The role of the ciliary body in restoring accommodation

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Restoring accommodation

• Various attempts have been made to solve or bypass the problem:
  – Monovision to correct presbyopia
  – Multifocal vision to correct presbyopia (lens-based, corneal)
  – Laser treatment of the lens contents
  – Scleral expansion procedures
  – Accommodative intraocular lenses
    • Single optic IOLs with flexible haptic support
    • Dual optic IOLs
    • Deformable Accommodating IOLs
    • Cubic optical elements (Alvarez principle)
  – Refilling the empty lens capsule (lens refilling, Phakoersatz)
  – Mechatronic concepts
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In order to restore accommodation so as to treat presbyopia, we need an active ciliary body.
The process of accommodation

- In a phakic eye of a young subject, contraction of the ciliary muscle moves the apex of the ciliary body to release at-rest zonular tension around the lens equator.

- These changes, together with the elastic lens capsule, allow the lens to assume the accommodative state\(^1\).\(^2\).


The ciliary muscle activity of a iridectomized monkey eye
The ciliary muscle

- The primates accomplish accommodation and disaccommodation through the action of the parasympathetically dominated ciliary smooth muscle.
- The muscle is attached anteriorly by means of true tendons to the scleral spur and trabecular network.
- It is attached posteriorly to the elastic network of Bruch’s membrane of the choroid.
Challenge

- Quantification of ciliary muscle contour changes during accommodation
- Hurdles:
  - Dynamics of accommodation
  - Ciliary body invisible hidden behind the iris
  - Ciliary muscle contour partly interferes with the ciliary processes anatomy

*Dynamic of accommodation, human eye*
Contour quantification during accommodation

- The existence of the ciliary processes complicate a precise quantification of the ciliary muscle structure.

UBM sequence in slow motion of a human subject under cyclopentolate

different cross sections of the ciliary body in 200 microns distance

Displayed ciliary body sections uninfluenced by accommodation process.
The ability to apply selective sections through the ciliary body is necessary to quantify ciliary muscle changes during accommodation.

3D ultrasound biomicroscopy
3D HF ultrasound for selective sectioning the ciliary body
(anterior segment viewed from behind)

3D Reconstruction of the human ciliary body

ciliary muscle

ciliary muscle and processes
Image acquisition, analysis and contour approximation

- pharmacologically induced accommodation
- 3D scan in accommodation and disaccommodation
- oblique slice reconstruction across ciliary muscle resp. ciliary muscle + ciliary processes
- contour approximation
- contour comparison

Image analysis

- The posterior wall of the iris had to be differentiated from the neighboring ciliary muscle

Approximation:
- ciliary muscle base: parabola
- posterior wall of the iris: straight line.

- The scleral spur served as a landmark for rotation the individual contours for averaging and contour comparison.

Contour approximation of one ciliary muscle section, typical example.
Investigated points of interest

*Contour comparison:*
- accommodated
- disaccommodated

**Anterior contour point**

**Lower contour point**

**Center of gravity**

Stachs O. *in Current Aspects of Human Accommodation part II*, R. Guthoff and K. Ludwig (Eds.), Kaden Verlag 2003, 105-118
Questions

• How does the muscle contour change during accommodation?

• Are there age dependent differences?

• Are there differences between phakic and pseudophakic eyes?
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• *Are there age dependent differences?*

• *Are there differences between phakic and pseudophakic eyes?*
Contour changes during accommodation

The contour of the ciliary body during accommodation and disaccommodation superimposed with a histological section

Hermann von Helmholtz (1855)
Ciliary body during accommodation and disaccommodation

By occurrence of an accommodation stimulus, a shift of the contour points (center of gravity Pf, anterior contour point Pv, and the lower contour point Pu) in direction to the lens equator is shown.

<table>
<thead>
<tr>
<th>Ciliary Muscle</th>
<th>Ciliary Muscle with Ciliary Processes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>Blue</td>
</tr>
<tr>
<td>Disaccommodation</td>
<td>Disaccommodation</td>
</tr>
<tr>
<td>Black</td>
<td>White</td>
</tr>
<tr>
<td>Accommodation</td>
<td>Accommodation</td>
</tr>
</tbody>
</table>
Questions

• How does the muscle contour change during accommodation?

• *Are there age dependent differences?*

• Are there differences between phakic and pseudophakic eyes?
The investigations show an activity of the ciliary muscle in young volunteers as well as in presbyopic age.
A shift of the ciliary muscle center of gravity from 0.04 up to 0.26 mm in direction of the lens equator was observed.

The investigations show a ciliary muscle activity in young volunteers as well as in presbyopical age.

