Article for health magazine “Shatayushi”.

Cataract surgery and intraocular lens implantation. Phacoemulsification and other newer techniques of treatment.

What is a Cataract

Cataract is the leading cause of preventable blindness and visual impairment throughout the world, and the removal of cataracts is the most common surgical procedure in the aged population. The current term *cataract* means both opacity of the lens and a torrent of water, in medical terms is a clouding of the eye’s natural lens (Fig. 1).

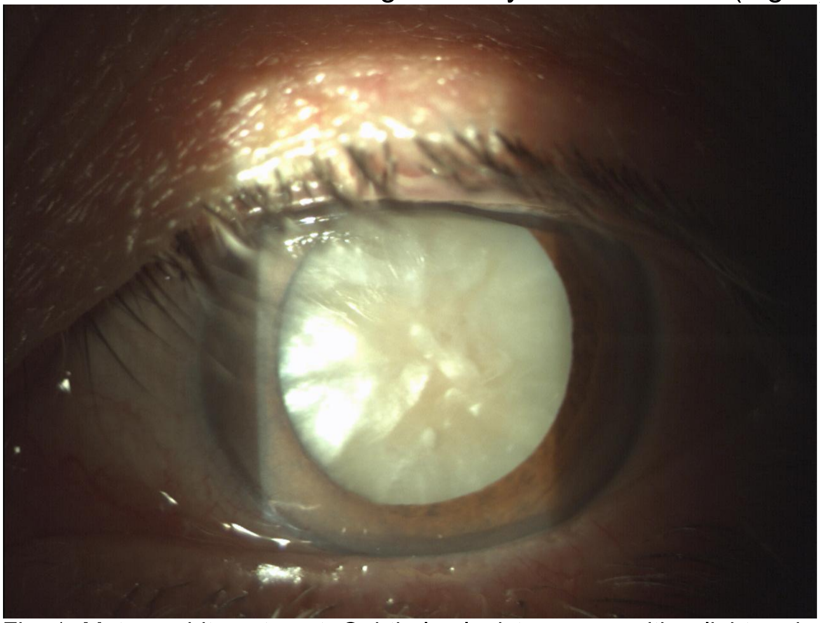


Fig. 1. Mature white cataract. Ophthalmologist can see with a light and a microscope (slit lamp) the lens located inside the eye that in this case is white.

When someone looks at something, light rays travel into the eye through the cornea (1), then through the space between cornea and iris, the anterior chamber of the eye that is filled by aqueous humor (2), through the pupil (3), through the lens (4), through the vitreous gel (5), and are focused onto the retina (Fig. 2).

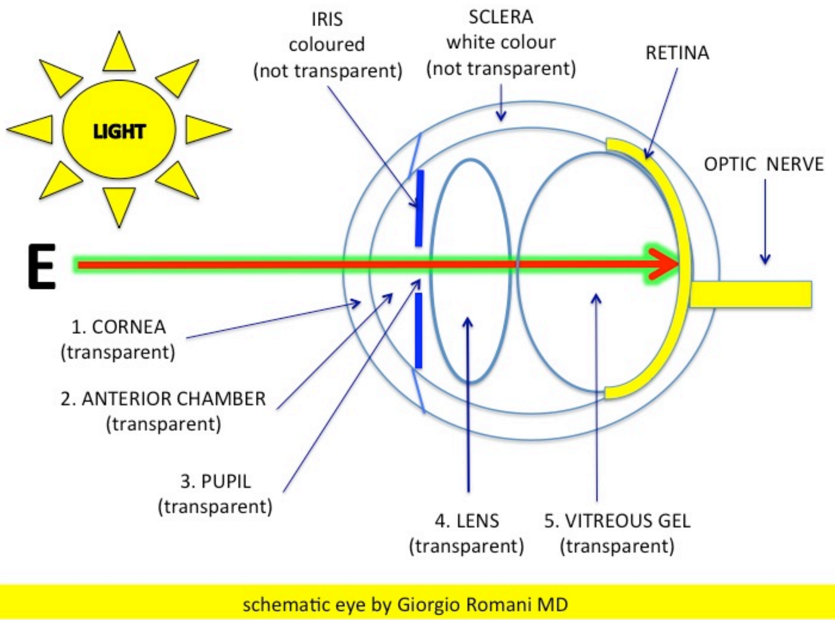


Fig. 2

The human lens is normally transparent, and cataract occurs when the lens loses its transparency by either scattering or absorbing light such that vision in that eye is compromised (Fig. 3).

