Research Article

Evolution of Femto Cataract Surgery……… Indications and Limitations.

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Abstract
The use of femtosecond lasers is considered an evolution in modern corneal and cataract refractive surgery. With accuracy, safety, and repeatability. As the technology advances, it will show surgical limits and open new ways for ophthalmic intervention in different situations. With time the transition from femto-LASIK to femto-cataract surgery became obvious that this innovation is very effective. This review presents some of the most important indications and limitations of femtosecond lasers in modern corneal and cataract surgery.
Keywords:
Femtosecond Laser, cataract surgery, phacoemulsification, indications, limitations.

Introduction
Femtosecond laser technology was first developed by Dr. Kurtz at the University of Michigan in the early 1990s[1] and was rapidly adopted in the surgical field of ophthalmology. Femtosecond lasers emit light pulses of short duration (10−15 s) at 1053 nm wavelength that cause photodisruption of the tissue with minimum collateral damage. This enables bladeless incisions to be performed within the tissue at various patterns and depth with high precision.[2,3] Femtosecond-laser-assisted cataract surgery (FLACS) is a new technology in the field of ophthalmology. The first implementation of femtosecond laser cataract surgery was performed in 2008 in Europe by Nagy et al.,.,[4] Today's cataract surgery patients expect not only improved vision after cataract extraction, but also excellent visual quality and spectacle independency, and pressure on ophthalmic surgeons is ever increasing. The use of this new technology may help health providers to improve their results.[5] this review paper presents the most recent advances and the evolution of femto cataract surgery.

The era of phacoemulsification & primary laser systems for cataract surgery
Kelman achieved a new milestone that revolutionized cataract surgery upto the present day. He took inspiration from dentistry during a session of dental hygiene; he thought that the same ultra-sounds used for tartar removal could be effective in cataract fragmentation.[6]

Viscoelastic agents have been developed synchronously with modern phacoemulsification techniques, playing an integral role in the success of this new technology. Improved surgical techniques & phaco machines technology for removing the anterior lens capsule have creased the incidence of both intraoperative and post-operative capsular complications.

To abolish or reduce the ultrasound emissions during surgery, many alternative devices were created such as the catarex of optex ophthalmics [San Juan Capistrano, California (CA)], presented by P Kratz in 1998. He used a high speed rotation inducer with a hand piece of 1.25 mm. This created, with 30,000–70,000 rotations per minute, a vortex that could suck up an emulsified nucleus and cortex without leaving a groove. Experimentation was supported by “Bausch & Lomb”.[7]

Ultraviolet lasers were tested, such as the 193 nm (argon fluoride), the 248 nm (krypton fluoride), the 308 nm (xenon chloride) and 351 nm (xenon fluoride), and an infrared laser, such as neodymium-doped yttrium lithium fluoride (Nd: YLF) (1,053 nm) that with laser pulses in the order of picoseconds, was able to fragment the core and cortex from the outside with the aid of a slit lamp.[8]

Dodick/ARC laser yttrium aluminum garnet (YAG) phacolysis with mono-manual or bimanual probes was marketed after Food and Drug Administration (FDA) approval in 1991. This machine was able to fragment and aspirate the lenticular material with the same hand piece, without generating heat, but with very long surgical times.[9]

The erbium (Er: YAG) laser (2,940 mm) was able to perform continuous curvilinear capsulorhexis, the cataract fragmentation, the filtration surgery for glaucoma and vitrectomy. The technique failed because of the frequent complications with the laser just as the erbium laser, experimented in Italy by Frosini and Franchini, and the holmium laser that was also abandoned due to treatment complexities.[10]

The AquaLase was introduced by Alcon (Fort Worth, Texas); a water system with limited use in the fragmentation of soft cataracts.[11]

The first steps toward the separation of tissues with ultrashort laser pulses have occurred in the late 1980s when DJ Schanzlin applied a picosecond laser (Nd: YLF) in cataract surgery.The picosecond laser, called intelligent surgical laser (ISL), was capable of performing capsulotomy and lens liquefaction.[12]

