 mmHg
bIOP: 18.4 mmHg
Pachymetry
CCT: 550 µm

DA Ratio SD: -0.31
Integr. Radius SD: -0.89
ARTh SD: -0.11
SP-A1 SD: -0.31
CBI: 0.16

● untreated ○ post LVC

Figure 2 Vinciguerra Screening Report. The result shows correlations between normality values and a biomechanically adjusted IOP. The parameters valuable to observe in patients following corneal crosslinking include DA ratio, integrated radius, SPA-1, and SSI. Personal archive.

4. Biomechanical changes in the cornea after crosslinking

It is essential to assess the efficacy of crosslinking. Crosslinking aimed to increase corneal rigidity so it is reasonable to evaluate the result of crosslinking by its corneal biomechanical properties. Corvis ST is a device that is able to differentiate keratoconus and normal cornea. Normal and stiffer corneas applanate slower thus lowering the velocity of applanation and higher radius of concavity [14].

Table 1. Comparison of newer parameters of Corvis ST following crosslinking

Author/ Reference	DA ratio		Integrated radius		SP-A1	
	Pre-op	Post-op	Pre-op	Post-op	Pre-op	Post-op
[15]	5.53±0.81*	5.29±0.71*	12.19±1.95*	11.26±1.89*	71.09±19.14	75.01±17.63
[11]	6.44±1.53	6.58±1.87	13.79±3.12	13.27±2.92	57.70±27.57*	63.36±27.09*
[16]	5.33±0.50*	4.90±0.40*	11.31±1.47*	9.42±0.80*	61.91±14.22*	69.85±10.25*
[17]	6.56±1.14	6.33±1.52	12.54±2.11*	11.79±2.29*	46.4±17.8	51.8±21.2

[14]	4.80 (3.6,7.9)*	4.60 (3.5,4.1)*	9.80 (6.7,16.7)*	9.60 (6.3,16.7)*	75.7 (43.7,145.2)*	77.5 (46.1,148.5)*

The changes in Corvis ST parameters have been reported with variations in previous studies (Table 1) [11], [14- 16]. SP-A1, integrated radius, and DA-ratio have been proven independent of intraocular pressure [17], [18]. As previously reported, the higher values of SP-A1 and lower integrated radius and DA ratio reflected a more rigid cornea. There is also another newly developed parameter, the SSI (stress-strain index), that is independent of IOP and central corneal thickness but dependent on age [19]. The higher SSI, the greater the corneal stiffness [20].

5. Conclusion

The parameters of Corvis ST were subject to alteration following crosslinking. The information on the biomechanical condition of the cornea may guide physicians to provide more effective treatment and monitor the efficacy of the treatment.

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