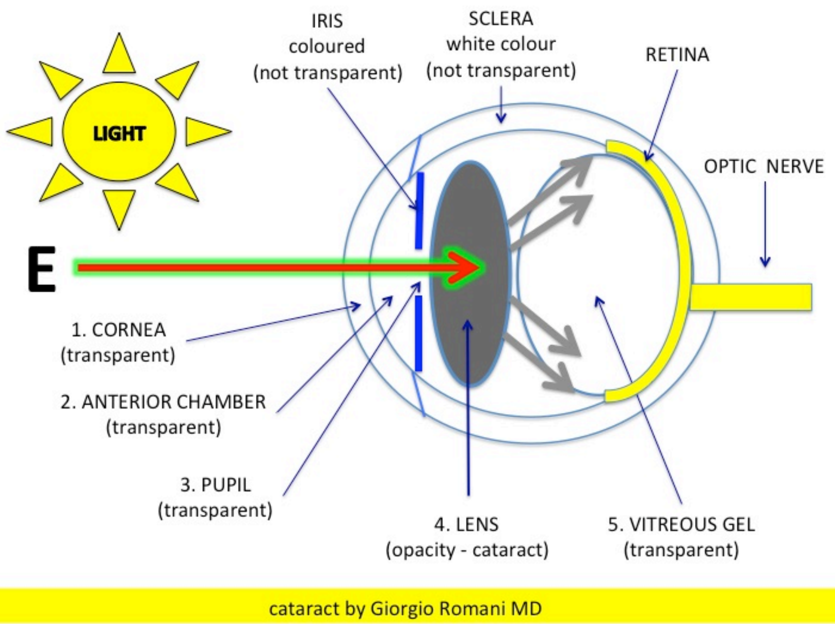


Fig. 3

Brief information about eyeball – anatomy and functions

Humans and animals have the ability to detect structures and events (perception). To achieve this goal they must be sensitive to at least one form of energy that can provide information about the environment (chemical, mechanical, electric and magnetic fields).
Light is the form of energy that can provide information rapidly (speed of light: 299,792,458 meters per second), and most animals and humans have some ability to perceive their sorroundings through vision. Visual perception is the ability to interpret the sorrounding environment by processing informations that are contained in visible light.

The human visual system can segregate an object from its sorroundings with the discrimination of luminance, color, texture, motion, and binocular disparity.
Light (visible light) is one form of electromagnetic radiation (a mode of propagation of energy through space). For human beings, radiation with wavelenghths between about 380 and 760 nanometres can be seen.
The sun's rays pass through the earth's atmosphere and the human eye differentiates colors according to the wavelength (example: blue 435 nm, green 545 nm, red 700 nm), the brightness, and the saturation.
All light rays striking the eye from one point in space, enter the eye passing first through the cornea, than through anterior chamber, pupil, lens, vitreous body and are brought to a focus at one point on the retina. Light is brought to a focus on the retina through the combined optical power of the cornea and the lens.
All the "*additive primary colors"* (blue, green, red) pass through a normal transparent cornea and lens and reach the retina. The retina is the essential constituent of the eye that serves the primary purpose of photoreception.
It is obvious that we gain advantage by having two eyes (binocular vision) rather than one. Two eyes means two distinct retinas that serve for a wider field of view, for an enhanced ability to detect faint objects (binocular summation), and for stereopsis.
Photoreception is the process by which light energy from the environment produces changes in specialized nerve cells in the retina, the rods and cones.
These changes result in nerve action potentials, which are subsequently relayed to the optic nerve and then to the brain, where the information is processed and consciously appreciated as vision (Fig. 4).

