INFLUENCE OF MECHANICAL PROPERTIES ON PHOTOREFRACTIVE KERATECTOMY OUTCOME

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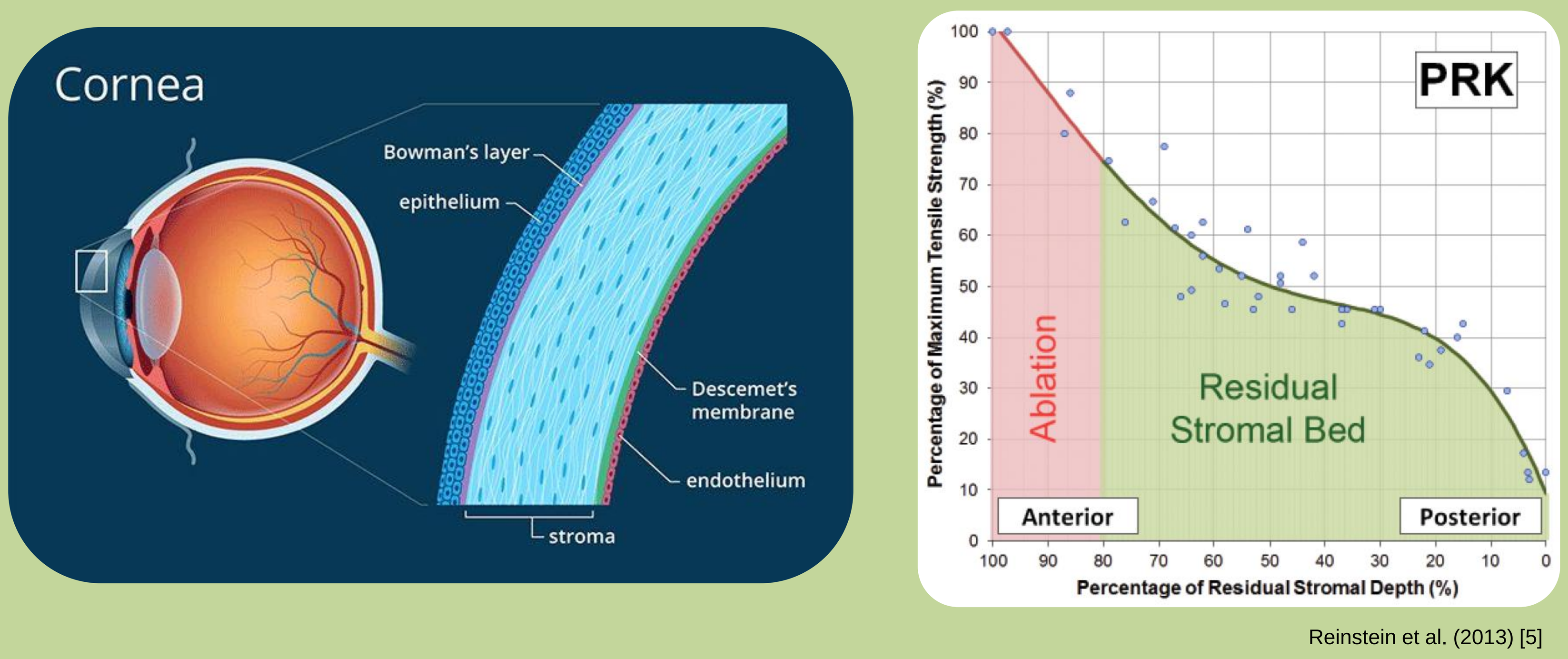
INTRODUCTION

