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Intraocular lens employed for cataract surgery

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Abstract. The aim of this paper is to illustrate the techniques of cataract surgery with implantation of intraocular lenses and some physical properties of the used materials. The new technology, coupled with extensive experience and the studied cases, permits to increase the standardization and accuracy of the engravings, by reducing the use and handling of surgical instruments inside the eye. At present it is possible to replace the cataract with crystalline lenses based on biopolymers such as PMMA, silicone, acrylic hydrophilic and hydrophobic acrylic. These materials are increasingly able to replace the natural lens and to ensure the fully functional of the eye. The role of femtosecond lasers in cataract surgery, to assist or replace several aspects of the manual cataract surgery, are discussed.

1. Introduction

The crystalline lens is a convex lens, flattened anterior-posterior direction, located behind the iris, suspended with a round ligament complex. Along with the cornea, it composes the main part of the ocular dioptre. Fundamental properties of the lens are transparency and dioptre power. Exclusive feature is the ability to change its dioptre power in order to focus on the retinal surface images from nearby objects. This ability called "accommodating" occurs with the change of curvature of the lens, especially, of the front face, and is a reflection of the focus-induced retinal images that determines the ciliary muscle contraction with the simultaneous convergence of bulbs and miosis.

The term is defined as any cataract lens opacity can result in a loss of transparency and a diffraction and scattering of light. Cataract is the most common among ocular pathologies. Its symptoms include a gradual reduction of visual acuity, altered colour perception, emergence of refractive defects and glare [1]. Fig. 1a shows a photo of an eye with cataract. The formation of cataracts is a para-physiological process that determines a slow and progressive crystalline opacity. There is no medical treatment to stop this deterioration and the only possible therapy is surgical. The technique involves the removal of the crystalline lens and replacing it with an artificial one that can correct visual defects as well as pre-existing myopia, hyperopia, astigmatism and presbyopia.

The intervention is completely painless, lasts approximately twenty minutes, in not complicated cases, and runs with a relatively simple and painless procedure. Actually, the technology presents in

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the operating room, and microsurgical operations for the surgery, requires precision and grace in the order of tens of microns for maximum post-operative result [2].

The growing development of artificial crystalline increasingly reliable, careful patient selection and the prior study of the individual case allow us to get a high reliability of the post-operative results, managing to simultaneously fix most defects existing visual as: myopia, astigmatism and hyperopia. Fig. 1b shows an artificial lens implanted in eye.

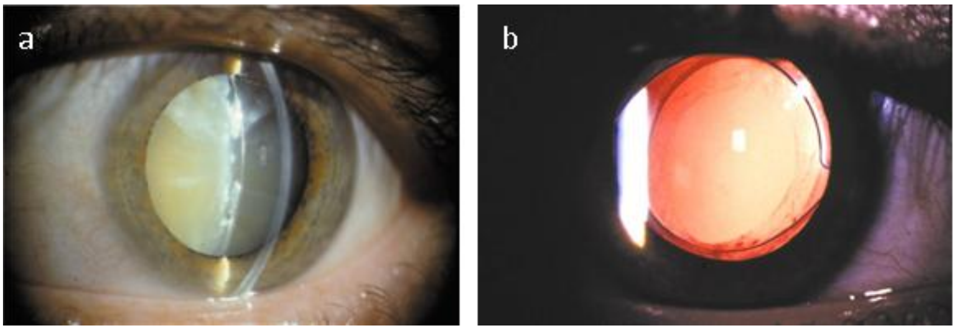

Figure 1. Eye with cataract (a) and eye with artificial crystalline implant (b).

2. Materials and methods

The cataract surgery is preceded by specialists visit and functional tests to ensure preventive health and the characteristics of the eye, to assess their capabilities and determine the exact conditions for deciding the most appropriate intervention. Some of the preliminary examinations required are:

- *Examination of visual acuity*: it is used to determine how many tenths you can see with best optical correction. Statistically a person in full welfare reaches 10/10 (ten tenths) of visual acuity.
- *Bio-microscopic examination* with a slit lamp: high magnification to examine the anatomy of the eye and cataract characteristics.
- *Evaluation of the fundus oculi*: specific examination of the retina and the optic nerve.
- *Numerical count and morphology of corneal endothelial cells*: when there are doubts about the number and viability of cells that make up the posterior layer of the cornea.
- *Tonometry:* measurement of rare eye pressure.
- *Ultrasonic/laser biometry,* to measure the length of the eyeball. It permits to calculate and customize the template and the optical power of the artificial lens to be implanted during surgery.
- *Stratigraphy OCT (Optical Coherence Tomography)* of the macular region: indicated for the presence of retinal and macular diseases (only in selected patients.)