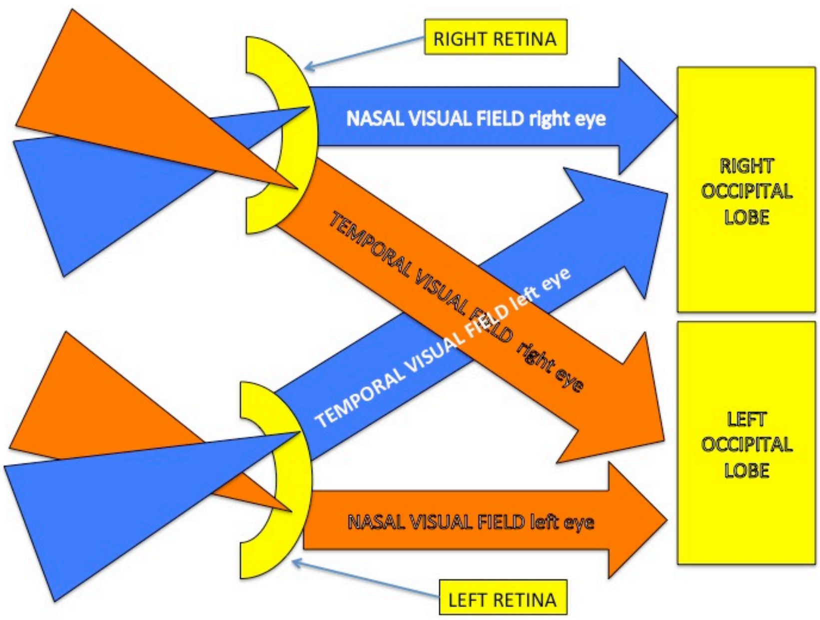


Fig. 4

The eyeball (eye, globe) is a slightly asymmetrical sphere (Fig. 5) with a diameter of about 23 – 24 millimeter (normal eye length).
Each eyeball is set in a protective cone shaped cavity in the skull called orbit (Fig. 6).
Humans and other animals with frontally located eyes attain binocular vision from the two retinal images through a series of sensory and motor process that culminate in the perception of singleness and stereoscopic depth.
The human lens is located inside the eye (Fig. 2, Fig. 5), enclosed in its capsule, and lies behind the iris and in front of the vitreous body. It is encircled by the ciliary processes and held in position by the zonular fibres laterally. The lens normally is a biconvex (outwardly curved on both sides), transparent and avascular structure, and is responsible for fine - tuning the image that is projected on the retina.
The lens comprises three parts: 1) the capsule, a membrane surrounding the lens

like a pocket; 2) lens epithelium, a layer of cells on the anterior (front) side of the lens; 3) lens fibres, long protein fibers that are closely packed and parallel. All three parts are transparent (Fig. 7).

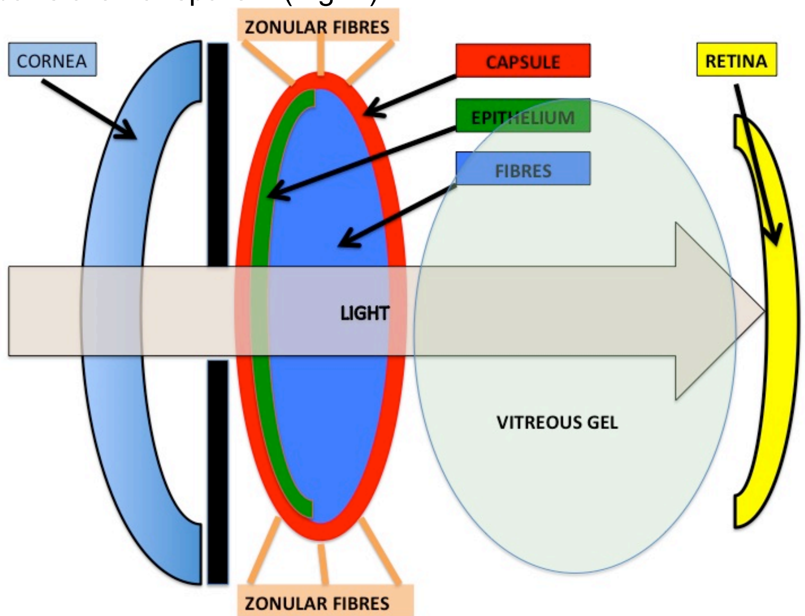


Fig. 7

The normal lens axis (antero – posterior diameter) in an adult is about 3.5 – 4 mm. The normal equatorial diameter in an adult is about 9 mm.

Vertebrate lenses are remarkably effective optical devices. In fact lens is transparent to the wavelenghths of light that can be detected by the photoreceptors located in the retina, have a focal point that is appropriate for the optical system in which it functions, and have a minimum of spherical and chromatic aberration.

The lens is flexible and its curvature is controlled by ciliary muscles through the zonules (zonular fibres). By changing the curvature of the lens, one can focus the eye on objects at different distances from it. This process is called accommodation. Control of lens shape (accommodation) is one of the most fascinating unanswered aspects of lens biology.

Lens continues to grow (0.023 mm per year) and alters shape throughout life, changing width and weight. The cumulative fiber total increases with time as additional growth shells are added incrementally at the lens periphery without a concomitant loss of any previously formed fibers.

