Achieving Proper Centration and Alignment for Vision Correction in Intraocular and Keratorefractive Surgery

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  - Mt Pleasant, SC

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Course Outline

- Introduction (Chang)
  - Importance of centration and alignment
  - Ocular axes and angles
  - Purkinje images

- Centering and aligning keratorefractive procedures
  - Laser Vision Correction (Waring)
  - Corneal inlays (Waring)

- Centering and aligning intraocular procedures
  - Diffractive and Toric IOLs (Chang)
  - Toric IOL re-alignment (Berdahl)

- Discussion / Conclusion

Introduction

Importance of centration and alignment

IOL Centration

- Good centration important
  - Maximize visual quality
  - Minimize visual side-effects

- Aspheric IOLs
  - Advantage lost when >0.8 mm decentration

- Diffractive multifocal IOLs
  - Effects not yet quantified
  - “Scapegoat” to explain why some patients with good Snellen VA are unhappy
**IOL Centration**

**Definition**

- **Laboratory studies**
  - Optical center or pupil (dilated) center
  - Scheimpflug or Purkinje devices to find IOL center
- **Clinical observation**
  - Monofocal IOLs
    - Edge not seen in pupil
  - Multifocal IOLs
    - Pupil center
      - Rings concentric with pupil
    - What about visual axis?

**Introduction**

**Ocular Axes and Angles**

- **Ocular Axes**
  - Optical Axis
    - Alignment of all 3 Purkinje images
  - Pupillary Axis
    - Pupil center / orthogonal to cornea
  - Line of Sight
    - Pupil center to fixation point
  - Visual Axis
    - Nodal point to fixation point
- **Ocular Angles**
  - Angle $\alpha$ (alpha)
    - Optical Axis to Visual Axis
  - Angle $\kappa$ (kappa)
    - Pupillary Axis to Line of Sight
    - Originally: Pupillary Axis to Visual Axis
  - Angle $\lambda$ (lambda)
    - Pupillary Axis to Line of Sight
    - Less commonly used than angle $\kappa$

Eye model / research definitions were not intended for intraocular surgery use.
Ocular Axes

Optical Axis

Undefined with lens / IOL tilt or decentration
(Purkinje images do not align)

Pupillary Axis

Changes with pupil centroid shift
(Can occur with dilation)

Line of Sight

Pupil center to fixation point
Ocular Axes
Line of Sight
Changes with pupil centroid shift
(Can occur with dilation)

Ocular Axes
Visual Axis
Nodal point to fixation point

Ocular Axes
Visual Axis
Has been defined as
0, 1, or 2 Nodal Points

Ocular Axes
Angle α
Optical Axis to Visual Axis

Where is the nodal point?
Theoretical concept in paraxial eye model
Ocular Axes
Angle $\kappa$ (original definition)

Pupillary Axis to Visual Axis

Ocular Axes
Angle $\lambda / \kappa$ (new definition)

Pupillary Axis to Line of Sight

**PERSPECTIVE**
The Subject-Fixated Coaxially Sighted Corneal Light Reflex: A Clinical Marker for Centration of Refractive Treatments and Devices

DANIEL H. CHANG AND GEORGE O. WARING IV

**PURPOSE:** To describe the inconsistencies in definitions, application, and usage of the ocular reference axes (optical axis, visual axis, line-of-sight, pupillary axis, and topographic axis) and angles (angle kappa, lambda, and alpha) and to propose a precise, reproducible, clinically defined reference marker and axis for centration of refractive treatments and devices.

**DESIGN:** Prospective

**MATERIALS:** Literature review of papers dealing with ocular reference axes, angles, and centration.

**RESULTS:** The inconsistent definitions and usage of the current ocular reference axes have led to a lack of transparency and reproducibility of studies and devices. This has also limited the reproducibility, reliability, and accuracy of the studies and devices. The subject-fixated corneal light reflex provides a precise, reproducible, and clinically defined reference marker and axis for centration.

**CONCLUSION:** This novel approach to centration of refractive treatments and devices has the potential to improve patient outcomes.

