The Quest Of Perfection In Intraocular Lenses

Konstantina J. Koufala

Even though cataract surgery has been practiced for over 2000 years, modern cataract surgery started just some 50 years ago.

- In 1949, Sir Harold Ridley invented the first IOL.
- First surgery November 29, 1949 at St. Thomas' Hospital
- Artificial acrylic polymethylmethacrylate (PMMA) IOL Bi-convex design.(Rayner-Ridley)
- Extracapsular technique on the left eye of a 45-year-old woman.
- Not sure of the stability of the lens, he removed it in a second surgery on February 8, 1950.

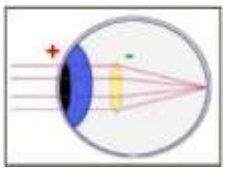
In the 1970s, IOL implantation after cataract surgery was considered a standard procedure.

PREMIUM IOLs

- ASPHERIC
- TORIC
- MULTIFOCAL
- ACCOMODATIVE IOLs

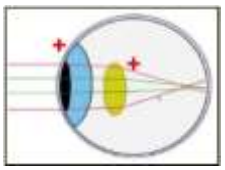
ASPHERIC IOLs

Human eye- Aspheric Optics



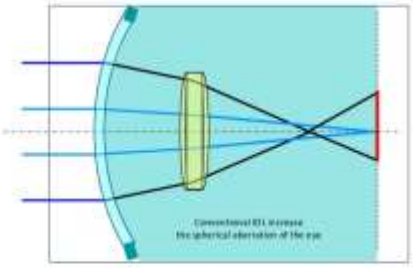
Cornea- Positive spherical aberration

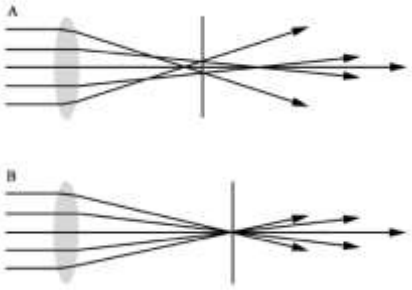
Young crystalline lens- Negative spherical aberration



Ageing- Crystalline lens gains Positive spherical aberration

Conventional IOLs increase the spherical aberration of the eye





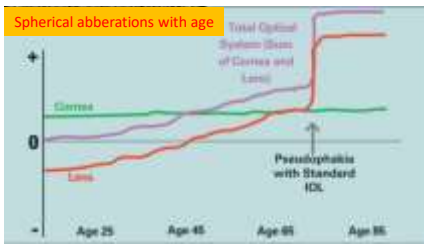
Peripheral light rays are defocused

What Spherical Aberration Should We Target?

Wavefront aberration analysis confirms that the average human cornea has +0.27 microns of spherical aberration throughout life.

20/20*	E	E	E	E
Average Corneal SA	+.27	+.27	+.27	+.27
Lens SA	-.27	-.17	0.0	+.15
Total Residual SA	0.0	+0.10	+0.27	+0.42

*Images simulated using ZernikeTool, created by George Dai, PhD



HOW TO OVERCOME THE INCREASE OF POSITIVE SA?

- Strategy 1:

– Lens with negative spherical aberrations balance the normally positive corneal spherical aberrations

- Strategy 2:

– Lens with minimum spherical aberrations that introduce no additional positive spherical aberration

ASPHERIC LENSES

- Anterior prolate surface
  - – Tecnis, Advanced Medical Optics (AMO)
- Posterior prolate surface
  - – Acrysof IQ, Alcon Laboratories
- Both Anterior and Posterior prolate surfaces
  - – Akreos AO, SofPort AO and L161 AO, Bausch & Lomb

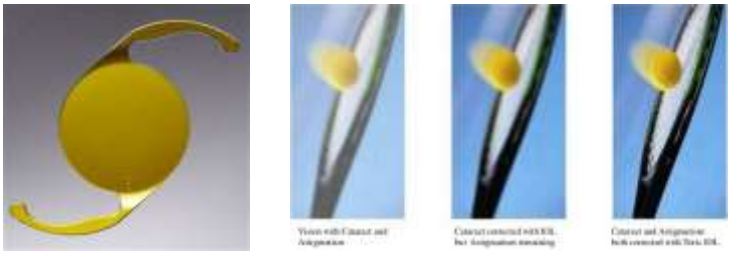
ASPHERIC IOLs

- Need perfect centration – Decentered IOLs can induce coma
- Decreased depth perception
- More expensive
- Not much difference in photopic conditions and in older age group
- Not for previous hyperopic corneal refractive surgery