Displacement of Centre Points as a result of pilocarpine stimulated accommodation
Ciliary Muscle Activity

<table>
<thead>
<tr>
<th>Contour point</th>
<th>Age of volunteers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>34 years</td>
</tr>
<tr>
<td></td>
<td>71 years</td>
</tr>
<tr>
<td>Center of gravity $P_f$</td>
<td>0.17 mm</td>
</tr>
<tr>
<td>Anterior contour point $P_v$</td>
<td>0.36 mm</td>
</tr>
<tr>
<td>Lower contour point $P_u$</td>
<td>0.56 mm</td>
</tr>
<tr>
<td></td>
<td>0.05 mm</td>
</tr>
<tr>
<td></td>
<td>0.18 mm</td>
</tr>
<tr>
<td></td>
<td>0.28 mm</td>
</tr>
</tbody>
</table>


Shift of the characteristic contour points during accommodation using the ciliary muscle of a young volunteer and an old volunteer.
Questions

• How does the muscle contour change during accommodation?

• Are there age dependent differences?

• Are there differences between phakic and pseudophakic eyes?
Displacement of Centre Points as a result of pilocarpine stimulated accommodation

The figure shows a ciliary muscle activity in old phakic eyes as well as in old pseudophakic eyes.
During accommodation in the investigated pseudophakic eyes a shift in the ciliary muscle center of gravity of median 0.12 mm towards the lens equator in comparison to that of phakic eyes with median of 0.11 mm was observed.
Examples for studies concerning ciliary muscle activity

<table>
<thead>
<tr>
<th>Study</th>
<th>Years</th>
<th>Method</th>
<th>Specimens</th>
<th>Ciliary muscle function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ostrin</td>
<td>2007</td>
<td>infrared photorefraction, goniovideography</td>
<td>monkeys</td>
<td>present with age-related decrease</td>
</tr>
<tr>
<td>Croft</td>
<td>2006</td>
<td>goniovideography, UBM</td>
<td>monkeys</td>
<td>present with age-related decrease</td>
</tr>
<tr>
<td>Stachs</td>
<td>2002</td>
<td>UBM</td>
<td>10 persons 20-70 years</td>
<td>present with age-related decrease</td>
</tr>
<tr>
<td>Glasser</td>
<td>2001</td>
<td>UBM, Video</td>
<td>Monkeys</td>
<td>present</td>
</tr>
<tr>
<td>Bacskulin</td>
<td>2000</td>
<td>UBM</td>
<td>105 persons 10-91 years</td>
<td>present</td>
</tr>
<tr>
<td>Strenk</td>
<td>1999, 2006</td>
<td>MRI</td>
<td>humans</td>
<td>present with age-related decrease</td>
</tr>
<tr>
<td>Bacskulin</td>
<td>1996</td>
<td>UBM</td>
<td>10 persons 54-86 years</td>
<td>partially present</td>
</tr>
<tr>
<td>Kalman</td>
<td>1993</td>
<td>Video</td>
<td>4 persons 16-48 years</td>
<td>present</td>
</tr>
<tr>
<td>Neider</td>
<td>1990</td>
<td>Video</td>
<td>14 monkeys 1-24 years</td>
<td>present with age-related decrease</td>
</tr>
<tr>
<td>Lütjen-Drecoll</td>
<td>1988</td>
<td>Morphological study</td>
<td>44 monkeys 0-35 years</td>
<td>muscle &amp; nerve degeneration</td>
</tr>
<tr>
<td>Fischer</td>
<td>1977</td>
<td>Model calculations</td>
<td>27 persons 15-55 years</td>
<td>present</td>
</tr>
<tr>
<td>Swegmark</td>
<td>1969</td>
<td>Impedance cyclography</td>
<td>Persons up to 60 years of age</td>
<td>present</td>
</tr>
</tbody>
</table>
MRI for age related changes in human ciliary muscle and lens

- Change in the ciliary muscle ring diameter by an 8 Dpt. Accommodation stimulus as a function of age
- For all subjects, the ciliary muscle continuous to contract with accommodation, even for advanced prebyopes
Accommodative Ciliary Body and Lens Function in Rhesus Monkeys

Centripetal ciliary body and lens equator movements were measured during accommodation in monkeys by goniovideography.

Average centripetal ciliary body movement in older eyes was 20% less than in young eyes.
• When monitoring ciliary muscle activity, we need to differentiate between ciliary muscle sections with and without ciliary processes, respectively.

• During pharmacologically stimulated accommodation, the ciliary muscle moves centripetally in the direction of the lens, covering a distance up to 0.3 mm (ciliary processes 0.5 mm), depending on the age and the subject.

• **Accommodative ciliary muscle activity was observed even in presbyopic eyes, which goes to show that ciliary muscle activity is not the limiting factor in restoring accommodation.**
• „Measure what is measurable, everything that is not measurable, make measurable.“

Galileo Galilei
Micro MRI, enucleated human eyes, 7.1T, ClinScan, Bruker Bioscan GmbH

40 years

85 years
AMO Groningen
T. Terwee

Institute for Biomedical Engineering
University of Rostock
Prof. Dr. Schmitz
Dr. H. Martin

Department of Ophthalmology
University of Rostock
Prof. Dr. R. Guthoff
Prof. Dr. J. Stave
Dr. H. Schneider
Dr. O. Stachs