Ocular Axes
Foveal Fixation Axis

Line that connects the Fovea and the Fixation Point

*In concept only
Unless there is perfect alignment of all 4 refractive surfaces, no light ray goes unbent

Ocular Axes and Angles
Problems with Application

- Cannot be defined in some (all?) eyes
  - Somewhat useful to communicate concepts
- How to translate into clinical and surgical practice
  - How do we find the visual axis or pupillary axis on a real eye?
  - What about pupil centroid shifting?

Ocular Landmarks for Positional Reference
Needs

- Feasibility in identification (of landmarks)
- Precision in definition
  - May need additional qualifications
    - Lighting conditions
    - Viewing / light source arrangement
    - Fixation
- Consistency in usage

We need a consistently registered coordinate system

Ocular Landmarks for Positional Reference
Candidates

- Pupil (center)
- Purkinje images
- Limbus (center)
- Anatomical apexes
Ocular Landmarks for Positional Reference

Pupil Center

Photopic

Need to specify lighting condition

Scotopic

Purkinje Images

- Reflections from the light-transmitting interfaces
- Four Purkinje reflections
  - PI: anterior cornea
  - PII: posterior cornea
  - PIII: anterior lens/IOL
  - PIV: posterior lens/IOL

Ocular Landmarks for Positional Reference

Purkinje Images

Intraoperative

Need to specify fixation

Postoperative

Ocular Landmarks for Positional Reference

Purkinje Images

Acrysof IQ ReSTOR SN6AD1

Crystalens Five-0 AT50SE

Tecnis Multifocal ZMB00
**Purkinje Images: PI**

- PI: Reflection from **anterior** corneal surface
  - Corneal light reflex
    - Air / anterior cornea (tear film)
    - Bright, upright image
  - Applications
    - Keratometry
    - Corneal topography / Video keratoscopy
    - Commercial eye tracking applications

**Corneal Light Reflex**

**Video keratoscopy**

**Intraoperative appearance**
- Depends on microscope light configuration
  - Zeiss Opmi Lumera has three lights
    - Broad illumination beam
    - Stereo coaxial illumination (SCI)
    - Unaffected by surgical instrumentation
    - Altered by shape of cornea

**Purkinje Images: PII**

- PII: Reflection from **posterior** corneal surface
  - Specular reflection
    - Posterior cornea: aqueous
    - Dim, upright image
      - Can be seen intraoperatively with air in the AC
  - Application
    - Specular microscopy

**Specular Microscopy**

**Purkinje Images: PIII**

- PIII: Reflection from **anterior** lens / IOL surface
  - Not seen in phakic eyes
    - Aqueous: anterior lens / IOL
    - Variable brightness, typically upright
      - Depends on IOL power
      - Fringing with diffractive rings
    - "Cat's eye reflex"
      - High index materials
      - Flat anterior IOL curvature

**Posterior Diffractive Rings**

**Anterior Diffractive Rings**
Purkinje Images: PIV

- PIV: Reflection from posterior lens / IOL surface
  - Faintly visible in some phakic eyes
    - Posterior IOL: aqueous / capsule / vitreous
  - Variable brightness, typically inverted
    - Depends on IOL power
    - Fringing with diffractive rings
    - Stretched by toric surface
    - Affected by IOL chromophore

Posterior Diffractive Rings  Anterior Diffractive Rings
Purkinje Images
Characteristics

<table>
<thead>
<tr>
<th>Source</th>
<th>PI</th>
<th>PII</th>
<th>PIII</th>
<th>PIV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source</td>
<td>cornea,</td>
<td>cornea,</td>
<td>lens/iol,</td>
<td>lens/iol,</td>
</tr>
<tr>
<td>anterior surface</td>
<td>posterior surface</td>
<td>anterior surface</td>
<td>posterior surface</td>
<td></td>
</tr>
<tr>
<td>Seen Clinically</td>
<td>yes</td>
<td>rarely</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Image Location</td>
<td>anterior lens/iol</td>
<td>anterior vitreous</td>
<td>corneal surface</td>
<td></td>
</tr>
<tr>
<td>Size*</td>
<td>smallest</td>
<td>—</td>
<td>largest</td>
<td>medium</td>
</tr>
<tr>
<td>Brightness*</td>
<td>bright</td>
<td>—</td>
<td>dim to very bright</td>
<td>medium to bright</td>
</tr>
<tr>
<td>Orientation*</td>
<td>upright</td>
<td>—</td>
<td>upright (usually)</td>
<td>inverted (usually)</td>
</tr>
<tr>
<td>Movement</td>
<td>slow</td>
<td>—</td>
<td>rapid</td>
<td>medium</td>
</tr>
</tbody>
</table>