- Better contrast sensitivity
- Better mesopic vision
- Night time driving – AcrySof® IQ Aspheric IOL patients had an average increase of 40 m (vs the control lens) in which to stop after identifying a warning sign
- Better option for younger patients

TORIC IOLs

- 22% of patients undergoing cataract surgery have substantial corneal astigmatism >1.25 D



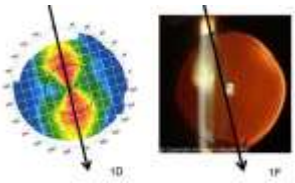
CANDIDATES ≥ 1.0D regular corneal astigmatism

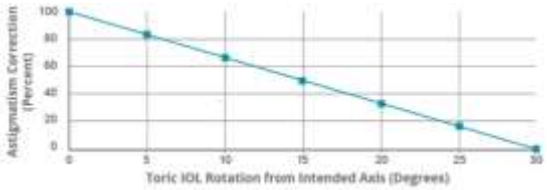
TORIC IOLs

- Staar Surgical Intraocular Lens
  - First FDA approved (in 1998) toric IOL
  - 2.00 and 3.50D
  - Plate-haptic
  - Poor rotational stability
  - limited power range
- AcrySof IQ Toric IOL (Alcon Labs, USA)
  - September 2005
  - T3 to T9
  - posterior surface has added cylindrical power and axis markings
- Acri.Comfort 646TLC and Acri.LISA toric 466TD
  - Carl Zeiss Meditec – incision < 2 mm
- Rayner Sulcoflex toric 653T (Piggy back sulcus lens)

TORIC IOLs

- Marking The Eye
  - reference marks at the 3- and 9-o'clock
  - sitting upright
- Aligning the Toric IOL with the Axis
  - Gross alignment
  - Viscoelastic removal
  - Final alignment





- For every 1 degree of axis rotation, 3.3% of the lens cylinder power may be lost
- At 30 degrees, all effect is lost

Currently available presbyopia correcting IOLs can be classified as:

- Pseudoaccommodative IOLs
  - -Multifocal IOLs, segmented Bifocal and Trifocal IOLs

  including the AT LARA ® (Carl Zeiss Meditec), FineVision (PhysIOL, Belgium), PanOptix (Alcon); RayOne Trifocal (Rayner)
  - -Extended depth of focus (EDOF) IOLs
- Partially accommodative IOLs, such as Crystalens (Bausch + Lomb) and Synchrony dual optic IOL (Abbott Medical Optics)
- Accommodating IOLs such as FluidVision (PowerVision), Juvene (LensGen) etc.

Multifocals:

- Diffractive and/or refractive designs
- Bifocal or trifocal
- Aim to focus an image onto more than one focal plane

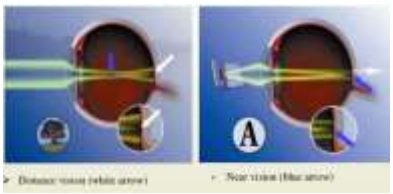
- The add powers of diffractive IOLs have decreased over the years to improve intermediate vision and photopic phenomena
- There is some degree of contrast sensitivity loss

Diffractive IOLs

RESTOR IOL (Alcon)

AcryLISA

TECNIS® Multifocal IOL

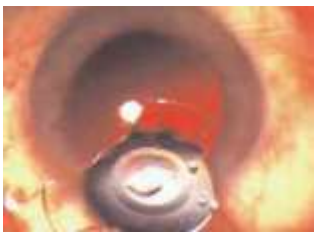


Refractive IOLs

M-flex

ReZoom Multifocal IOL (AMO)

MF4



Refractive vs Diffractive IOLs

REFRACTIVE MULTIFOCAL IOLS	DIFFRACTIVE MULTIFOCAL IOLS
Excellent intermediate and distance vision	Excellent reading vision and very good distance vision
Near vision fair but may not be sufficient to see very small print	Fair Intermediate vision
Patients who read for prolonged periods of time or in poor lighting may experience eye fatigue.	Patients who do lots of computer work may not accept it well
PUPIL DEPENDENT	LESS DEPENDENT ON PUPIL

Diffractive lenses have been shown to offer good distant,intermediate and near vision with better optical quality than refractive lenses

