Optic Nerve Head Biomechanical Strain as a Potential Biomarker for Progression in High and Pathologic Myopia

Donny Q.V. Hoang, M.D., Ph.D
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Overview

• Purpose: To determine if biomechanical changes in the optic nerve head (ONH) can serve as a biomarker for progression in high myopia (HM).

• Methods: 53 eyes of 53 subjects: 11 low myopia (LM), 17 HM and 25 pathologic myopia (PM), underwent macular and ONH SD-OCT scans in: (0) primary gaze, (1) with acute IOP elevation (to ~40 mmHg) through ophthalmodynamometry. (2) 20° adduction, (3) 20° abduction, and (4) supine.
  – Scans were segmented for prelaminar tissue (PLT) and lamina cribrosa (LC) using deep learning and digitally-aligned before performing digital volume correlation (DVC) analysis to quantify IOP- and gaze-induced PLT and LC displacements and calculate the effective strain.

• Conclusion: HM eyes tend to be more sensitive to IOP elevation as compared to LM eyes. PM eyes experienced abnormally high strains and they were equally influenced by IOP elevation and adduction.

• ONH strain differs significantly between LM, HM and PM eyes and has the potential to serve as a biomarker for progression.
Background

- A link between myopia and glaucoma has long been reported, with HM eyes shown to have increased susceptibility to glaucoma, and glaucomatous characteristics present in myopic optic discs. *(Nagaoka et al. PLoS One. 2015)*

- Although many studies have explored palliative therapies for the vision-threatening changes in high myopia and glaucoma, only a fundamental understanding of the biomechanical alterations in scleral tissue underlying these changes will allow for preventive therapies.

- We therefore use ophthalmodynamometry, deep learning and digital volume correlation analysis to quantify effective strain in the posterior layers of LM, HM and PM eyes.
Overview

• 3 Conditions – Low Myopia (11), High myopia (17), Pathologic myopia (25)

• 4 Loads – Acute IOP elevation, 20° Adduction, 20° Abduction, Supine (CSFP elevation)

• 4 Tissues analyzed – Prelamina, Choroid, Sclera, Lamina

• Outputs – Effective strain, displacement magnitude, posterior displacement magnitude with respect to BMO
  – Each volume has approximately 3000 tracking points, each point has the corresponding output parameters mentioned above.
AI-based Segmentation to identify ONH Tissue on OCT

Baseline (Normal Gaze) Scan
Example of a Fully-Segmented Volume
Displacement Vectors in Response to IOP elevation
Deformation Tracking for Eye undergoing IOP elevation

*Nasal*

*Temporal*

*displacement exaggerated by 5 times*
Deformation Tracking during ADduction

*displacement exaggerated by 5 times
Deformation Tracking during ABduction

*Nasal*  

Temporal

Eye Rotation

*displacement exaggerated by 5 times*
Strain Visualization – IOP Elevation
PM eyes have higher effective strain than LM

Significant difference at $p = 0.05$

<table>
<thead>
<tr>
<th></th>
<th>Low Myopia</th>
<th>High Myopia</th>
<th>Pathologic Myopia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average effective strain</td>
<td>0.0320</td>
<td>0.0322</td>
<td>0.0427</td>
</tr>
</tbody>
</table>

Low Myopia $n = 11$  
High Myopia $n = 17$  
Path Myopia $n = 25$
Average effective strain (by myopia level and region)

Low myopia

Pathologic myopia

High myopia

Central region = best-fit circle to Bruchs membrane opening
Adduction results in the highest strain.

<table>
<thead>
<tr>
<th></th>
<th>IOP</th>
<th>Adduction</th>
<th>Abduction</th>
<th>Supine</th>
</tr>
</thead>
<tbody>
<tr>
<td>average effective strain</td>
<td>0.0381</td>
<td>0.0400</td>
<td>0.0392</td>
<td>0.0373</td>
</tr>
</tbody>
</table>

![Box plot showing strain comparison](image)
Average effective strain (by load and region)

IOP elevation

ADduction

ABduction

Supine

Average effective strain (by load and region)
Lamina Cribrosa Experiences the Highest Effective Strain

<table>
<thead>
<tr>
<th>average effective strain</th>
<th>Prelamina</th>
<th>Choroid</th>
<th>Sclera</th>
<th>Lamina</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.0374</td>
<td>0.0336</td>
<td>0.0341</td>
<td>0.043</td>
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</tbody>
</table>

Bar chart showing the average effective strain for Prelamina, Choroid, Sclera, and Lamina Cribrosa.
IOP Elevation Results in the Largest Posterior Displacement

<table>
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<th>Abduction</th>
<th>Supine</th>
</tr>
</thead>
<tbody>
<tr>
<td>average posterior displacement (micron)</td>
<td>-2.90</td>
<td>-1.34</td>
<td>-0.60</td>
<td>0.002</td>
</tr>
</tbody>
</table>
Summary

• PM eyes experience significantly (p < 0.05) higher strains than LM and HM eyes.
• Central regions of the ONH experience significantly higher strain than peripheral.
• Nasal regions experience significantly higher strain than other regions.
  – This is especially true under Adduction.
• Adduction exerts highest strain on the tissue.
• LC tissue tends to experience highest strain as compared to other tissue.
• IOP elevation causes the ONH tissue to displace posteriorly – this is a distinct feature as compared to other type of loads.
• ONH strain differs significantly between LM, HM and PM eyes and has the potential to serve as a biomarker for progression.
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  donny.hoang@snec.com.sg