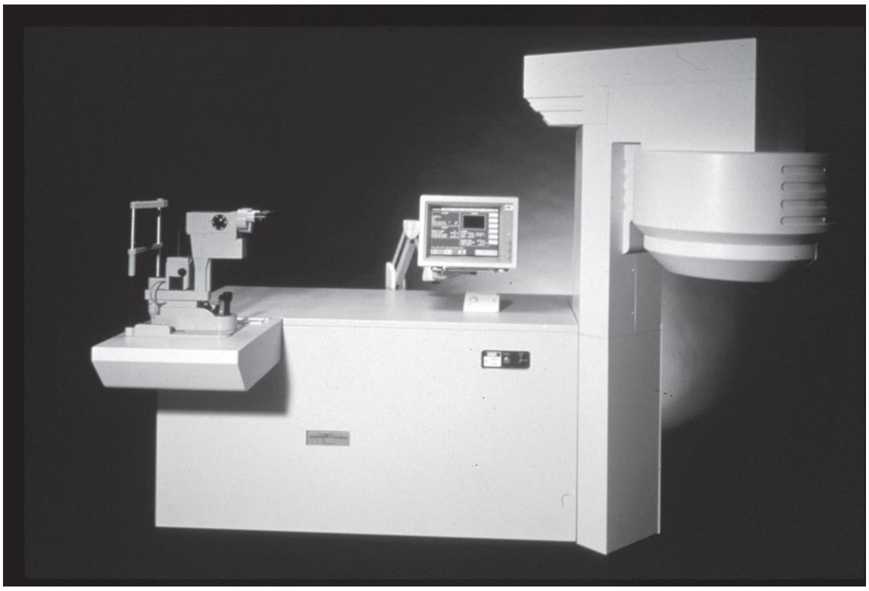

Figure 1: Intelligent surgical laser (ISL) unit. [12]

Phacoemulsification and femto cataract surgery:

Cataract is responsible for half of the global burden from vision impairment. In the western world, phacoemulsification is the surgical procedure of choice routinely providing excellent visual and safety outcome. Approximately 18 million cataract procedures are performed globally every year, rising up to 24 million soon due to demographic changes, aging population, and changes in indication for crystalline lens surgery.[13]

Nevertheless, it is not a perfect procedure and room for improvement exists. Complications such as endophthalmitis, cystoid macular edema, endothelial cell damage, vitreous loss and retinal detachment remain sight threatening concerns.[14]

The femtosecond laser is now commercially available to perform three key steps in small incision cataract surgery: capsulotomy, lens fragmentation and wound construction.[15]

Femtosecond lasers work on the principle of photodisruption brought about by a tightly focused beam of ultrashort pulsed light energy with enough peak power to create plasma. The focused femtosecond pulses induce optical breakdown with significantly less pulse energy, thereby minimizing collateral damage.[16]

Currently there are six Femtosecond laser machines at or near the point of commercial release. These include LenSx (Alcon Laboratories, USA), Catalys (Abbott Optimedica Corp, USA), LensAR (LensAR Inc, USA), Technolas Femtec (Custom Lens, Germany), Victus (Baush& Lomb, USA) and LDV Z8 (Zeimer, Switzerland). All laser systems share a common platform which includes an anterior segment imaging system, patient interface and femtosecond laser to image, calculate and deliver the laser pulses. The specific technology to achieve these steps differs between the individual machines with notable differences in imaging and docking systems and laser treatment algorithm.[17]

Current research suggests that the use of femtosecond lasers in cataract surgery will provide selective benefits both for the surgeon and the patient; however, there remains little if any evidence that LCS provides superior safety or visual outcomes as compared with conventional phacoemulsification.[18]

Femtosecond laser cataract surgery (FLACS) was first presented in 2008[4] by Nagy et al., and received United States Food and Drug Administration [FDA] approval in 2010[19] since then, it has received tremendous input of research and development to constantly improve outcomes.

