Biologic Tissues Properties Deduction Using an Opto-Mechanical Model of the Human Eye

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Introduction

The visual accommodation is a complex biomechanical & optical process. **Today in vivo imaging technologies do not allow to measure the eye components material properties** such as the refractive index or the stiffness: these properties are essential to understand & diagnose the effect of aging on the eye accommodative performance and develop new surgeries. To address this problem, *Kejako SA* has set up **a parametric 3D mechanical model of the human eye, in addition with an optical evaluation.**

This paper present how this model can be used to deduce with reverse engineering some of these non-measurable properties from in vivo imaging such as the **refractive index distribution in the Crystalline Lens**.

KEYWORDS: Biomechanics, Optics, Imaging, Reverse Engineering, Human Vision, GRIN, Refractive Index, Soft Tissues

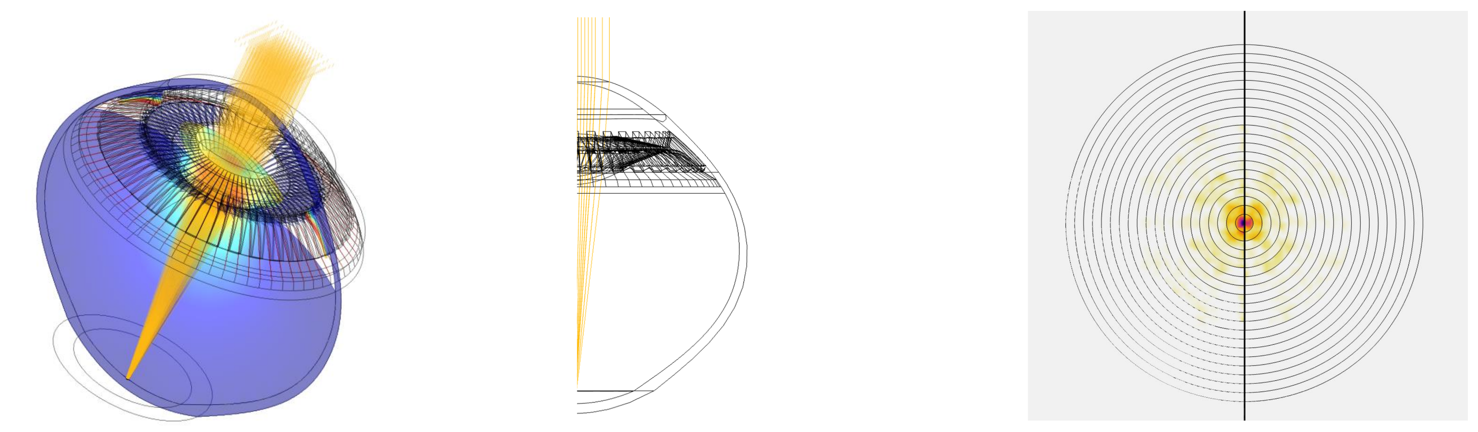

Figure 1. Biomechanical model of the human eye developed by Kejako. The model is validated and fully able to achieve the emmetropic accommodation and the effects of aging [4] - such as the progressive loss of vision amplitude *(presbyopia)*. The model is coupled with the **Ray Optics** module and the extremely fine subdivision of the retina *(right)* enables to evaluate the optical acuity for each condition of focus mechanically simulated with the **Non Linear Structural Mechanics** module.

Material & Methods

The geometry has been modelled from a 22 Y.O. patient eye from OCT *(figure 2)*. The *in-vivo* geometry was injected in the **parametric CAD model** to generate the patient's eye geometry *in-silico*. The eye was focusing on both far vision stimuli (0D - ∞) and near vision stimuli (6D – 0,17m).

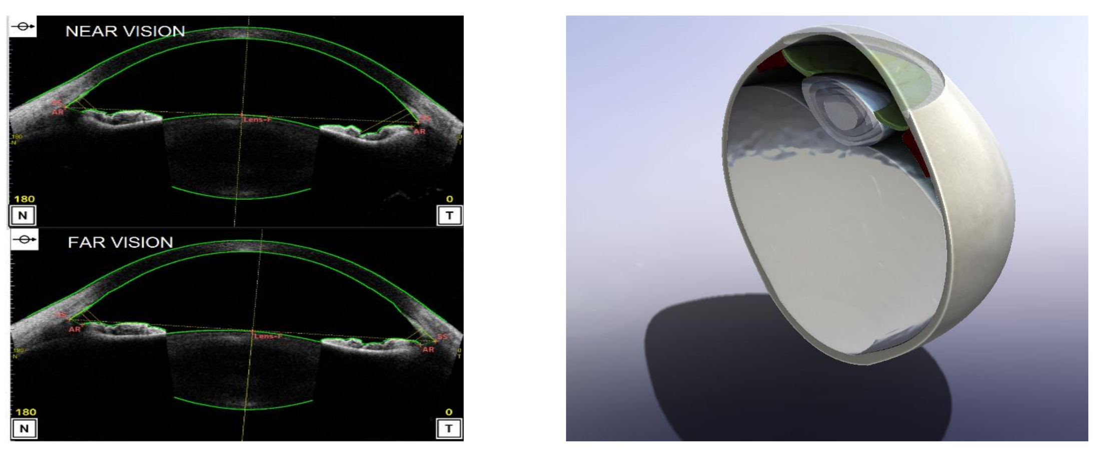

Figure 2: *(Left)* In vivo OCT-based imaging of a young emmetropic woman (22 Y.O.) in far and near vison. *(Right)* CAD model of the same patient in the near vision state.