*PIII and PIV dependent on IOL power

Global Presbyopic Population

<table>
<thead>
<tr>
<th>Region</th>
<th>Total Population (Millions)</th>
<th>2020 Presbyopes (Millions)</th>
<th>% of Population</th>
<th>Economic Means (Millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Singapore</td>
<td>5.0</td>
<td>2.6</td>
<td>46.0%</td>
<td>1.2</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>7.3</td>
<td>3.6</td>
<td>49.3%</td>
<td>1.4</td>
</tr>
<tr>
<td>Japan</td>
<td>121.6</td>
<td>60.9</td>
<td>50.1%</td>
<td>23.1</td>
</tr>
<tr>
<td>US</td>
<td>341.4</td>
<td>125.2</td>
<td>36.7%</td>
<td>57.6</td>
</tr>
<tr>
<td>Western Europe</td>
<td>393.4</td>
<td>176.0</td>
<td>44.7%</td>
<td>68.6</td>
</tr>
</tbody>
</table>

-2013: more than 140 million presbyopes in the U.S.
-2020: 2.1 billion presbyopes worldwide.

Source: CIA World Factbook for Population/Age & Market Scope
Where should you place an inlay?

A. Pupil center  
B. First purkinje  
C. Other

Centration guidance system

Inlay Placement

- Target inlay placement over the 1st Purkinje
- If there is a significant difference between 1st Purkinje and pupil center, place inlay halfway between
- The guideline for inlay placement is to target within 300 microns from desired position
Pre-Op Purkinje Results

- Provided centration planning metrics:
  - Purkinje vs Pupil Cord Length (μm)
  - Purkinje vs Pupil Angle (degree)
  - Purkinje vs Pupil (x/y distance in μm, direction)

Post-Op Purkinje Results

- Provided achieved centration metrics:
  - Purkinje vs Pupil Cord Length (μm)
  - Purkinje vs Pupil Angle (degree)
  - Purkinje vs Pupil (x/y distance in μm, direction)
  - Inlay vs Pupil (x/y distance in μm)
  - Inlay vs Purkinje (x/y distance in μm)

Guiding Recentration

- Immediately Post-op
- After Recentration

**Inlay Location**
- 511 microns temporal
- 98 microns superior

**Day 1 Post-Op**
- 20/25, J3

**Inlay Location**
- 9 microns temporal
- 90 microns superior
**Case 1: Centration Planning**

Pre-Op Data:
1) Purkinje vs Pupil:
   - -375μm (x)
   - -219μm (y)
2) Cord Length: 435μm

Inlay Placement Target:
1) Inlay vs Pupil:
   - 186μm (x)
   - 110μm (y)
2) Inlay vs Purkinje:
   - 186μm (x)
   - 110μm (y)

**Case 2: Centration Planning**

Pre-Op Data:
1) Purkinje vs Pupil:
   - 110μm (x)
   - 50μm (y)
2) Cord Length: 121μm

Target Inlay Placement:
1) Inlay vs Pupil:
   - 110μm (x)
   - 50μm (y)
2) Inlay vs Purkinje:
   - 0μm (x)
   - 0μm (y)

Courtesy of Ray Applgate

**Centration and Laser Vision Correction**
Summary

- Centration is an important consideration in keratorefractive surgery
- Preoperative assessment of “angle kappa” and anatomy aids in successful placement
  - Similar to planning with topography
- New diagnostic and intraoperative technology
- Improved our understanding of importance of centration for all refractive surgery
  - LVC
    - Presbylasik
  - MFIOLs

Thank You

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www.georgewaringiv.com

Centering and aligning intraocular procedures

Diffractive Multifocal IOLs

Identifying Ocular Axes: Clinical
Use Purkinje Images

Pupil Center
Subject Fixated Coaxially Sighted Corneal Light Reflex
Identifying Ocular Axes: Clinical

2D projection

- 2D anterior segment imaging
  - Precise X-Y axis information
  - No depth (Z-axis) information
  - Pupillary axis and Line of sight are represented as same coordinate on the image

But are they?

