Evolution of Diffractive Multifocal Intraocular Lenses

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Presentation Overview

- Multifocal IOLs
  - two lens powers
- Early Diffractive multifocal IOL
  - full-optic, equal energy
  - rigid, meniscus, strong loops (it is not just the optics)
- Full-optic, equal energy, foldable
- Full-optic, unequal energy, foldable
- ReSTOR Apodized diffractive
- Discussion
Multifocal IOLs

- Two primary lens powers
- Base power for distance vision
- “Add” power for near vision
20 Years of Multifocal IOLs (1987-2007)

Zonal Refractive: Each zone has either distance or near power

- 2 zones
  - e.g. IOLAB NuVue
  - n=near, d=distance
  - e.g. Storz True Vista

- 3 zones
  - e.g. AMO Array/ReZoom
  - d=distance, n=near

- 5 zones

Diffractive: Light goes into both distance and near powers from all zones

- ~ 30 diffractive zones.
  - e.g. 3M 815LE, Pharmacia 811 E, AMO Tecnis 9001

Apodized Diffractive: Central diffractive blends into outer distance power

- 12 diffractive zones.
  - e.g. Alcon AcrySof ReSTOR
**Diffractive Multifocal Lenses**

- Physical geometry is very important
  - Place zone boundary where optical distance to image increases by 1 wavelength
  - Create optical jump in phase at boundary
- Zones shaped to direct light
- Light from all zones goes to both images
- Adjacent zones have similar effects

![Diagram](image.png)
Full-optic Equal-Energy Diffractive IOL
Theoretical Energy Balance at 550 nm

- Constant diffractive steps heights across entire lens.
- Steps only ~ 1-2 microns.
- Distance and near ~ 41% for all pupils.
- Additional energy goes to higher diffraction orders.

81% theoretical maximum.
Full Optic Equal-Energy Diffractive IOL
Initial 3M Diffractive IOL, 1988

- Rigid PMMA lenses
  - 6mm diameter, large incision
- Meniscus optic shape
  - meniscus lenses no longer used
- Closed-loop and long haptics
  - large force on capsule
Improvements to IOLs and surgery:
The lens platform is also important

- Foldable lenses have replaced rigid lenses
  - smaller incisions, lower aberrations
- Phacoemulsification and capsular bag implantation
  - IOLs stable in the bag
- Gentle haptics
  - strong haptics of early lenses displaced the optic
- Reduced PCO (Posterior Capsular Opacification)
  - improved contrast
- Aberration control (shape factor and asphericity)
  - reduced spherical aberration
  - improved large-pupil contrast
More recent Full Optic Equal-Energy Diffractive IOLs
Lenses with published clinical data

- Biconvex 3M IOLs, rigid PMMA
- Biconvex Pharmacia 811E, rigid PMMA
- Biconvex AMO Tecnis Z9001, foldable silicone, aspheric
Full Optic Unequal-Energy Diffractive IOLs

- Changing the step heights changes the energy
  - lower steps send more light to distance
  - higher steps send more light to near
  - all zones have the same optical effect

- “Distance dominant” or “Near dominant”
Full Optic Unequal Energy Diffractive IOLs

- Shorter steps send less light to near.
- Taller steps send more light to near.
- Diffractive step heights control the energy.
- Total energy for the two powers typically ~81%.

Distance energy for shorter steps; near energy for taller steps.

Near energy for shorter steps; distance energy for taller steps.

Pupil Diameter (mm)

Fraction of Energy to Distance (d) or Near (n)

- Equal d
- Equal n
- 70/30 d
- 70/30 n
Full Optic **Unequal** Energy Diffractive IOLs

- Energy balance sometimes given just for primary powers
  - portion of total energy not always given
  - e.g. 70%:30% distance:near energy,
    - actually 57% distance, 25% near at design wavelength

- IOL examples are Adatomed, Acri.Twin, and Acri.Lisa IOLs
  - foldable diffractive lenses
  - biconvex
  - aspheric
  - sloped diffractive steps for Acri.Lisa

- Limited published clinical data
Limitations of Full Optic Diffractive IOLs

The theoretical relative energy at design wavelength between distance and near is about 81%. Most large pupil activities involve distance vision, while near vision is rarely used for large pupil activities. Near vision with large pupils can create a halo effect for distance vision.
Apodized Diffractive Surface and Energy Balance

Taller steps at lens center delay light about 1/2 wavelength and divide light fairly equally between two images.

Smaller steps further out decrease the optical delay to smaller fraction of wavelength and direct less light to near.

Zone curvature is steeper than base curve at center.

Zone curvature is flatter and similar to base curve.

Grossly magnified schematic.

Base Curve.
ReSTOR use of Apodization to Control Defocused Light

- Only central diffractive region directs light into near power
- Any halo at night due to defocused second image has reduced diameter and reduced energy
- "Distance" Focus
- "Near" Focus
The ReSTOR Apodized Diffractive Optic

Step heights decrease peripherally from 1.3 – 0.2 microns

Central 3.6 mm apodized diffractive structure

Outer refractive region
Energy Balance Comparison

- **Equal d**
- **Equal n**
- **70/30 d**
- **70/30 n**
- **ReSTOR d**
- **ReSTOR n**

**Energy Balance Comparison**

- **Apodized diffractive**
- **Unequal energy diffractive**
- **Equal energy diffractive**

**Pupil Diameter (mm)**

**Fraction of Energy to Distance (d) or Near (n)**
Apodized Diffractive Design

- Diffractive zones are in same locations as for full-optic diffractive IOL
  - zone location determined by “Add” power
- Apodized diffractive structure blends into peripheral refractive region
- Matches optical properties to visual needs
- Reduces nighttime visual phenomena
- Increases overall percentage of light used
Apodized Diffractive IOL Lens Platform

- Proven AcrySof material
- Single-Piece design
- Slow, controlled, unfolding
- Easy to insert

~ 25 Million AcrySof lenses implanted
Large Binocular Depth of Focus

excellent distance vision

excellent near vision

4.5 D Amplitude of Functional Vision

6 D Depth of Focus

n=22 ReSTOR, n=17 monofocal
High level of Spectacle Independence

Overall Spectacle Wear

% of Subjects

Never: 80
Sometimes: 17
Always: 3

ReSTOR (N=339)
Modest Visual Disturbances
120-180 Days Post-Operative

<table>
<thead>
<tr>
<th>None, Mild</th>
<th>Moderate</th>
<th>Severe</th>
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<tr>
<td>Night Vision Problems</td>
<td>Halos</td>
<td>Glare</td>
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<tr>
<td>ReSTOR® N=457</td>
<td>94%</td>
<td>19%</td>
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<tr>
<td>Monofocal Control N=156</td>
<td>2%</td>
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Conclusion:
Diffractive Multifocal IOLs

- Diffraction divides light between two powers
- Diffractive step heights control the energy balance
- Apodized diffractive IOL has gradual change in step heights
  - central distance/near vision region
  - outer “refractive” distance vision region
  - allocates appropriate light energy according to activity and light levels
  - designed to minimize photic issues
  - high level of spectacle independence
Thank You