Trifocal Intraocular Lenses for Presbyopia Correction

PhysIOL FINEVISION

100% trifocal optical body

Convoluted
- Apodized
- Reduces step height

2 Models with different haptics
- Micro
- Pod

Two diffractive structures
+3.50D addition for near vision
+1.75D addition for intermediate

Optic: Aspheric trifocal diffractive
Material :25% hydrophilic acrylic
Filtration: UV and blue light blocker
Optic body diameter: 6.15mm
Overall diameter: 10.75mm
Refractive index:1.46
Angulation: 5°
Power: from +10D to +35D (0.5D steps)

PanOptix IOL -Toric

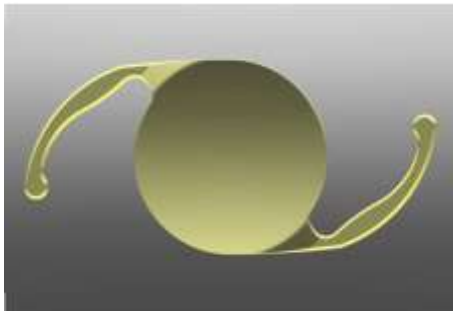


Table 1 Characteristics of ReSTOR +3.0 D and PanOptix IOLs

	PanOptix	ReSTOR +3.0 D
Technology	Trifocal	Multifocal
Diffractive zone	4.5 mm	3.6 mm
Central zone	Diffractive	Diffractive
Optic type	Nonapodized	Apodized
Near add powers	+3.25 D	+3.00 D
Intermediate add powers	+2.17 D	None
Active orders	Zeroth, second, and third	Zeroth and first
Asphericity	−0.1 µm	−0.1 µm
Lens color	Yellow	Yellow

PATIENT SELECTION FOR MfIOLs

- Most important factor
  - Strong desire to be spectacle independent
- Functional & occupational requirements
  - Occupational night drivers (avoid)
- Pre-existing ocular pathologies
- Hypercritical & demanding patients – strictly avoided
- Irregular astigmatism (avoid)
- With a monofocal lens in one eye
- History of previous refractive surgery
- Previous PK
- Chances of IOL dislocation
- Recommended for most but NOT ALL patients

SPECIAL CONSIDERATIONS FOR MfIOLS

Counselling (most important)

- Accurate Biometry
  - – new biometry methods strongly recommended
- Power Calculation
  - – Plano to <+0.25 – newer formulae
- Surgical Technique
  - – Round, centered CCC completely overlapping the lens optic
  - – Removal of all viscoelastic from behind the lens

DISADVANTAGES

- Loss of contrast sensitivity
- Glare and halos
  - – scattering of light at the dividing line of the different zones
  - – improves with bilateral implantation, because of “a bilateral summation” effect
- Less satisfactory visualization of fundus
  - difficulty in vitreo-retinal procedures
- Requires Visual-Cortical Neuro-adaptation

Principles of increasing the depth of focus & pseudoaccommodation

EDOF lenses work by creating a single elongated focal point to enhance “range of vision” or “depth of focus”

Diffractive technology for chromatic aberration correction
Echelette design

Refractive technology
Modulation of Spherical aberration

Small aperture optics

EDOF IOLs work on different principles:

A) Echelette design:

Tecnis Symfony IOL (AMO, California)

- FDA approved in 2016
- Biconvex, anterior aspheric and posterior
- Achromatic diffractive surface IOL
- Echelette design reduce chromatic aberration.
- Bilateral implantation with micromonovision has shown to give very satisfactory vision at all distances.
- Symfony Toric IOL correct coexistent astigmatism.

A) Echelette design:

AT LARA 829MP (Carl Zeiss Meditec)

- Preloaded
- Single-piece trifocal diffractive
- MFIOL
- 6.0 mm biconvex optic with an
- overall length of 11mm
- Hydrophilic acrylic IOL with a
- hydrophobic surface
- Diffractive rings cover the entire
- optic diameter

- Diffractive aspheric design
- Chromatic correction
- Smoother phase zones
- Shallower angles optimise contrast sensitivity and minimise light scattering and visual side-effects.
- Higher visual acuity over a wider range of focus than Tecnis Symfony

B) Small-aperture IOLs:

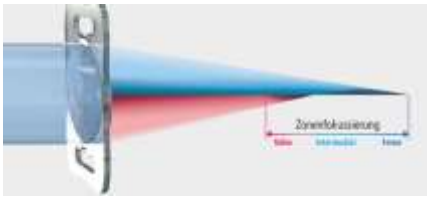
IC-8™ Extended Depth of Focus IOL

- Optic Design
  - Single piece hydrophobic acrylic
  - 6.00 mm optic diameter
  - 12.50 mm overall diameter
- Mask
  - PVDF & nano-particles of carbon
  - 1.36 mm aperture
  - 3.23 mm total diameter
  - 3200 microperforations
  - 5 microns thick