Ocular Landmarks for Positional Reference

2D projection

Pupillary Axis

Foveal-Fixation Axis

Where is the system being viewed from?

Clinical / Surgical View

Line of Sight is most accurate descriptor of pupil location…but connotes the wrong concept.

Line of Sight
Ocular Landmarks for Positional Reference

SF-CSCLR Axis

The Subject-Fixated Coaxially Sighted Corneal Light Reflex (SF-CSCLR) Axis

The SF-CSCLR / SF-CSCLR axis could serve as the reference point for centration...and tilt.

Now that we have an axis, we can begin to study tilt.

Ocular Landmarks for Positional Reference

SF-CSCLR Axis and Tilt

Chord µ (µscotopic): 0.36 mm @ 203°
Ocular Landmarks for Positional Reference

Chord μ (µ)

- Small chord μ (µ) = 0.09 mm
- Large chord μ (µ) = 0.46 mm

Identifying Ocular Axes: Clinical

Clinical Markers for Centration and Alignment

<table>
<thead>
<tr>
<th>Name</th>
<th>Definition</th>
<th>Closest Historical Equivalent</th>
<th>Abbreviation</th>
<th>Alternate Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foveal-Fixation Axis</td>
<td>Line from Fovea to Fixation point</td>
<td>Visual Axis</td>
<td>FFA</td>
<td>—</td>
</tr>
<tr>
<td>Subject-Fixated Coaxially Sighted Corneal Light Reflex</td>
<td>—</td>
<td>Corneal Vertex</td>
<td>SF-CSCLR</td>
<td>Chang-Waring Reflex / CW Reflex</td>
</tr>
<tr>
<td>Subject-Fixated Coaxially Sighted Corneal Light Reflex Axis</td>
<td>Line from SF-CSCLR to Fixation point</td>
<td>—</td>
<td>SF-CSCLR Axis</td>
<td>Chang-Waring Axis / CW Axis</td>
</tr>
<tr>
<td>Chord μ</td>
<td>Line from SF-CSCLR to Pupil Center</td>
<td>Angle K</td>
<td>Chord μ</td>
<td>Chang-Waring Chord / CW Chord</td>
</tr>
</tbody>
</table>

Zeiss IOLMaster 700

**Identifying Ocular Axes: Surgical**

*Use Purkinje Images*

- **Optical Axis**
- **SF-CSCLR Axis**
- **Pupil Center**
- **Line of Sight / Pupillary Axis**

**Ocular Axes and Centration**

- **Small CW-Chord**
  - CW-Chord: 0.09 mm
  - IOL Centration: SF-CSCLR

- **Large CW-Chord**
  - CW-Chord: 0.37 mm
  - IOL Centration: Neither

**Intraoperative IOL Positioning**

- **IOL position can be adjusted**
  - Can primarily be moved in direction perpendicular to area of peripheral bag-haptic contact
  - Depends on IOL material and design
    - **Tecnis Multifocal 1-Piece IOL**
      - Hydrophobic acrylic
      - Modified C loop haptics

  Direction of best movement is ~30° to 45° clockwise from (to the right of) haptic insertion

**Ocular Axes and Centration**

- **Optically**
  - Best to center on SF-CSCLR Axis / FFA
  - Hyperopic LASIK
  - Eye model studies

- **Cosmetically**
  - “Looks better” to center on pupillary axis
  - Pupil easy to see intraoperatively
    - Reference for capsulotomy creation
    - Easy to see at slit lamp postoperatively

**SF-CSCLR Axis / FFA centration provides best visual outcomes**
Intraoperative IOL Positioning

Vector Forces

- IOL Shifted to Left
- "Centered" in bag
- IOL Shifted to Right

Slight distention of bag counteracts inward force vectors.

