A New Stiffness Parameter in Air Puff Induced Corneal Deformation Analysis

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Purpose
To investigate a new stiffness parameter in corneal deformation analysis and compare responses in normal (NL) and keratoconic (KC) subjects, matched for intraocular pressure (IOP).

Methods
A new stiffness parameter (SP) is defined as the resultant pressure at inward application, divided by corneal deflection amplitude at highest concavity (HCDeflectAmp). The spatial and temporal profiles of the Corvis ST air puff (Oculus, Wetzlar, Germany) were characterized using hot wire anemometry from 0 to 16mm from the nozzle. Measured velocity was correlated in time with the pressure profile exported by the Corvis ST, measured within the nozzle. The z position of the cornea at the time of inward application was used to calculate an adjusted air pressure value (adjAPi) at the time and position of first application. An algorithm to correct IOP estimation based on finite element modeling, termed IOPfem, was used for the equation: SP = (adjAPi) - IOPfem/HCDeflectAmp. Linear regression analyses between dynamic corneal response parameters (DCR’s) and SP were performed on a retrospective dataset of 180 KC eyes and 482 NL eyes. DCR’s from a subset of 158 eyes of 158 subjects in each group were matched for IOPfem and compared using t-tests. Significance threshold was p < 0.05.

Results
Table 1: Mean ± Standard Deviation in IOPfem-Matched t-Test Comparison

Figure 1: Averaged ocular topography of normal and keratoconic eyes. A: Cornea in the Profillation phase of the first air puff; B: Cornea in the Profillation phase of the second air puff; C: Cornea in the Profillation phase of the third air puff; D: Cornea in the Profillation phase of the fourth air puff; E: Cornea in the Profillation phase of the fifth air puff; F: Cornea in the Profillation phase of the sixth air puff.

Figure 2: Top: Measured velocity from the hotwire anemometry; Bottom: Control of the air puff velocity relative to the center.

Figure 3: Averaged ocular topography of normal and keratoconic eyes. A: Cornea in the Profillation phase of the first air puff; B: Cornea in the Profillation phase of the second air puff; C: Cornea in the Profillation phase of the third air puff; D: Cornea in the Profillation phase of the fourth air puff; E: Cornea in the Profillation phase of the fifth air puff; F: Cornea in the Profillation phase of the sixth air puff.

Figure 4: Phases of deformation expressed as deflection amplitudes, with a lower value indicating a stiffer cornea. A: HCDeflAmpl showing a greater concave radius tends to be stiffer; B: Velocity showing that stiffer corneas have lower velocities due to greater resistance to deformation; C: DCA Ratio, showing that stiffer corneas have less difference in deformation between the center and periphery; D: DCA Ratio showing that stiffer corneas have less difference in deflection between the center and periphery; E: HCDeflAmpl showing that stiffer corneas have lower deflection; F: HCDeflArea showing that the least arclength at the center is stiffer.”

Acknowledgments


References

Conclusions

1. Keratoconic eyes demonstrated less resistance to deformation than normal eyes with similar IOP.
2. All of the deformation parameters investigated showed a significant relationship with the new stiffness parameter.

This may be useful in future biomechanical studies comparing populations.

Discussion

All DCR’s evaluated showed a significant difference between NL and KC, except peak distance, as shown in Table 1. The KC group had lower SP values, thinner pachymetry, shorter applanation lengths, and greater absolute values of applanation velocities, earlier first application times and later second application times, greater HC deformation and HC deflection amplitudes, and lower HC radius of concave curvature (greater concave curvature). As KC progresses, all DCR’s evaluated showed a significant relationship with SP in both groups, as shown in Table 2 and Figure 5. Stiffer eyes were associated with greater pachymetry, longer applanation lengths, lower absolute value of applanation velocities, lower applanation times, later second application times, lower HC deformation and HC deflection amplitudes, shorter peak distances, greater HC radius of concave curvatures (flatter), and higher values of IOPfem.

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Table 2: Regression Analysis Statistics between Stiffness Parameter and Dynamic Corneal Response Parameters

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