- A-constant: 120.5
- Diopter Range: +20.0 D to +27.5 D (Equivalent to +18.0 D with a typical lens due to Aconstant)
- Injector System
  - 3.5 mm incision for capsular bag insertion, non-folding, single use
    - Effective in post-LASIK eyes and corneas with irregular astigmatism
    - Pinhole principle, similar to the Kamra corneal inlay, to increase depth of focus to about 3D

C) Low-near add multifocal IOLs:

- LS 313 MF15„LentisComfort“(Oculentis,Germany)
- Total diameter 11.00 mm
- Optic diameter 6.00 mm
- Design 1-piece



- Optic asymmetrical,sector shaped refractive
- +1.5 Dpt. near addition
- Optic material lhydrophilic acrylic

D) Combination/customised technologies:

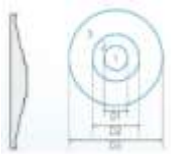
- Mini Well Ready IOL (SIFI Medtech)
- Wavefront technology
- Aspheric profile with three circular zones

➢ central distance

➢ surrounding distance with spherical aberration of opposite sign

➢ and a peripheral distance with monofocal characteristics that together give a range of focus.

Total diameter	10.75 mm
Optic diameter	6.00 mm
Design	1-piece
Optic	biconvex progressive multifocal aspherical
Optic material	hydrophilic acrylic



Mix and Match

- In cases of bilateral EDOF IOL implantation with -0.5 to -0.75D micromonovision strategy or

  a mix-and-match strategy with EDOF in the dominant eye together with multifocal in the non-dominant eye may be used if the patient desires more near vision.

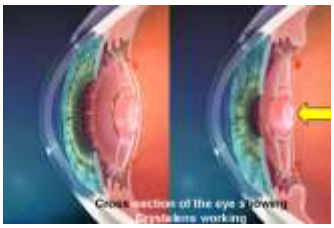
- This approach is called **“mix and match”** or **“blended vision”** and provides promising results and higher rates of spectacle independence.

Accommodative IOLs

Theory:

Enhance defocus at near and intermediate distances

Change the optical power of the eye.



Achieved by:

- forward-backward axial movement or
- flexibility in lens thickness or shape.
- 1 mm of anterior movement of lens = 1.80 D of accommodation

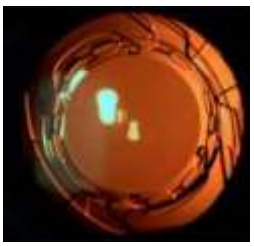
Current available technologies do not deliver enough "accommodation" to provide near vision functionality.

- Capsular fibrosis can affect the presbyopia-correcting abilities.
- The aging ciliary muscle have not the strength or the mechanical force required to entirely power current lenses.
- Posterior capsular opacification and capsular contraction results an asymmetric vaulting and lens tilt.

- **Silicone**

  – Crystalens (Bausch & Lomb)
  – Only FDA approved IOL for correction of presbyopia

The accommodative IOL from NuLens uses a small piston to displace material in the center of the lens to add power.

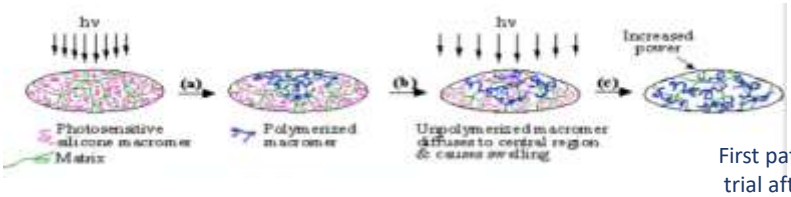


- **Hydrophilic Acrylic**

  – BioComFold type 43E (Morcher GmbH)
  – 1CU (HumanOptics AG) – Tetraflex (Lenstec Inc.)

Light Adjustable IOLs (LALs)

- Silicone based IOLs (also polyacrylic prototype)
- Implanted not completely polymerized
- UV Photo polymerization *in situ* to change the shape and power and character of the lens (inc. toric or multifocal)
- Development of a light delivery device for precise manipulation
- Precise power adjustment for complex situations– esp for patients who underwent refractive laser surgery
- Allows trial periods for monovision or bifocal type IOLs



First patient implanted in the FDA trial after all treatment has been done.