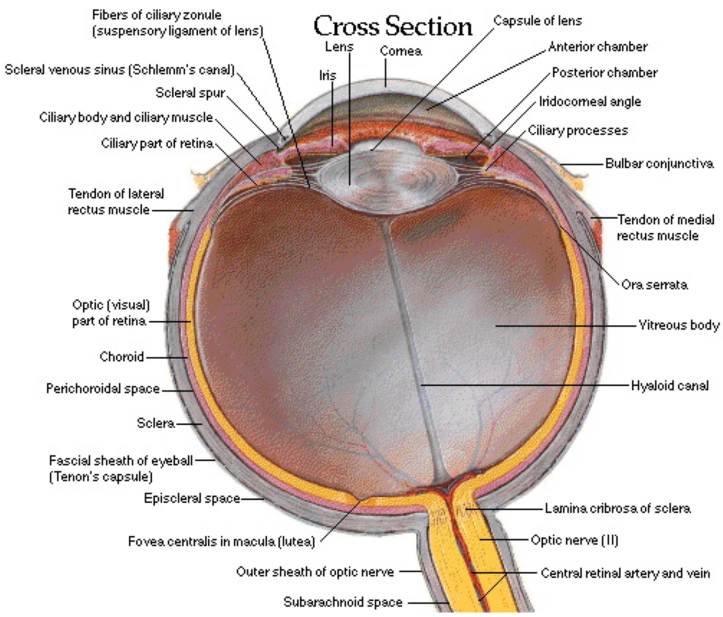


Fig. 5

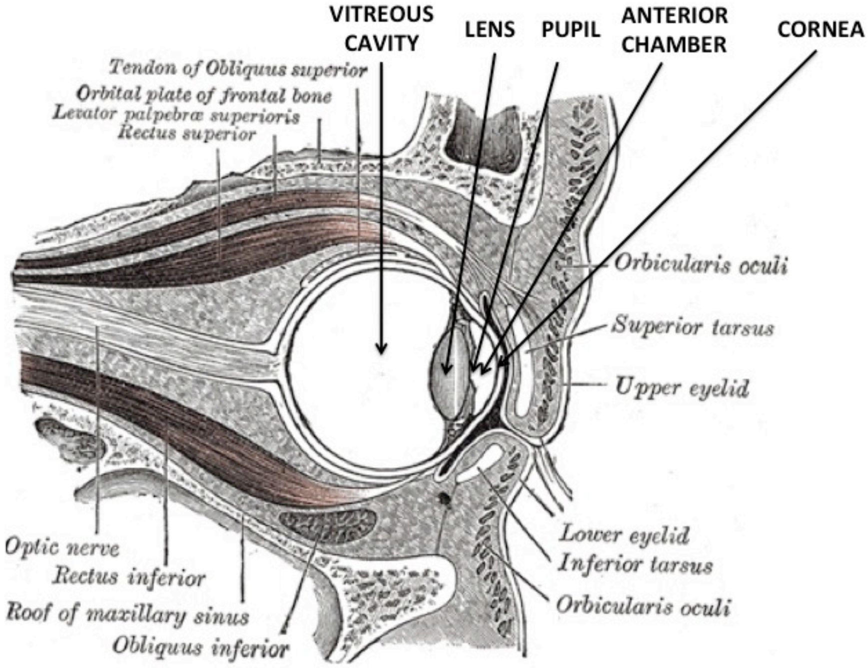


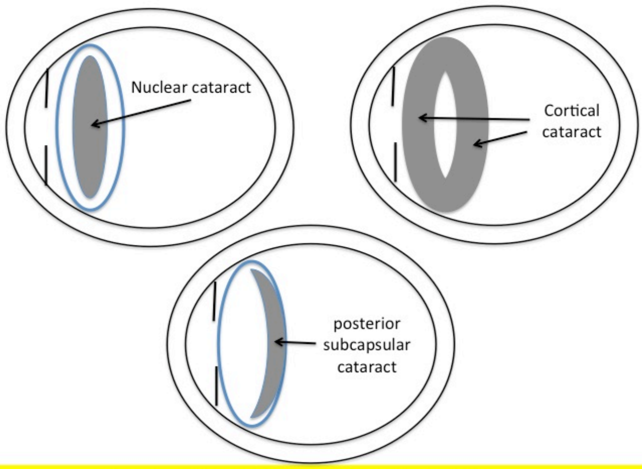
Fig. 6

Why the cataract occurs – brief information about etiology of Cataract

Opacification of the lens (cataract) is almost a normal part of the ageing process but also occurs after any pathology of the lens.
Nutritional elements intake like lutein and zeaxantihin probably decrease in cataract risk. Smoking and excessive alcohol consumption are significant risk factors for cataracts.
Here is a list of some type of cataracts:

a) Age related cataract (3 main type: nuclear, cortical and posterior subcapsular).