Intraoperative IOL Positioning

Correlation to Postoperative

- Change in IOL position
  - From Intraoperative to Postoperative (n = 18)

  \[ R = 0.91 \]
Centration Stability

- Excellent centration stability over time
  - Compared to POD 1
  - One-piece Tecnis Multifocal IOL

<table>
<thead>
<tr>
<th>Position Change (Compared to Day 1) of IOL Center Relative to:</th>
<th>&lt; 2 months</th>
<th>2–4 months</th>
<th>4–6 months</th>
<th>6–12 months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative to Corneal vertex</td>
<td>0.10 ± 0.06</td>
<td>0.09 ± 0.07</td>
<td>0.08 ± 0.07</td>
<td>0.10 ± 0.07</td>
</tr>
<tr>
<td>Correlation (R)</td>
<td>0.75</td>
<td>0.93</td>
<td>0.97</td>
<td>0.98</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mean change in IOL position (mm)</th>
<th>Relative to Pupil center</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.15 ± 0.09</td>
<td>0.14 ± 0.05</td>
</tr>
<tr>
<td>0.18 ± 0.07</td>
<td>0.13 ± 0.05</td>
</tr>
<tr>
<td>Correlation (R)</td>
<td>0.35</td>
</tr>
</tbody>
</table>

Chang DH. Centration stability of a one-piece aspheric diffractive multifocal IOL. Poster at the ARVO Annual Meeting, Ft. Lauderdale, FL. 2012.

Centering and aligning intraocular procedures

Toric IOLs

Aligning Toric IOLs

Rotational alignment is important

Misalignment at 6°

Realignment at 175°

www.astigmatismfix.com

Alignment Begins with Centration

Hands must be centered to align correctly
IOL must be centered to align correctly.

Where is the center?

OS: +18.5 ZCT150 @ 090

OS: +24.0 ZCT300 @ 080

OS: +28.0 ZCT400 @ 120

Where is the center?
Centering and Aligning Toric IOLs

- Center IOL on the (SF-CSCLR)
- Rotate IOL to be parallel to corneal marks
- Must align all 5 points:
  - SF-CSCLR
  - Toric marks on both sides of IOL
  - Both peripheral corneal marks

Residual Astigmatism after Toric IOL – Now what?

John Berdahl M.D.

Residual Astigmatism

POM #1 SN6AT9 Toric IOL @ 110°

Vas 20/60

MRX – -1.00 + 1.75 x 150 20/25

Causes of Residual Astigmatism

Wrong Location
- Poor Measurements
- Poor Calculations
- Surprising SIA
- Posterior Ks
- IOL Rotated
- Poor IOL Placement

Wrong Lens
- Poor Measurements
- Poor Calculations
- Surprising SIA
- Posterior Ks

Wrong Eye
- Ocular Surface Disease
- ABMD
- Irregular Astigmatism

Treat Disease
Causes of Residual Astigmatism

Wrong Location
- Poor Measurements
- Poor Calculations
- Surprising SIA
- Posterior Ks
- IOL Rotated
- Poor IOL Placement

Wrong Lens
- Poor Measurements
- Poor Calculations
- Surprising SIA
- Posterior Ks
- IOL Rotated
- Poor IOL Placement

Surgically induced Astigmatism
Causes of Residual Astigmatism

Wrong Location
- Poor Measurements
- Poor Calculations
- Surprising SIA
- Posterior Ks
- IOL Rotated
- Poor IOL Placement

Wrong Lens
- Poor Measurements
- Poor Calculations
- Surprising SIA
- Posterior Ks

Will Rotating IOL Help?