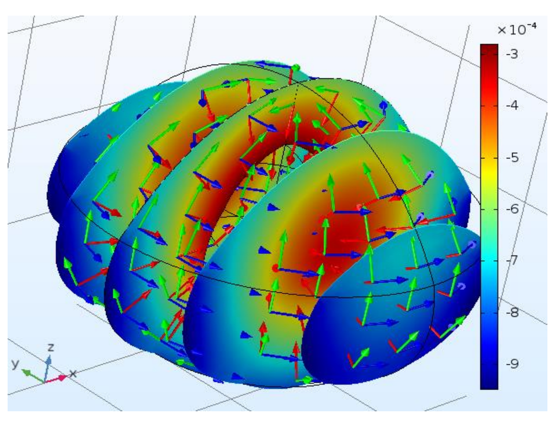

Figure 3: A gradient of distances in the lens is generated using the **Wall Distance** Physics and linked to the displacement field.

The near vision patient geometry was injected in the complete opto-mechanical parametric eye model (Figure 1).

Most studies consider the refractive index of the lens tissues as homogenous [1]. However many MRI [3] and *ex-vivo* studies highlight that the refractive index is graded in the lens and spatially dependent. To model this physiological property, the **Wall Distance** physic was used (Figure 3).

A two parameters function was then applied to the distance field generated to create a gradient of refractive index coherent with natural properties (Equation 1).

$$n = f(\boldsymbol{n_{plateau}}, \boldsymbol{G_{int}}, \boldsymbol{wd.Dw}, \boldsymbol{U})$$

Equation 1: spatial refractive distribution function with the following variable: $\boldsymbol{n_{plateau}}$: Maximal refractive central value // $\boldsymbol{G_{int}}$: gradient intensity // **wd.Dw** : vector of distance from the boundaries (normed in the function to obtain 0 at the periphery, 1 at the center) returned by *the wall distance physics* static step // **U** : displacement field

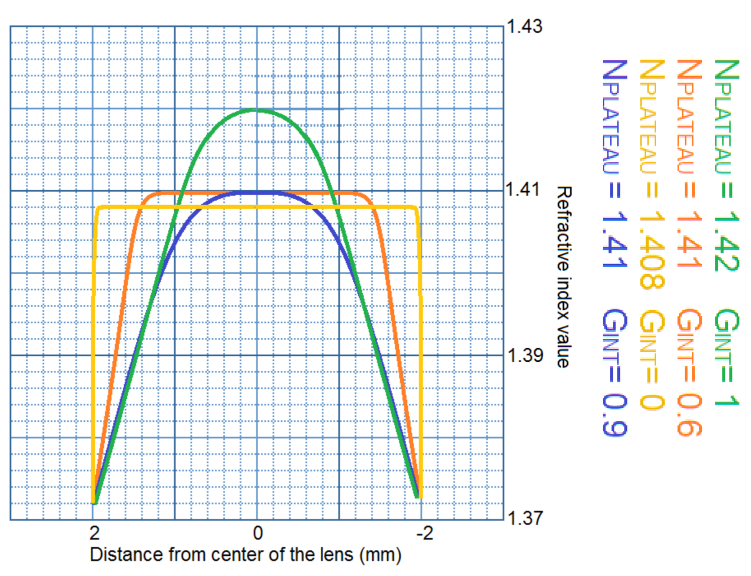

Figure 4: Effect of the two parameters on the gradient of refractive index through the optical axis.

The aim of the study is to compute the **lens refractive index and its spatial distribution** from the two extreme states of vision measured. We apply the following method:

- *A) From the near vision geometry, the model is set in tension with load ramping to achieve the deformation corresponding to far vision (tolerance : +/-5%)*
- *B) The equivalent refractive index corresponding to the far vision (0D) is computed with a parametric sweep on the value n of the lens materials*
- *C) With emmetropia as hypothesis, and using the previous equivalent refractive index value computed we deduce the corresponding distance of focus for the near vision geometry*
- *D) The equivalent refractive index corresponding to the near vision (6D) is computed with a parametric sweep on the value n of the lens materials*
- *E) A couple of parameters for the gradient of refractive index function matching both vision states is iteratively computed with parametric sweep on the two variables*

Results

A) Far vision geometry comparison with measurement (Table1) < 3%

B) Far vision equivalent refractive index $\boldsymbol{n_{FV}}$ **= 1.436**

C) Amplitude of accommodation obtained of **4,35 D**

D) Near vision equivalent refractive index $\boldsymbol{n_{NV}}$ **= 1.441**

E) A couple of parameters for the gradient function with $\boldsymbol{n_{plateau}}$ **= 1.4175** and $\boldsymbol{G_{INT}}$ **= 0.95**

Values	Expected	Simulated	%Difference
Thickness(mm)	3,440	3,440	0.00%
Ant. Curv. Radius (mm)	11,610	11,650	0,34%
Pos. Curv. Radius (mm)	6,240	6,400	2,56%
Ant/Pos. Disp. Ratio	0,810	0,805	0,62%

Table 1: The far vision geometry from simulation is coherent with the measurement values

Discussion

For both conditions of vision, and to achieve the amplitude of accommodation of 6D, two equivalent refractive index were needed for each position (coherent with [1]). Therefore a unique gradient could model perfectly both conditions with values coherent with the literature [2]. We highlight that the gradient of refractive index induces a **non linear optical response** of the optical power of the lens depending on its accommodative shape [5], *improving the amplitude of vision.*

Conclusion

We were able to deduce a non measured complex material gradient using reverse engineering from simple imaging. This kind of process could reveal really useful in the diagnosis and *in-vivo* characterization of the eye tissues in further studies.

This method could also be improved and automated with the addition of the **Optimization Module**.

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