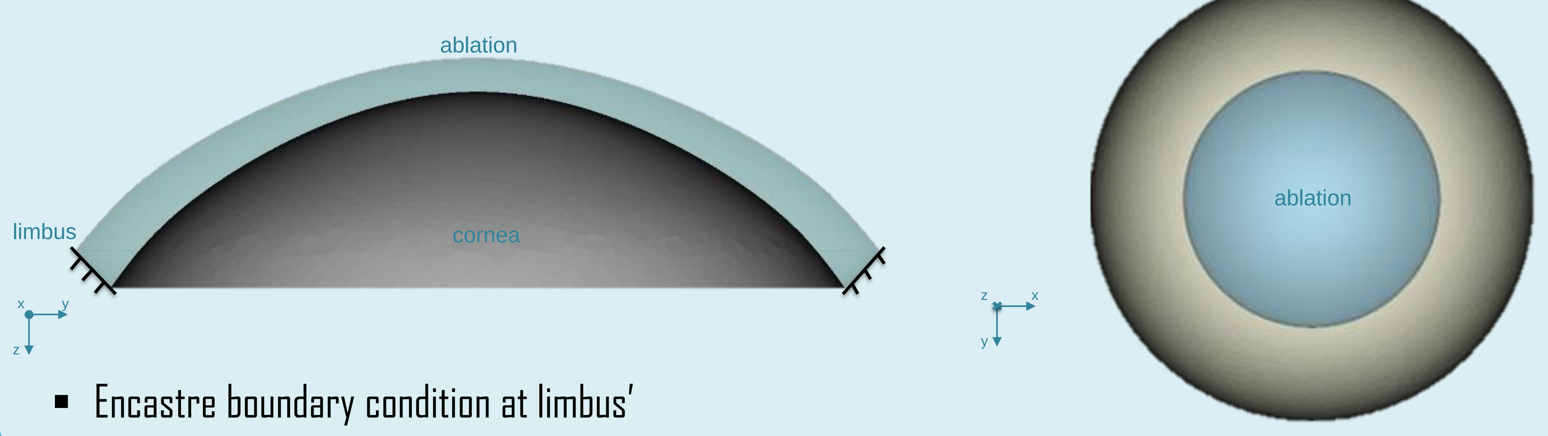
- Laser refractive surgeries are widely used in correction of vision defects such as **myopia** and **astigmatism**.
- **Photorefractive Keratectomy (PRK)** consists of reshaping the anterior corneal surface with a laser, by following an ablation profile [2], in order to achieve the spectacle independence (**desired diopters correction**).
- The removal of the ablation tissue affects the **biomechanics** of the cornea, causing deformations and stresses on the tissue, due to the action of the intraocular pressure (**IOP**) inside the eye cavity.
- In this work, a **FE model** of the cornea has been developed to address the influence of geometrical, physiological and material parameters on the final outcome of PRK surgery simulation.



Reinstein et al. (2013) [5]

MATERIALS AND METHODS

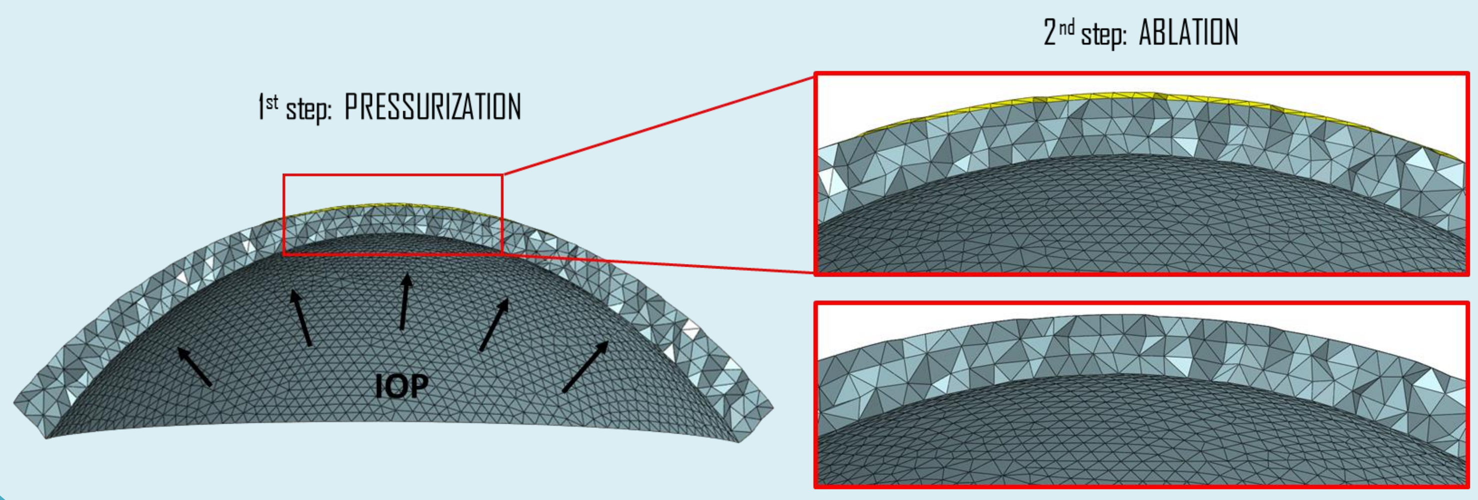
FE Model



- Encastre boundary condition at limbus'
- Zero-pressure algorithm

Navarro et al. (2013) [1]

PRK Surgery Simulation



Material Model

Strain energy density function

$$\psi = \psi^{\text{matrix}}(\bar{I}_1, J) + \sum_{i=4,6} \psi^{\text{fibers}}(C_{dis}, H_i)$$