The lens is FDA approved for postoperative adjustment of sphere and cylinder

SMART LENS

(Medennium Inc.,Irvine, Calif.)

- From thermodynamic hydrophobic acrylic material which makes it astable, flexible, gel polymer.
- Injected through a normally sized capsulorhexis
- Reconfigures itself
- High refractive index
- Prevent PCO

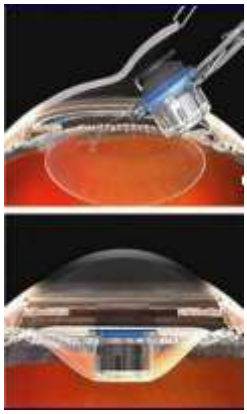
IOL IMPLANTATION IN SPECIAL SITUATIONS
ANIRIDIA IOLs for the correction of aniridia and iris coloboma.

- Coloured body and haptics
- Additional optical correction
- Available for scleral and sulcus fixation

- The "Iris Prosthetic System", consists of different standard combinable elements and is used for artificial iris reconstruction.
- Provides occlusion of partial or total iris defects and creates a new iris diaphragm (pupil reconstruction).
- Used in combination with a posterior chamber IOL, for refractive correction, and a Capsular Tension Ring, for stabilizing the capsular bag.

IOL IMPLANTATION IN SPECIAL SITUATIONS
Intraocular lenses in age-related macular degeneration

TELESCOPIC IOL

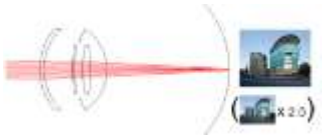


- The LMI (Lipshitz Macular Implant)
  - optics is 6.5mm
  - slightly thicker than a standard IOL
- Contains 2 miniature mirrors
  - 2.8 mm posterior doughnut shaped mirror that reflects light anteriorly
  - 1.4 mm central retina
  - facing mirror which in turn focuses the light on retina).
  - 25 X magnification of central images
- Does not affect peripheral vision.

IOL IMPLANTATION IN SPECIAL SITUATIONS
Intraocular lenses in age-related macular degeneration

Scharioth Macula Lens

- Based on magnification at closer distances
- Incorporates a +10 D central area in the lens
- Magnification is only achieved when the object is in a range of 10 to 15 cm from the eye
- The closer the object to the eye, the higher the magnification
- It provides no distance vision magnification



IOL IMPLANTATION IN SPECIAL SITUATIONS
PIGGYBACK IOLs

An intraocular lens that "piggybacks" onto an existing intraocular lens or two IOLs are implanted simultaneously.

- First IOL is placed in the capsular bag.
- The second (piggyback) IOL is placed in the bag or sulcus.

Advantages
- Easier to place 2nd IOL than to explant IOL & replace it
- Less risk
- More predictable
- Better image quality
- Presbyopia correction

ADD-ON SULCOFLEX

COMPLICATIONS
- Interlenticular opacification (Add on) (Interpseudophakos Elshnig's pearls) (RED ROCK SYNDROME)
- Unpredictable final IOL position

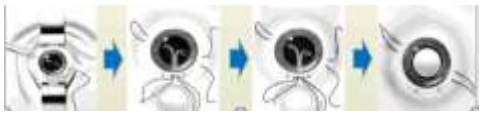
IOL IMPLANTATION IN SPECIAL SITUATIONS
SCLERAL Suported IOLs

• PCIOLS sutured to the sclera through sulcus
• Widely used technique if there is no capsule or only sections of peripheral capsule.
• No endothelial damage
• Low risk of iris chaffing
•Some risk of suture breaking
• Some risk of suture erosion

Techniques of fixation:
-Ab-interno
-Ab-externo

- Single loop
- Double loop

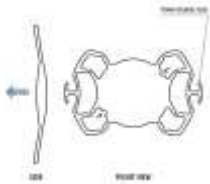
-Single haptic fixation
-Double haptic fixation



IOL IMPLANTATION IN SPECIAL SITUATIONS
GLUED OR SCLERAL FIXATED IOLs

INDICATION: Eyes with a deficient posterior capsule.

SCLERAL IOL Carlevale



In Quest Of Perfection

What is New in IOL Technology?