There is a learning curve for laser cataract surgery (LCS), which may initially lead to an increased complication rate. This was moderately exaggerated in surgeons not familiar with the use and limitations of a femtosecond laser.[20]

Indications of femtolaser cataract surgery

Patients with quantitative or qualitative endothelial damage; with the femto-phaco the use of intraocular instruments is reduced, as is their permanence in the eye bulb. The surgical movements are reduced thanks to the phacolysis (cubes, circles or quadrants) that sometimes allows use of only endosaccular phase 2 of phaco, or even exclusively the irrigation/ aspiration (away from the endothelium). In addition, numerous studies, first Z Nagy on LenSx®, followed by many other pioneer surgeons, and confirmed in our experience, show that the emission of ultrasound is reduced on average by 30–60%.[21] Today, the Fuchs dystrophy together with other endothelial dystrophies is considered a classic indication for femtolaser procedure because of its less stress induced on corneal endothelium.[22]

Patients who need a more precise biometric result because they are candidates for Premium IOL: The reproducibility of the capsulorhexis allows the precise and centered positioning of the IOL and with less chance of high-order aberrations (e.g. coma, tilting, etc.).[23]

Patients at higher risk of infection (diabetics and immune compromised): Thanks to the ability of femtolaser to create safer incisions, as the trapezoidal, and "self-sealing" incision on three levels.[24]

Patients who require customization of the intervention for topographical reasons, (regular astigmatism or irregular astigmatism) with arcuate incisions if there is no indication to the toric IOL.[25]

Patients with weak zonules such as Weill-Marchesani syndrome, Marfan syndrome and pseudoexfoliation (PEX): For the capsulorhexis precision and the respect of the zonula biomechanic that will be less stimulated because of the reduced number of ultrasound and tractions. This is not possible in cases of pseudoexfoliation in which the mydriasis is poor and does not allow the femto-laser to be able to perform the capsulorhexis (Figs 107A to C). At European Society of Cataract and Refractive Surgeons (ESCRS) in Milan (September 2012), S Masket described the importance of capsulorhexis in Weill-Marchesani syndrome in which, after a capsulotomy is performed with femto-laser you can proceed with a safer phaco, using the capsular hooks and the ring for distension before the implantation. The pseudoexfoliation syndrome is one of the main femtocataract indications. In fact, a precise capsulorhexis, perfectly circular and centered, can better distribute the weight of the pseudophakic lens and the capsular tractions later, which may cause, even years later, a dislocation of the entire capsular bag due to the zonula breaking, despite a flawless phacoemulsification being performed.[26]

Patients with very advanced cataracts, in which the shorter duration and use of ultrasounds will save corneal endothelium, and avoids the so-called “tunnel burn” (although in rare cases of white cataracts, the opacity are such that no transmission of the laser beam is permitted and the femto-treatment is limited to the capsulorhexis and incisions).[27]

Patients more predisposed to develop Irvine Gass syndrome [cystoid macular edema (CME)]. In case of blood barrier alteration, diabetic, maculopathies or pre-existing vitreomacular interface syndromes, the reduction of the intervention as well as the lowest number of ultrasounds, indirectly reduces the formation of edema.[28]

Patients with nystagmus to avoid peri-bulbar anesthesia: Even if the applanation procedure can be more complicated, once the docking is done, then the capsule will be easily removed. [29]

Mechanism of action of femtosecond laser

Femtosecond lasers utilize photodisruption to mediate their surgical effects. Photo-disrution is a complex, nonlinear process based on ionization in transparent tissue. As in inorganic materials, tissue photo-disruption begins with laser-induced optical breakdown, when a strongly focused, short-duration laser pulse generates a high-intensity electric field, leading to the formation of a mixture of free electrons and ions that constitutes the plasma state. [30]

The optically generated hot plasma expands with supersonic velocity displacing surrounding tissue.[31-34] As the plasma expansion slows, the supersonic displacement front propagates through the tissue as a shock wave. The shock wave loses energy and velocity as it propagates, relaxing to an ordinary acoustic wave that dissipates harmlessly. [35]

