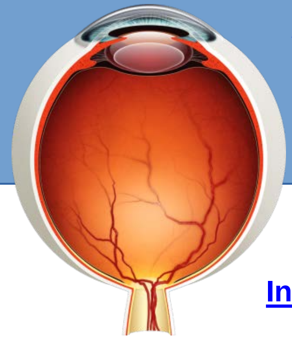

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Numerical Approach of the Ciliary Muscle Contraction. A Preliminary Step to Reproduce Human Accommodation

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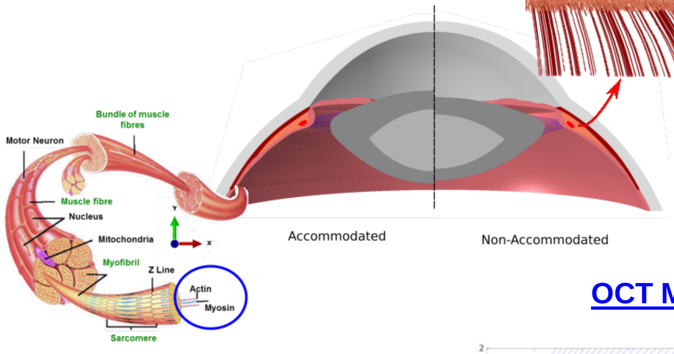
Introduction

- Eye accommodation is the process by which the eye changes optical power to focus on an object in a near or far distance
- The ciliary muscle is the engine of the accommodation process



- Muscle fibres generate force through the action of actin and myosin cross-bridge cycling and provoke different types of contraction

Objective: To model the ciliary muscle contraction by means of a thermodynamically consistent 3D electro-mechanical continuum model

Mathematical Model

Strain energy function

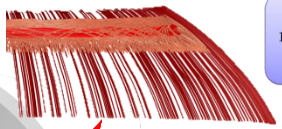
$$\Psi = \Psi_{vol}(J) + \bar{\Psi}_p(\bar{\mathbf{C}}, \mathbf{N}) + \bar{\Psi}_a(\bar{\mathbf{C}}_e, \bar{\lambda}_a, \mathbf{M})$$

Energy from collagen fibres — Energy stored in muscle fibres

$$\Psi = \Psi_{vol}(J) + \underbrace{\bar{\Psi}_p(\bar{I}_1, \bar{I}_2, \bar{I}_4)} + \underbrace{f_1(\bar{\lambda}_a) f_2(f_r, t) \bar{\Psi}'_a(\bar{J}_4)}$$

B. Calvo et al. 2010 — J.Grasa et al. 2013

Wagner et al. 2019



Contraction velocity relationship

$$\mathbf{P}_a - \frac{\partial \bar{\Psi}}{\partial \bar{\lambda}_a} + \left(2\bar{\mathbf{C}}_e \frac{\partial \bar{\Psi}}{\partial \bar{\mathbf{C}}_e} \bar{\mathbf{F}}_a^{-T}\right) : \frac{\partial \bar{\mathbf{F}}_a}{\partial \bar{\lambda}_a} = C \dot{\bar{\lambda}}_a$$

$$C = C(\bar{\lambda}_a) \geq 0$$

B. Hernandez et al. 2010

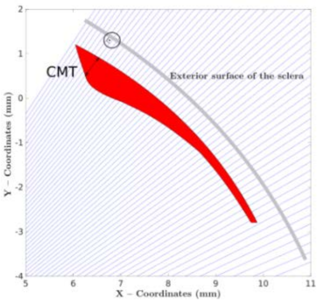
For the active response, let consider:

$$C = \frac{1}{v_0} P_0 f_1(\bar{\lambda}_a) f_2(f_r, t)$$
$$\bar{\Psi}'_a = P_0 \frac{1}{2}(\bar{J}_4 - 1)^2$$
$$P_a = -\nu P_0 f_1(\bar{\lambda}_a) f_2(f_r, t)$$

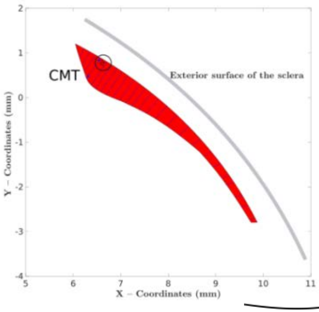
Active behaviour

$P_0 (MPa)$	$v_0 (m \cdot s^{-1})$	$\nu (s^{-1})$
1.50	0.90	0.59

OCT Measurement Techniques

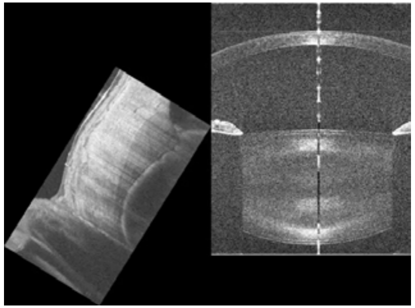


Strasser et al. 2020

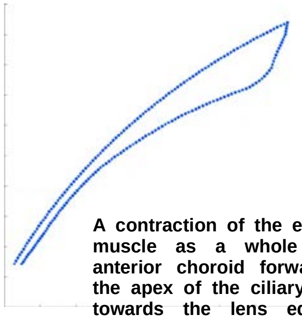


Ruggeri et al. 2016

Results

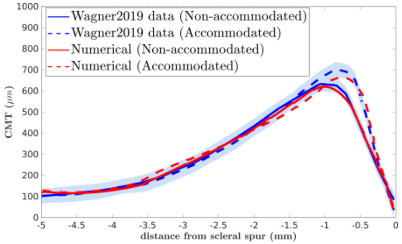


Ruggeri et al. 2016

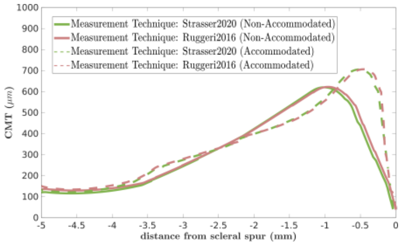


A contraction of the entire ciliary muscle as a whole pulls the anterior choroid forward, moves the apex of the ciliary processes towards the lens equator and serves the primary function of releasing resting zonular tension

Comparative of the numerical and experimental morphological contraction



Comparative of the OCT measurement techniques



Conclusions

- The morphology of the ciliary muscle contraction was accurately reproduced with the electro-mechanical continuum model proposed
- Ciliary muscle properties were calibrated according to experimental in vivo data
- There is not statistically significant difference between the OCT measurement techniques

References

[1] B. Calvo et al. 2010.
[2] J.Grasa et al. 2013.
[3] B. Hernández-Gascón et al. 2013.
[4] T. Strasser et al. 2020.
[5] M. Ruggeri et al. 2016
[6] S. Wagner et al. 2019