Currently there are two basic categories of intraocular lenses (IOL), rigid and soft ones, made of various types of materials and with various shapes and sizes with different optical characteristics.

The **rigid lenses** are made of poly-methyl-methacrylate based on PMMA monomer $(C_5O_2H_8)_n$, a special plastic similar to perplex. They have the advantage of being easy to build and to have a low cost. They have a big drawback of requiring a large incision to be introduced into the eye and to apply several stitches, healing times become longer and, therefore, also the period for full recovery.

The **foldable lenses** made of silicone or acrylic material, based on dimethyldioxane monomer $(C_2H_6OSi)_n$, which can be more hydrophilic or hydrophobic requiring more complex techniques and expensive but they have the great advantage to be inserted through tiny incisions that do not require stitches and allowing the patient anatomic and visual rehabilitation very fast.

Modern cataract surgery requires, without doubt, the implantation of an artificial crystalline lens. PMMA is a material that at body temperature shows a glass-like appearance and is stiff and brittle, based on a polymer structure to individual chains closely joined together. It has a perfect transparency to visible light and a low optical dispersion index. It is hydrophobic and this can result in unwanted tack with endothelial cells and inflammatory cells in aqueous reducing the corneal transparency. A typical transmission spectrum measured in folding IOL is shown in Fig. 2 for PMMA (a) and (b) Acrylic [3]. The modern IOL have about 5 mm optic diameter and have a smooth texture to be folded and inserted into the eye through an incision of only 2-2.5 mm that normally it does not require stitches. Silicone has the advantages of having low costs of production, to be sterilized in autoclaves, high biocompatibility and it is very soft. Silicone doesn't produce endothelial damage but it has the disadvantages to decentralize the lens, to have a low refractive index, to be not very thin and to be chemically sensitive to IR radiation. Instead, acrylic based lens have the advantages to have high refractive index and thus to have little thickness, to be absorbent in the UV region, to have a wetting angle variable and to have high flexibility to be easily implanted. Acrylic lens has the disadvantages to be more expensive.

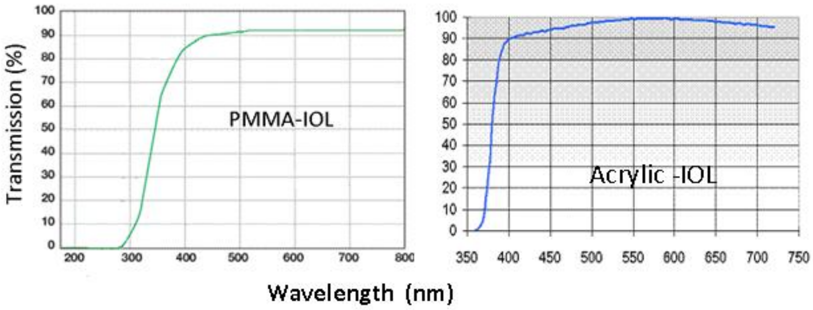

Figure 2. Optical transmission of a typical PMMA intraocular lens (IOL) (a) and of an Acrylic based IOL (b).

There are different kinds of IOL with design and different physical and optical characteristics: monofocal, multifocal and accommodative, toric, aspheric, apodizzated and UV filters. Fig. 3 shows some typical design of IOL lenses. Routinely incisions are created manually by introducing a sharp, sterile blade into the cornea. The use of a manual blade makes it difficult to control the length and architecture of the incision, which may affect the stability of the wound under pressure. Following the surgery this could manifest by the corneal wound leaking increasing the potential risk of infection.

Figure 3. Three typical designs of IOL elastic lens based on silicone or acrylic.

The access to the cataract is initiated through small incisions (around 2mm in length) made into the peripheral cornea zone. Known as Clear Corneal Incisions (CCI) they remain the preferred method for surgeons accessing the anterior chamber of the eye during cataract surgery. Previously large incisions (approximately 5-7mm in length) were made into the sclera (white part of the eye). This is a highly vascularized part of the eye and which required particular consideration for older patients on blood thinning therapy. To ensure that the incisions were adequately sealed, sutures were required following surgery. The need for sutures prolongs the eye recovery process. The CCI surgery is micro invasive and can be considered to be self-sealing (that means no sutures are required).