In many people, components of more than one type are present.
Fig. 7



Age related form of cataract by Giorgio Romani MD

b) Congenital cataract. Are cataracts that are present at birth or that appear soon after birth. They can include early onset hereditary cataracts or cataracts caused by infectious agents (rubella infection in early pregnancy). Immunization against rubella has reduced the incidence of rubella cataracts.
c) Drug induced cataract: corticosteroids, phenothiazines, miotics, amiodarone, statins, tamoxifen.
d) Traumatic cataracts: contusion, penetrating and perforating injuries, intralenticular foreign bodies, radiation (ionizing, infrared, ultraviolet, microwave), chemical injuries, metallosis, electrical injuries.
e) Metabolic cataract; diabetes mellitus, galactosemia, hypocalcemia, Wilson disease, myotonic dystrophy.
f) Cataract associated with other ocular and systemic diseases: uveitis, exfoliation syndrome, cataract and atopic dermatitis, cataract and degenerative ocular disorders.

Normal lens are constituted mostly by water and proteins (mostly soluble proteins). The hardness of the human lens increases with age. Lens hardness depends on factors such as changes in the nature of lens proteins, compactness of fibres and other biochemical changes. Increased hardness is associated with coloration of the lens and advancing age. In all forms of senile cataract with a pigmented nucleus, the hardness is noticeably increased. This phenomenon is particularly pronounced in black cataracts.

Water insoluble protein fraction increases with age even if the lens remains relatively transparent. In fact, conversion of the water insoluble proteins appears to be a natural process in lens fiber maturation, but it may occur to excess in cataractous lenses.

In cataracts with significant browning of the nucleus (brown or brunescent cataracts) the increase in the amount of water insoluble protein correlates well with the degree of opacification. Associated oxidative changes occur.

Lens fiber cells have the highest proportion of cholesterol of any plasma membrane in the body, and the amount of cholesterol increases as the fiber cells mature. The presence of high concentration of cholesterol and spingomyelin is likely to cause lens fiber cell membrane to be rigid. In very advanced cases of nuclear cataract the nucleus of the lens become opaque and brown and is called brunescent/brown cataract. In very advanced cases of cortical cataract, when the entire cortex becomes white and opaque, the cataract is said to be mature.

The lens, at this stage, takes up water, swelling to become an intumescent cataract.

When degenerated material leaks through the lens capsule, leaving the capsule wrinkled and shrunken the cataract is said to be hypermature.

When further liquefaction of the cortex allows free movement of the nucleus within the capsular bag, the term morgagnan cataract is used.

Signs and symptoms of Cataract

Cataract may develop in one eye or in both eyes. Different types of cataract may have different effects on vision. In general terms cataract cause blurry, cloudy or dim vision. May cause also double vision in one eye, poor night vision, and frequent eyeglasses prescription changes.

Cataract causes an increase of glare (halos around light and photosensitivity).

Objects may become not as bright or colorful as they used to be. As the cataract progresses it interferes with daily activities (reading, driving, walking, etc.). Cataract may increase the dioptric power of the lens and especially nuclear cataract (opacification located in the centre of the lens) may determine the “ second sight “ experience that means that the need for spectacles diminishes.
Someone learn of their decline in vision only after being examinated by an eye doctor.

Short Review about older line of treatment of cataract

The oldest (2457 – 2467 B.C.) documented case of cataract throughout history was reported in a small statue contained in the Egyptian Museum in Cairo, Egypt.
Old Egyptian knew the disease, in fact a wall painting in the tomb of the master builder Ipwy at Thebes (about 1200 B.C.) reveals an ophthalmologist treating the eye of a craftsman.

Couching.

One of the oldest cataract surgical procedure was “ *couching* “ (lens depression).
This technique involved using a sharp instrument to push the cloudy lens to the bottom of the eye (in the vitreous body). Perhaps this procedure is that which is mentioned in the Code of Hammurabi (1792 – 1750 B.C.).
Sushruta, an ancient Indian surgeon, first described in Sushruta Samhita, an Indian medical treatise (around 600 B.C.), the couching technique, in which a curved needle was used to push the lens into the rear of the eye and out of the visual axis.
This technique is today still used in some part of Africa and Yemen.
The first reference to cataract and its treatment in the West are found in 29 B.C. in a work of the Latin Aulus Cornelius Celsus, which describes also the couching operation in *De Medicinae*.
Couching was a very dangerous technique to treat cataract with frequent serious complications (blindness).
Later couching technique would be replaced by cataract extraction surgery.

