CORNEA MECHANICAL MODEL OF KERATOCONUS EARLY CAUSES, USING PATIENT-SPECIFIC GEOMETRY AND MICROSTRUCTURAL DATA

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Introduction

Cornea is a front part of the eye providing two thirds of its optical power through its lens shape. In keratoconus disease, the cornea shape is progressively altered to become conical, leading to optical aberration [1]. A late detection imposes a surgery, explaining the need of early diagnosis.

Keratoconus origin is not clearly determined [2]. While it is associated with a cornea thinning and a decrease of the mechanical properties, it is not clear which of these two effects is the driving one.

We propose a modeling approach in which we change independently the cornea geometry and mechanical properties from healthy to keratoconic ones.

Methods

We combined a multiscale model with a patient-geometry (see Fig.1) to simulate the mechanical response of corneas under pressure. The cornea behavior contains an isotropic contribution (matrix), and an anisotropic part (collagen lamellae). Orientations and fractions of each component come from experimental observations [3,4].

Mechanical parameters are then determined by fitting experimental inflation data from the literature [5]. This gives a reference set of parameters for healthy cornea.

The keratoconus origin is studied by using first the geometry of keratoconic cornea with reference mechanical parameters, and second the geometry of healthy cornea with altered mechanical parameters. We compared the evolution with pressure of the SimK (a measure of cornea curvature) with the literature [6].

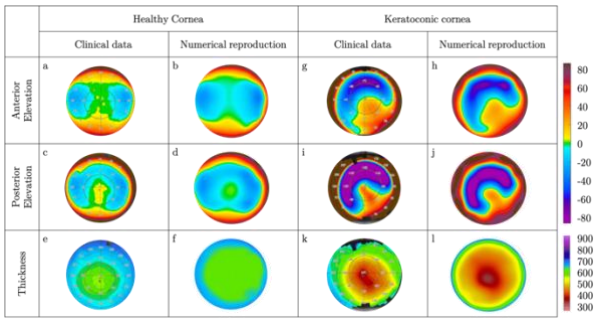

Figure 1: Elevation and thickness maps of healthy and keratoconic cornea (clinical and numerical reproduction, anterior and posterior). Scale bar in µm. Figure from [7].

Results

Our simulations of healthy cornea show that the mechanical response comes mainly from the collagen, and in particular its prestretch.

Keratoconic variations in SimK cannot be reproduced without changing the mechanical parameters, whatever the initial geometry. At the same time, changing the mechanical parameters is sufficient to recover the keratoconus response, even for a healthy geometry while. We can also compute the full elevation maps, showing a cornea similar to a keratoconus at a very early stage.

Discussion

Our work shows that the keratoconic response is primary controlled by a weakening of the mechanical parameters [7]. More precisely, it is the collagen stiffness which seems the most critical parameter. This is consistent with the classical idea that collagen-rich tissues mechanical response is controlled by the collagen fibers. Our result show then the interest of cross-linking treatments, which stiffen the collagen lamellae.

References

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