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3. Femtosecond lasers

A femtosecond laser is a laser which emits optical pulses with a duration well below 1 ps (*ultrashort pulses*), i.e., in the domain of femtoseconds (1 fs = 10^{-15} s). It thus also belongs to the category of ultrafast lasers or ultrashort pulse lasers working in mode locked in near infrared light to create precise subsurface cut (photodisruption of deeper tissues).

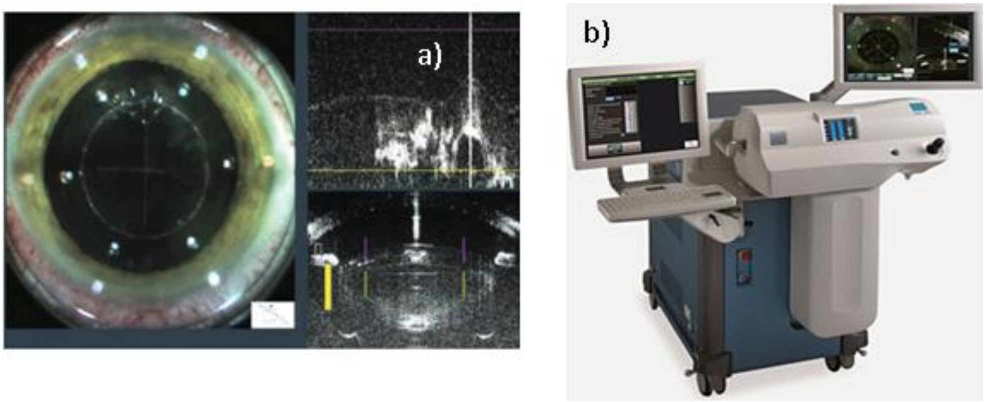


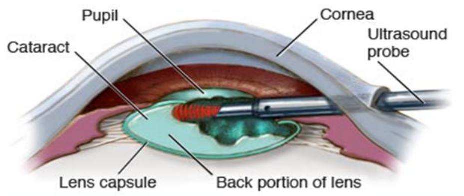
Figure 4. Photo of a phase during cataract procedure laser surgery (a) and femtosecond laser with OCT eye imaging (b).

The role of femtosecond lasers in cataract surgery is to assist or replace several aspects of the manual cataract surgery. These include the creation of the initial surgical incisions in the cornea, the creation of the capsulotomy, and the initial fragmenting (breaking up) of the lens, as indicated in Fig. 4a for a new generation surgery. The femtosecond laser may also produce incisions within the peripheral cornea to aid the correction of pre-existing astigmatism. The preliminary results are very promising. In cataract surgery *fs* laser cutting is performed inside and on the surface of the crystalline lens. Since lens position and orientation differs from eye to eye, precise 3-dimensional imaging is required to define location of the lens capsule in order to properly apply the laser cutting patterns. Image-guided laser cataract surgery is based on the use of integrated Optical Coherence Tomography (OCT). A typical instrumentation is reported in Fig. 4b. Laboratory studies have shown that the femtosecond laser produces consistent and stable incisions in the eye. This has been attributed both to the controlled, reproducible generation of the incisions and the configuration of the corneal wound created. It would suggest that laser-cut, clear corneal incisions offer the potential of less risk of wound leak thereby further reducing the risk of infection following surgery. In addition to creating the main cataract surgical wound, femtosecond lasers are used to create limbal relaxing incisions (LRIs). LRI microsurgery can reduce the amount of astigmatism presents in the eye and often improves the post-operative uncorrected visual acuity. Typically, corneal incisions to control astigmatism have been performed by hand held blades. The major factors determining their effectiveness are the incision length, depth, and uniformity, the location relative to the centre of the cornea, the incision geometry, the patient's age, and the amount of astigmatism. The precision of the laser created incisions should allow the surgeon greater control over the final refractive endpoint possibly leading to improved visual outcomes. Again further data is required at this point to confirm these assertions.

4. Results and discussion

The treatment of cataracts is surgical and it involves only the removal of the lens replacement and implantation of artificial crystalline lens. Today it runs in surgery, under local anesthesia, no stitches and it allows a good visual recovery as early as next day. It is a technologically advanced intervention, which requires an optimal experience of the surgeon and his team but also of a modern and perfect instrumentation. The latest techniques for micro-surgical cataract surgery are using mini-invasive tools that help the surgeon to break up and remove the opaque lens nucleus without damaging the delicate structures inside the eye. With the aid of a microscope, the operator inserts a small tube with a diameter of 0.8 mm. which emitting ultrasound, sputter crystalline fibres allowing their full suction. This technique is called "ultrasonic phacoemulsification" [4]. Fig. 5 shows a scheme of phacoemulsification with the implantation of an intraocular lens. This technique allows you to remove the cataracts through an opening of only 2.75 mm. Through the same aperture is then injected a foldable artificial lens, which once positioned opens like a flower definitively at the headquarters levels.

a)



b)

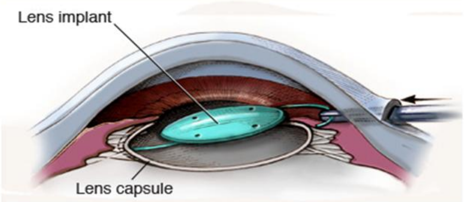


Figure 5. Scheme of phacoemulsification (a) with implant of an intraocular lens (b).