Cataract extraction.

Cataract extraction is a category of eye surgery in which the lens of the eye is removed while the elastic capsule that covers the lens is left partially intact (Extracapsular - ECCE) or the lens is removed totally with its capsule (intracapsular – ICCE).
In 1747 French ophthalmologist Jacques Daviel performed successfully the first extracapsular extraction (ECCE).
The English Samuel Sharp first performed a successful intracapsular cataract extraction (ICCE) in 1753.
One of the chief problems to be solved in the development of ICCE was how to lyse or break the zonular fibers.
To achieve this goal the English Lieutent Colonel Henry Smith used external manipulation with a hook to break the inferior attachments mechanically and express the cataractous lens from the eye (Smith – Indian operation); Verhoeff and Kalt used forceps; Stower and Ignacio Barraquer used a suction like device called “*erysiphake*”; Joachin Barraquer used chemical dissolution in 1957.
In 1865 the German ophthalmologist Albrecht von Graefe refined the operation by removing the lens through a much smaller linear incision in the sclera of the eye.
Fine suture material, the binocular operating microscope, and modern sterilization techniques increased surgical success and reduced the number and severity of complications.
Harold Ridley successfully implanted the first intraocular lens (IOL) in London on 1949. The IOL was made of polymethylmethacrylate (PMMA), which became the gold standard of implant materials.
Cataract extraction surgery with IOL implantation became the commonest type of eye surgery.

Manual Small Incision Cataract Surgery (MSICS or Blumenthal technique): this technique is an evolution of ECCE where the entire lens is expressed out of the eye through a self-sealing scleral tunnel wound. An appropriately constructed scleral tunnel is watertight and does not require suturing. The "small" in the title refers to the wound being relatively smaller than an ECCE, although it is still markedly larger than a phaco wound. Head to head trials of MSICS vs phaco in dense cataracts have found no different in outcomes, but shorter operating time and significantly lower costs with MSICS.

In 1967, Anton Banko and Charles D. Kelman (ophthalmologist in New York) invented *“an instrument for breaking apart and removal of unwanted material, especially suitable for surgical operations such as cataract removal, including a handheld instrument having an operative tip vibrating at a frequency in the ultrasonic range with an amplitude controllable up to several thousandths of an inch“* (US patent 3 589 363 july 25, 1967). Kelman introduced phacoemulsification after being inspired by his dentist’s ultrasonic probe.

<u>Brief information about Phaco technique.</u>

Phacoemulsification (PHACO) and foldable intra - ocular lens (IOL) implant is now the worldwide gold standard technique for cataract surgery.
All the modern cataract surgeries techniques (ECCE, MSICS, PHACO) are precise and delicate microsurgery procedures (done with operating microscope).
In order to understand how precise the surgical hand must be during cataract surgeries, imagine that the lens capsule that completely envelops the lens (predominantly composed of collagen) is thin about 2 – 3 microns in the posterior part and 9 – 14 microns at the anterior pole.
All the modern techniques, of cataract surgery, especially phacoemulsification, necessitate the anterior capsule to be opened by the surgical hands (recently also by the laser) in a circular manner with micro instruments. This step (capsulorrhexis) is the one of key factor for a successful cataract surgery and for a correct implant of the intraocular lens inside the capsular bag (Fig. 8).