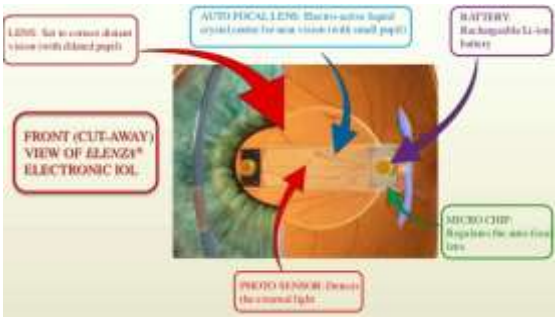
Electromechanical IOLs in development:

The Sapphire Autofocal IOL (Elanza)

CONCEPT: The pupil responds to accommodation by getting smaller.

The IOL includes sensors that detect very small changes in pupil size.

Presents a liquid crystal optic that responds to change in pupil size and automatically changes optical power for the near vision.



Electromechanical IOLs in development:

Vista Ocular (Ohio, US)

Targets the ciliary muscle's action potential as the accommodative signal. This design also incorporates rechargeable battery power with a flexible lens system to change optical power in a variable fashion.

Continuous Transitional Focus IOLs

Precizon Presbyopic (Ophtec, Netherland)

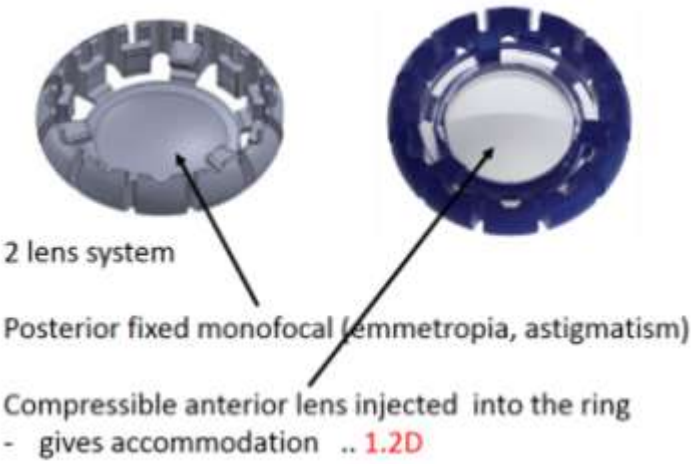
- New aspheric presbyopia-correcting IOL
- Continuous transitional focus (CTF) optical design.
- Offers full range of vision
- Provides a smooth, continuous transition from near to infinity with low peaks due to its transitional zone

The FluidVision IOL (PowerVision)

- Hydrophobic acrylic lens is placed in the capsular bag.
- Incorporates a novel design with a 6-mm central optic surrounded by a peripheral reservoir that is filled with isorefractive index silicone oil.
- Upon the accommodative response, the fluid is displaced centrally into the lens, thereby expanding the central membrane of the optic and creating accommodative power.

RESTORATION OF ACCOMODATION… CHANGE OF CURVATURE IOLs

LensGen Juvene IOL



Lumina IOL (Akkolens)

- This two-element varifocal lens is designed for sulcus placement.
- It changes focal powers when its elements shift in the plane perpendicular to the optical axis.
- **Demonstrated accommodative capability in more than 50 eyes with one year of follow-up.**
- This lens holds major promise, and future experience will confirm the performance and safety of this device.

DynaCurve IOL

- Similar in concept to the FluidVision but working in the sulcus.
- Achieves accommodation through use of a fluid or gel to change its shape.
- The DynaCurve IOL is implanted in front of the collapsed capsular bag, which is used as a component of a dynamic diaphragm.
- This capsular diaphragm activates the lens components (a small chamber filled with silicone, a piston-like element, and a flexible membrane), and the lens changes shape.

Liquilens (Vision Solutions Technologies)

- Liquilens uses gravity instead of anatomical forces.
- It uses the fluidics of two immiscible optically clear biocompatible fluids and their interplay to introduce an additional index of refraction into the line of sight that provides additional power when the patient looks down at a 60 to 70 degree angle.
- When the patient looks forward, the fluid is out of the way and the lens provides distance vision

Accommodating IOLs

- Despite showing some initial promise and positive reports, all commercialised accommodating IOL designs to date, have **failed to translate into real accommodation**.
- The human brain is **not multifocal** but monofocal with extended depth.
- Once a working accommodating IOL is available, **the neural adaptation** that we need to acquire with a multifocal IOL **will not be needed**.
- Therefore, interest in the potential for a truly accommodating IOL persists.

Thank you for your attention!