Isotropic Neo-Hookean term + Volumetric term

$$\psi^m = C_{10}(\bar{I}_1 - 3) + \frac{1}{D}(lnJ)^2$$

Anisotropic Holzapfel-Gasser-Odgen term [1]

$$\psi^f = \frac{k_1}{2k_2}\left(e^{k_2(\bar{I}_i^* - 1)^2} - 1\right) \text{ for i=4,6 where}$$

$$\bar{I}_1^* = tr(H_i C_{dis}) = 2k_{ip}k_{op}\bar{I}_1 + 2k_{op}(1 - 2k_{ip})\bar{I}_i + \left(1 - 6k_{ip}k_{op} - 2k_{op}(1 - 2k_{ip})\right)\bar{I}_n$$

k_{ip}: in-plane dispersion $\in [0.1, 0.5]$
k_{op}: out-of-plane dispersion $\in [1/3, 0.5]$

C_{10} [kPa]	k_1 [kPa]	k_2 [-]	D [kPa^{-1}]
30	20	400	0,0003636

Wang et al. (2021) [2]

Statistical analysis

2^5 full factorial design

	C_{10} [kPa]	k_1 [kPa]	k_2 [-]	IOP [mmHg]	Thickness [μm]
Min	15	10	200	13	490
Max	45	30	600	18	550

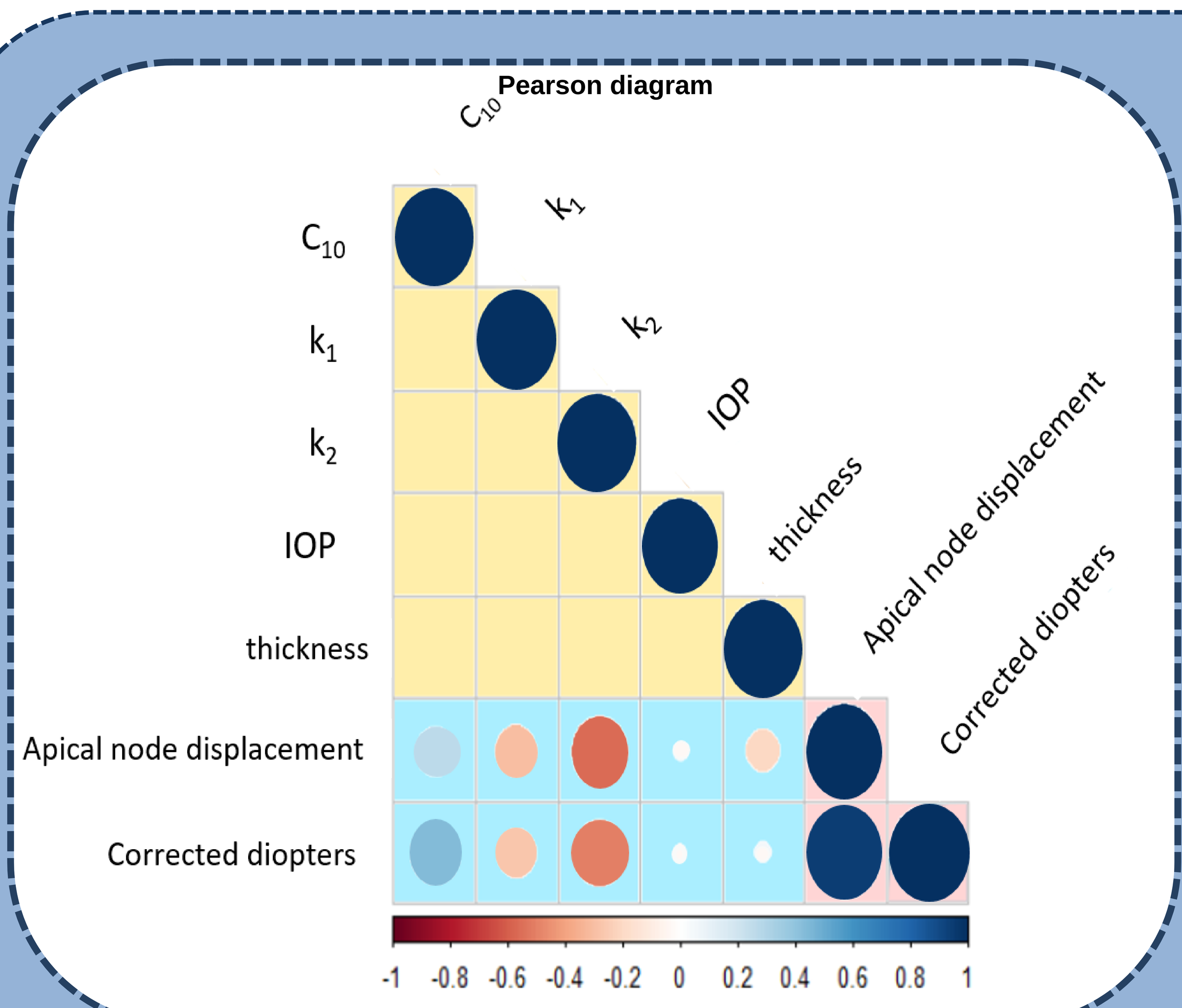
Simulations' outcomes considered:
- diopters corrected
- apex displacement of anterior corneal surface