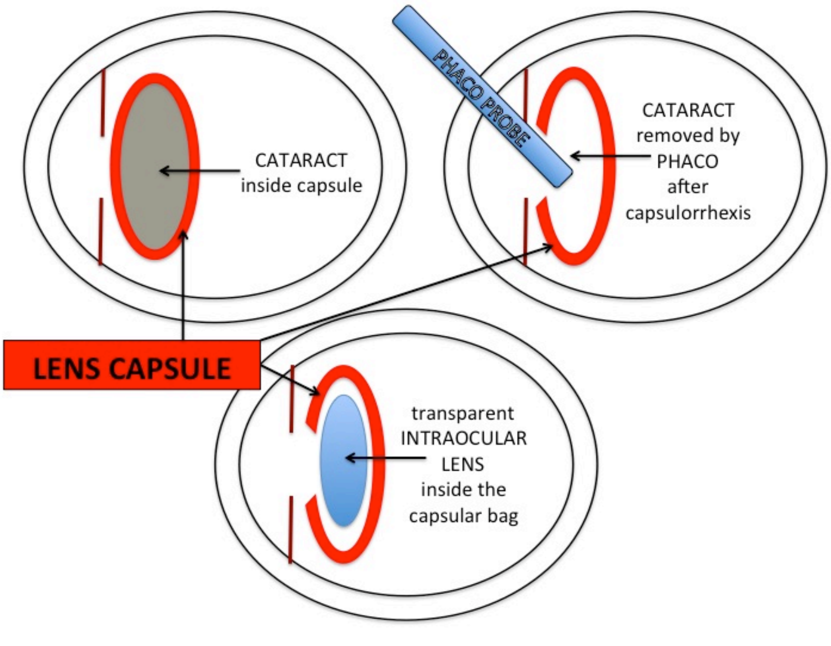


Fig. 8 Vision is restored after IOL implant inside the capsular bag.

The patient during the surgery lays confortably in a bed in the operating room.
Phacoemulsification is normally an outpatient procedure (patient do not sleep in the hospital).
Phacoemulsification technique is done in the operating room. The eye surgeon necessitate of an operating microscope and a phacoemulsification machine. Also

there is the need of surgical instruments and devices.

The procedure is done with topical anesthesia (anaesthetics eyedrops), intracamerular anesthesia (injection in the anterior chamber of the eye), local injection near the eye or in the surface of the eyeball (sub - tenon, peribulbar or retrobulbar) or rarely general anesthesia (ex. pediatric cataract). Everything in the operating room must be sterile during the procedure (phaco probe, instruments, liquids, surgeon hands and sterilized gloves for every case, etc.).

Also, before the surgery, the skin of the eyelids and the eye surface are well disinfected with povidone - iodine.

All phacoemulsification machines consist of a computer to generate ultrasonic impulses, and a transducer and piezo electric crystals to turn these electronic signals into mechanical energy. The eye surgeon performs a small incision in the eye (tunnel 2 – 3 mm) in the cornea or in the limbus (the margin between cornea and sclera).

The lens capsule (anterior lens capsule) is opened in a circular manner with microforceps or a needle (capsulorrhexis or Continuous Curvilinear Capsulorrhexis CCC introduced in cataract surgery in 1991 by Gimbel H, and Neuhan T.).

When the visibility is poor for the surgeon, in very advanced cataracts (ex. white cataracts, brown or brunescent cataract), or when there is also a corneal opacity, could be necessary staining the anterior lens capsule with the injection of colorants in the anterior chamber of the eye, before the capsulorrhexis. Most eye surgeon use trypan blue used in cataract surgery since 1999. Trypan blue is a vital stain first synthesized by Nobel Prize Paul Ehrlich in 1904. After capsule staining, capsulorrhexis is done with better control, and the solution of trypan blue is removed from the eye.

The phaco probe is then inserted inside the eye through the small incision and emulsify and aspirate cataractous lens material inside the eye (through the pupil). During phacoemulsification a fluidic circuit is employed, in order to maintain a stability of the anterior chamber of the eye, during aspiration of cataractous material.

The forces that emulsify the cataract are a blend of the jackhammer effect and cavitation (a sort of shock waves). Phaco probe deliver ultrasonic waves inside the eye with an energy controlled by the sugeon with a foot pedal. During phacoemulsification there is a delivery of heat with subsequent risk of damage of ocular structures (cornea, iris, capsular bag).

After aspiration of cataractous lens the capsular bag is clear and empty. Through the same corneal incision the ophthalmologist inject a foldable intraocular lens (IOL) with an injector. The IOL is placed inside the capsular bag.

At the end of the procedure the corneal wound will be closed with or without suture.

During the phacoemulsification procedure the surgeon will be helped by injection inside the eye of viscoelastic material (Ophthalmic Viscosurgical Device or OVD).

Use of viscoelastic material during anterior segment surgery (specially cataract surgery), introduced in 1979, has decreased the incidence of corneal edema as a complication. OVDs are mainly constituted by sodium hyaluronate, chondroitin sulfate, or hydroxypropyl - methylcellulose and serve to amortize the forces inside the eye generated during the procedure (ex. IOL implant).

Lens Implant

Cataract surgery with intraocular lens implantation is perhaps the most effective surgical procedure in all of medicine.