IOL Xchange or LVC

Toric IOL Misalignment

Ideal Axis of Toric IOL

Actual Axis of Toric IOL

Toric Misalignment of T9

0°  5°  10°  15°
**IOL Misalignment**

<table>
<thead>
<tr>
<th>Misalignment</th>
<th>% Loss</th>
<th>Absolute Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>0deg</td>
<td>0%</td>
<td>0D</td>
</tr>
<tr>
<td>5deg</td>
<td>17.5%</td>
<td>0.18D</td>
</tr>
<tr>
<td>10deg</td>
<td>35%</td>
<td>0.36D</td>
</tr>
<tr>
<td>15deg</td>
<td>50%</td>
<td>0.51D</td>
</tr>
<tr>
<td>30deg</td>
<td>100%</td>
<td>1.03D</td>
</tr>
</tbody>
</table>

**Math Frowns on Misalignment**

\[ \alpha = \frac{1}{2 \tan \theta} \]

\[ 5^\circ \text{ misalignment} = 0.4\% \text{ loss of power} \]

\[ 5^\circ \text{ misalignment} = 17\% \text{ loss of power} \]

**Residual Astigmatism**

POM #1 SN6AT9 Toric IOL @ 110°

\[ \text{Va}_{30} \quad 20/60 \]

MRX = -1.00 + 1.75 x 150  20/25

www.astigmatismfix.com
Mark Current and Ideal Axis

Before Rotation

-1.00 + 1.75 x 150  Va₆c  20/60

After Rotation

plano +0.50 x 112  Va₆c  20/20

Filtering Criteria

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient Eye</td>
<td>Left Eye; Right Eye</td>
</tr>
<tr>
<td>Original Calculated IOL Axis</td>
<td>0° to 180°</td>
</tr>
<tr>
<td>Current Sphere</td>
<td>-6D to 6D</td>
</tr>
<tr>
<td>Current Cylinder (plus power)</td>
<td>0.5D to 10D</td>
</tr>
<tr>
<td>Current Axis of Astigmatism</td>
<td>0° to 180°</td>
</tr>
<tr>
<td>IOL Cylinder Power</td>
<td>0D to 10D</td>
</tr>
<tr>
<td>Current IOL Axis</td>
<td>0° to 180°</td>
</tr>
<tr>
<td>IOL Type</td>
<td>Not Selected; SN6AT3; SN6AT4; SN6AT5; SN6AT6; SN6AT7; SN6AT8; SN6AT9; Staar 2.0; Staar 3.5; ZCT225; ZCT300; ZCT400; BL1UT25; BL1UT200; BL1UT275</td>
</tr>
</tbody>
</table>

Effectiveness

Astigmatism Prior to Rotation: 1.83 D

0.93D corrected  
(51% Reduction)

Astigmatism After Rotation: 0.90 D
**Causes of Residual Astigmatism**

1.) Change in Ideal Axis*  
-76% (2091)  

Possible Causes:  
- Inaccurate measurements/calculations  
- Inaccurate cyclotorsion measurement  
- SIA  
- Posterior Corneal Astigmatism  
- Unstable Astigmatism (underlying disease)  

2.) IOL Rotation*  
-70% (1912)  

Rotation Direction  
(of IOLs that rotated >5° [n=1904])

- Clockwise: 38% (729)  
- CCW: 62% (1175)
Rotation Magnitude

Mean: 20.8°
Median: 22.8°

Residual Astigmatism #2

POW#1 SN6AT9 Toric IOL @ 158°

$V_a$sc 20/70
MRX – -1.75 + 3.50 x 092 20/25
Step By Step

1. Measure MRX
2. Measure IOL Axis and know its toricity
3. Plug info to Astigmatismfix.com
4. Does rotating IOL neutralize Astigmatism?
5. Is Spherical Equivalent Acceptable?
6. Can IOL be Easily Rotated?
7. Mark Current and Ideal Axis
8. Loosen IOL with Viscoelastic
9. Rotate IOL
10. Remove Viscoelastic
An ounce of prevention....
Mark in upright position
Use multiple confirmatory K Sources
Intraoperative Alignment can help
Use intraoperative aberrometry Know SIA, including how it affects the axis

Summary
 Rotate IOL
 S.E. near target
 Astigmatism Neutralizable

Laser Vision Correction
 S.E. not at target
 Astigmatism not neutralizable
 IOL cannot be rotated easily

Final Thought
Much more important with higher powered toric IOLs and toric multifocals
-Might be eliminated with the Calhoun Light Adjustable Lens

Thank you
Discussion / Conclusions

Centration and Alignment