The cooling plasma vaporizes a small volume of tissue, eventually forming a cavitation bubble. The cavitation bubble consists mainly of CO_2, N_2, and H_2O (figure 2) which can diffuse out from the tissue via normal mechanisms. [36]

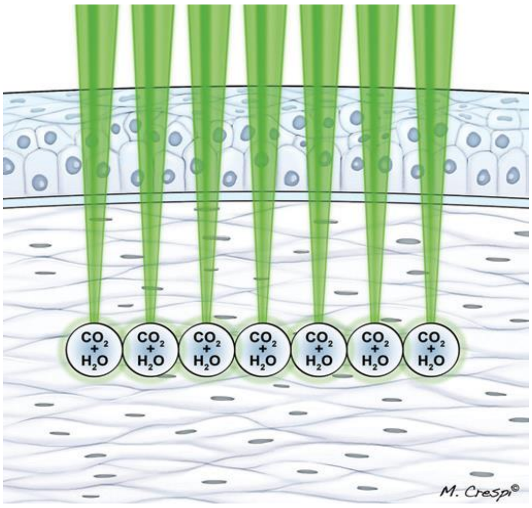

Figure 2: The microplasma of gas and H_2O separates tissue structures precisely [36]

Photodisruption with the nanosecond-pulsed neodymium: yttrium-aluminum-garnet (Nd: YAG) laser was already well established clinically in the early 1980s for procedures such as posterior capsulotomy and internal sclerostomy.[37]

These procedures were associated with relatively large collateral tissue damage zones due to the high-energy threshold associated with the nanosecond pulse durations. Laser–tissue interaction studies have shown that the photodisruption threshold (and therefore the amount of laser energy deposited in the tissue) can be markedly decreased when the pulse duration is shortened to the hundred femtosecond range. [38]

The decreased laser pulse energy results in smaller shock waves and cavitation bubbles. Incisions are created by scanning the focal spot of the laser pulse so that the cavitation bubbles are coalescing, thus creating a cleavage in the tissue.

The markedly reduced cavitation bubble size of the femtosecond laser photo-disruption provides more precise incisions while the most important consequence of the reduced shock wave range is minimized collateral damage in the tissue adjacent to the incisions. Additionally, the development of compact diode-pumped femtosecond laser technologies, such as Nd: glass and ytterbium based laser crystals has further enabled commercial developments of femtosecond laser technologies for ophthalmic surgery.[39]

The key performance figures of femto-second lasers are the following:

- The pulse duration (which is in some cases tunable in a certain range).
- The pulse repetition rate (which is in most cases fixed or tunable only within a small range).
- The average output power and pulse energy.[40]

Learning Curve of femto cataract surgery

The introduction of any new surgical procedure or technical device always involves a learning curve. For femtolaser, this seems to be faster for refractive surgeons, probably because they are familiar with the docking procedure, as this procedure is performed as well during LASIK surgery. In a study of Bali et al.,.,[41] divided a cohort of the first 200 eyes undergoing FLACS (capsulotomy, lens fragmentation and corneal incisions) into four consecutive groups, each including 50 eyes. This study showed a global decrease in difficulty or complication during the laser procedure and phacoemulsification over the course of the study, including the mean number of docking attempts (from 1.9 to 1.2, $p < 0.001$), uncompleted corneal incisions and anterior capsulotomy tags (from 18% to 6%).

The rate of anterior radial tears and posterior capsular rupture with vitreous loss in the whole cohort were of 4% and 3.5%, respectively. Four of 200 eyes presented a posterior lens dislocation (2%). Roberts et al.,[42] published a cohort study of 1500 consecutive cases with femto-secondaided capsulotomy, lens fragmentation and corneal incision and compared the first 200 with the 1300 consecutive eyes. They showed increased safety between the first 200 and the following 1300 cases with an incidence of capsular complication rate (anterior and posterior tears) decreasing from 7.5% (15/200) to 0.62% (8/1300) ($p < 0.001$).