Before 1949 (first IOL implant done by Harold Ridley), cataract surgery resulted in aphakia (eye without lens), and patients were destined to wear high hyperopic spectacles that were of considerable weight and that caused image magnification and distorsion to the sides.

As a general rule the eye after cataract removal needs an intraocular lens to be similar

to a normal eye. In fact the normal crystallin lens is a lens with about + 20 dioptries of power. This refractive power is necessary to converge the images onto the macula.
IOL implantation inside the eye is a safe and well recognized advantage.
Normally is done at the end of the cataract surgery procedure.
The sites of implantation of the intraocular lens are

- the posterior chamber (in the capsular bag or in the sulcus)
- the iris plane
- the anterior chamber
- scleral fixated.

The capsular bag implantation is the best solution, but it is not always possible for the surgeon to implant there, especially if the capsular bag is broken or absent. In fact there must be the anatomical integrity of the eye's structures to implant in the bag.
Most common IOLs material are: polymethyl-methacrylate (PMMA), silicone, hydrogel or hydrophilic acrylic, hydrophobic acrylic, thermoset, collamer.
All the materials are inert inside the eye if the lens is implanted in a correct position.
One of the major disadvantages of standard IOLs is that they are primarily focused for distance vision, and are unable to accommodate (change focus from far to near). Recently are available also accommodating IOLs that provide excellent vision at all distances (far, near, intermediate) and reduce the dependence on glasses after cataract surgery.
Injection inside the eye of a foldable IOL has the advantage that surgeon do not have the necessity to enlarge the main corneal incision to insert the IOL. This type of IOL is injected through a very small incision and it opens inside the capsular bag.
Intraocular lenses (IOLs) have many dioptric powers. Before surgery eye doctors calculate the power of the IOL to be implanted for each patient. This pre operative process is called biometry. The pre – operative biometry has a major influence on the success or failure of IOL implantation, and accurate eye measurement are important in preventing refractive errors. Corneal power (curvature), and axial length of the eye are the main values to calculate. After biometry it is important to discuss with patients their postoperative refractive expectations.

Complications

The rate severe adverse events (specially endophthalmitis) after cataract surgery (ECCE or PHACO) are declining with modern techniques and in the hands of experienced cataract surgeons. Complications resulting in permanent loss of vision are rare (intraocular bleeding).
The most common intraoperative complication of phacoemulsification is posterior capsule rupture. The posterior capsule rupture could determinate the necessity of a further surgery (if it happens at the beginning of the procedure, when the cataract is still inside the capsular bag, cataract materials drop into the vitreous cavity) or the impossibility to implant the IOL.
Common postoperative complications include posterior capsule opacification (that could be treated with YAG laser), corneal edema (swelling of the cornea), cystoid macular edema (swelling of the macula), retained lens fragments, endophthalmitis, IOL dislocation, increased pressure inside the eye, retinal detachment.

Brief information about precautions to be taken before and after the operation

To reduce the risk of infection from surgery, eye doctors normally prescribe antibiotic eyedrops to use one or two days before surgery.
Following cataract surgery, the operated patient leaves the operating room. The patient normally stay about one hour in the hospital/clinic and then, is discharged home after giving medical instructions.
Patients need to protect operated eye by wearing an eye shield (normally transparent) also during sleep. It is helpful to wear sunglasses in bright light.
After complex cataract surgeries or combined surgeries in the eye, the patient may be

asked to remain in the hospital/clinic for few days.
It is very important for the success of the surgery to start postoperative therapy (normally eyedrops) at home and to attend the scheduled postoperative controls.
During the first week patients must avoid strenuous activity such as sport or bending heavy lift, and also must avoid getting water, dust in the operated eye.
In most cases the patient is examinated the day following the surgery, than after one week, than after 30 – 40 days.
It is safe to wait about 40 days before doing cataract surgery in the other eye.

Conclusion

Cataract surgery with an IOL implantation is a safe procedure.
The advent of Femtosecond lasers in ophthalmic surgery (2001) opened a new era also in cataract surgery. Image guided laser cataract surgery was first conceptualized (2005) by D. Palanker and M. Blumenkranz.
Then Femtosecond laser procedure was used in cataract surgery in 2008 by Prof. Z. Nagy (Hungary), and followed in USA (Stephen Slade) and in Asia (M. Lawless).
The role of femtosecond lasers in cataract surgery in this moment is to assist or replace several steps of the manual cataract surgery.
The history of cataract surgery techniques will progress.

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