The phacoemulsification aims to respect the natural anatomy of the eye, even with a valve incision, which in most cases does not require suturing minimizing astigmatism and inconvenience to the patient. In some phacoemusificators it is used a ultrasound probe that revolves on its axis both longitudinal and torsional (OZIL), it helps the surgeon in the delicate fragmentation of the nucleus before his aspiration.

The spread in cataract surgery with micro necessitated the use of IOL with optical big dish, can be implanted through the tunnel after being bent and relax once placed inside the eye. Silicone and acrylic based IOLs can be folded and implanted through a cut of between 1.8 mm and 3.2 mm. The acrylic IOL can be hydrophobic and hydrophilic, in relation to the amount of water present in their structure [5].

The hydrophobic IOL showed no tendency to become cloudy, although fingerprints have been described left on the optical plate by bending and insertion tool, and the possibility of formation of bright particles inside the optical plate. The silicone IOL showed the possibility of yellowing and hydrophilic acrylic IOL to become cloudy for the accumulation of calcium and phosphates on the surface and in the substance of the optics of the lens.

When the cataract is removed, it reappears in 20% of cases within a range going from few months to about one year after surgery and the vision may return to decrease for the emergence of so-called secondary cataract. Secondary cataracts is caused by posterior capsule opacity that is claiming support the lens and now it keeps in place the new artificial crystalline lens. This fabric over time can lose its natural transparency decreasing the vision. Several years ago it was necessary to return to the operating room. Today this can be easily treated on as outpatients, with no hassle and permanently with the help of Yag laser to perform so called posterior capsulotomy by disruption of the masses. This laser emits bursts of 100 mJ at 1064 nm IR field with duration of nanosecond that can be focused on the opaque posterior capsule to vaporize when giving their energy. However, radiation is transparent in thin IOL. The use of laser light in cataract surgery, for a variety of purposes, it is becoming increasingly widespread. Next to the worldwide used ultrasonic phacoemulsification in cataract surgery, actually the application of the femtosecond lasers become true. Such devices use energetic pulses with duration of about 10 fs, used in repetition rate, to perform the anterior

capsulorhexis and to crush the cataract material. Near infrared impulses "ablate the tissue without heat which makes it even less invasive ocular surgery. The cataract operation is completed by removing the masses by a surgeon. After the cataract operation eyesight recovery is usually very fast. This method simplifies the cataract surgery in some selected cases however it cannot be used in advanced cataracts or in presence of corneal opacity.
After the cataract surgery can use a laser light for shaping the customizable or intraocular lenses hi-tech. In this case the laser light model intraocular lenses to meet the Visual requirements of the patient and correct vision defects remains after cataract surgery. From this point of view in physics research relating to the field of laser-tissue interaction is helping the clinic to improve more and more results. Studies on laser ablation of IOL lenses made of PMMA, Silicone and Acrylic resins are increasing in actual literature.

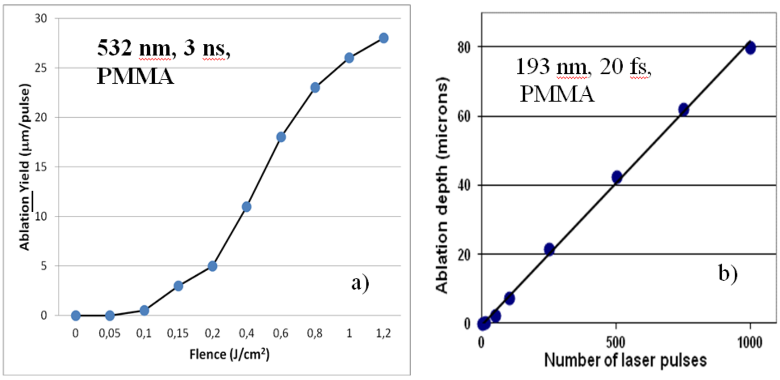


Figure 6. Ablation yield of IOL-PMMA as a function of the laser fluence at 532 nm wavelength and for 100 laser shots (a) and Ablation depth in PMMA produced by fs laser pulses at 193 nm wavelength and at 18 J/cm^2 fluence (b).