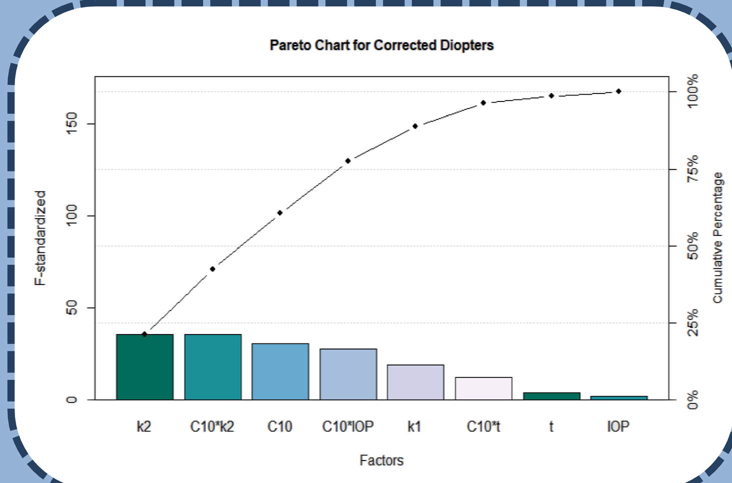
32 simulations to be analyzed

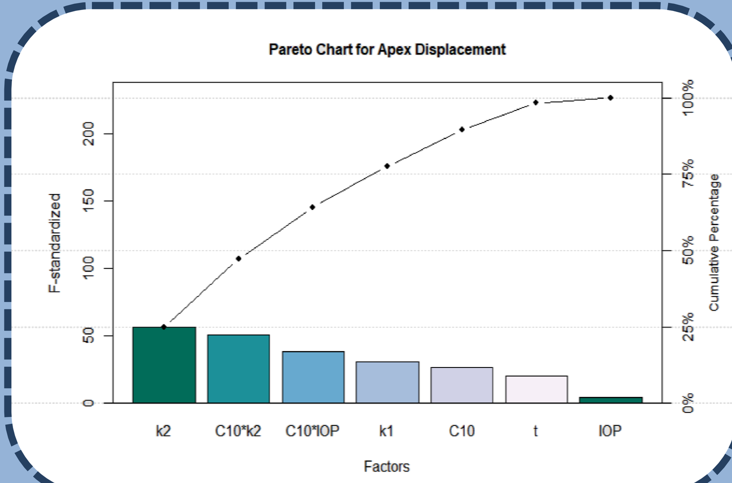
ANOVA statistical analysis

RESULTS

- The **constant k_2** turned out to be the **most influential factor**:
  - highly **non-linear contribution** of the anisotropic component of the material.
  - need of incorporating the collagen fibers when modeling the corneal tissue [2].
- **High influence** of C_{10} (isotropic contribution) and k_1 (fibers' stiffness).
- **Lower effect** of the IOP and the corneal thickness with respect to the other parameters.
- Also the **interaction** among the parameters was taken into account.







CONCLUSIONS

- In general, the material constants and their interactions have shown the major influence in determining the behavior of the corneal model.
- It is of major importance to set the proper material constants in order to perform a reliable PRK simulation, having as final goal the post-surgical optical quality of the patient.
- To achieve this goal, post-surgery mechanical deformations cannot be neglected.

REFERENCES

[1]. Navarro, R., Rozema, J. J., & Tassignon, M.-J. (2013). Optical Changes of the Human Cornea as a Function of Age. *American Academy of Optometry.*
[2]. Wang, S., & Hatami-Marbini, H. (2021). Constitutive Modeling of Corneal Tissue: Influence of Three- Dimensional Collagen Fiber Microstructure. *Journal of Biomechanical Engineering, 143*(3).
[3]. Cano, D., Barbero, S., & Marcos, S. (2004). Comparison of real and computer-simulated outcomes of LASIK refractive surgery. *Journal of Optical Society of America.*
[4]. Reinstein, D. Z., Archer, T. J., & Randleman, J. B. (2013). Mathematical model to compare the relative tensile strength of the cornea after PRK, LASIK, and small incision lenticule extraction. *Journal of Refractive Surgery, 29*(7), 454–460.

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