Fig. 6a shows an example of the result obtained at the Physics Department of the University of Messina for the ablation of PMMA as a function of fluence with a Nd: Yag laser at 532 nm second-harmonic wave-length and 3 ns pulse. Measurements were performed by measuring the ablation mass per 100 laser shots. The ablation shows a threshold value, of about 100 mJ/cm^2, beyond which the ablation increases nearly linearly with the laser fluence up to values of about 1 J/cm^2. After this value the ablation yield tends to saturate [6]. Fig. 6b shows the ablation yield in PMMA-IOL, in terms of removed depth vs. number of laser pulses, produced by *fs* laser shots at 18 mJ pulse energy, 193 nm wavelength, 0.1 mm^2 spot, and 18 J/cm^2 laser fluence (b).

The new technology, coupled with extensive experience operating casuistry and of more than 24,000 patients operated in the last 20 years, allows us today to further increases the standardization and accuracy of engravings, 40% reduction of the use and handling of surgical instruments inside the eye. In summary the new cataract surgery involves less trauma, more precision, more standardization and faster visual recovery and predictable.

The femtosecond laser is able to create a near perfect, round opening in the anterior capsule by dissecting it with a spiral laser pattern crossing the anterior capsule. To avoid distortion of the incoming laser beam on gas bubbles and tissue fragments, the spiral pattern is applied first posterior to the capsule, and advances anteriorly. The surgeon then is able to simply remove the capsule with surgical forceps. This has several potential benefits over the radially-created manual procedure. In conventional cataract surgery the incidence of anterior capsular tears has been documented from 0.79% in very experienced hands to 5.3% within teaching institutions.

The capsulotomy may also impact on the visual outcome. An irregularly-shaped capsulotomy may influence the position of the implanted IOL leading to decentration and tilt which may cause a decrease in the patient's quality of vision. The ability to create a precise, well-centered capsulotomy should therefore optimize the surgeon's ability to achieve the patient's anticipated visual outcome. Measurements have shown that in comparison to manually created capsulotomies those created with a laser have significantly lower internal aberrations following surgery. The femtosecond laser has the capability to assist the fragmentation (breaking up) of the cataract. The laser applies a number of pulses to the lens in a pre-designed pattern which then allows the surgeon to use current technology to remove the lens matter. This additional step has been shown to reduce the average time and energy required to break up and remove the lens by approximately 50%. Inherently this should make the overall procedure safer and less traumatic to the eye, which may further reduce the risk of postoperative swelling and lead also to a faster visual recovery. The ability of surgeons to provide significant advantages to patients at risk of major intraoperative and postoperative complications will continue to increase and ultimately it may represent a substantial benefit of femtosecond technology. This may prove to be the greatest potential advantage of laser-assisted cataract surgery although data significant to provide a clinical benefit is not available at this time in point.

5. Conclusions

For the cataract surgery a key parameter is represented by a careful selection of the most suitable intraocular lens. Usually you run several tests before you can locate intraocular lenses for each patient. Thanks to scientific research much boost in this area to usable materials, the means and the technologies available today to the ophthalmologist, there are now several types of intraocular lenses and research and innovation continue to make great strides in this area.

The Standard IOL can be employed for near and far view. However, under conditions of low contrast or night vision the vision quality is not optimal.

The Aspheric IOLs allow a better quality of night vision compared with traditional intraocular lenses. The Toric IOL can correct astigmatism.

The hi-tech IOL can be customized with light in selected cases that provide the best view possible without glasses. The Multifocal IOL that have two or more focal points allows you to see well from far and from near after cataract operation.

The Accommodative IOL through a special form of the lens restores the natural mechanism of focus to close that generally is lost with the age.

The IOL for macular holes (OriLens and LMI Lipshitz Macular Implant), ideal for those suffering from cataracts and macular holes, it's a telescopic lens system (intraocular telescope) that allows you to enlarge the image.

The use of last generation *fs* lasers permits to resolve the cataract problems using a less invasive surgery a very accurate instrumentation which permits clear and very controllable corneal incisions, precise capsulotomy, accurate phacofragmentation of the cataract and to resolve complications reducing the pressure on the eye and the risk for the patient.

In conclusion, the cataract surgery, thanks to the new instrumentation development, has become a clinical procedure less invasive and always with appreciable results that significantly improves the quality of life of patients.

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