Contraindications to femtolaser cataract surgery

Conjunctiva: Anything that hinders correct docking is a contraindication to laser treatment. A postglaucoma surgery bleb, conjunctival or palpebral pathologies that limit palpebral opening, and even loose conjunctiva can make correct docking impossible, which means no laser surgery can be performed. It is important to bear in mind that there are considerable differences between docking for LASIK and docking for cataract surgery. The former only needs contact with the cornea, includes the ablation of the superficial layers of the cornea, is performed quickly, requires xy energy, raises intraocular pressure quite a lot, and the surface of contact with the cornea is flat. Docking for cataract surgery requires the suction ring to adhere to the conjunctiva, OCT procedures must be performed, ablation mainly involves intraocular tissue, laser times are longer, and the contact surface is curved to follow the curvature of the cornea better and induces less increase of intraocular pressure. [43]

Exposure of the eye: Very deep-set eyes, an excessively prominent nose, reduced palpebral opening, and a cornea that is too curved or too flat can make docking ineffective and therefore laser-assisted surgery cannot be performed.[43]

General conditions: Lack of cooperation from patients for health reasons (Alzheimer's, paralysis, muscular deficit, and systemic pathologies) or excess anxiety can be contraindications to surgery.
Nystagmus may be a contraindication only if eye movement is excessive.

Patients with hearing loss or claustrophobia. Patients with bleeding disorders or under therapy with anticoagulants (relative contraindication since it is only related to a greater amount of subconjunctival hemorragies due to suction).[44]

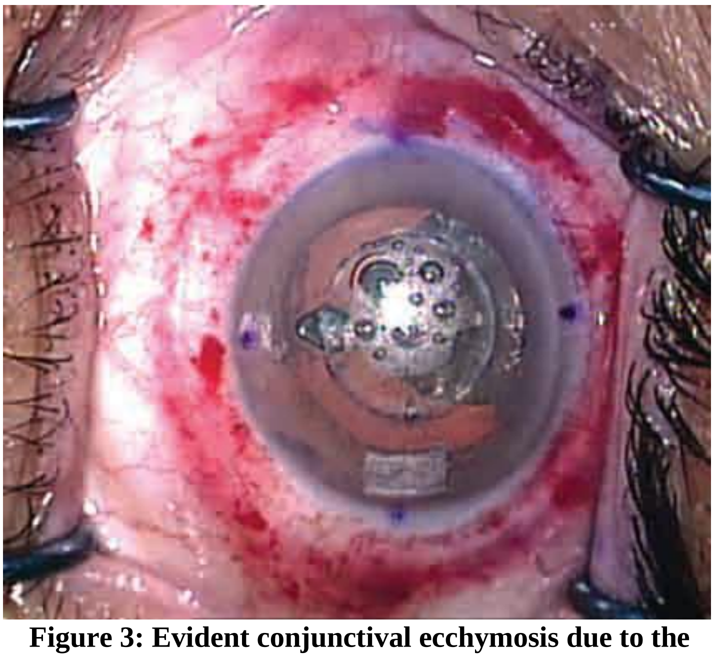

Figure 3: Evident conjunctival ecchymosis due to the Process of suction [44]

Transparency of the cornea: To achieve its goal, the laser beam must release its energy into the crystalline lens without interference. Any corneal opacity or nebula can reduce or block the passage of laser beams. This mainly affects the capsulotomy that may be incomplete. The same applies to action on the lens material and/or corneal tissue, even if this is less important in the general context of the operation. Likewise, corneal edema (caused by some pathologies of the cornea) can limit or block the transmission of the laser.[45]

Diameter of the pupil: In most cases, surgeons desire a capsulotomy centered on the pupil, with a diameter between 4.5 and 5.5 mm. Laser emission should also be at least 1 mm from the edge of the pupil, so that iris pigment does not interfere with the passage of the laser energy (and also because excessive proximity stimulates meiosis of the pupil). Patients with a small pupil, pupils with synechiae, or decentered pupils may not be suitable for laser surgery.[46]

Depth of the anterior chamber: Increased distance between the cornea and the anterior capsule of the lens does not affect laser surgery, but a shallow chamber could do so because the laser emission for capsulotomy may be too close to the endothelium and damage this important layer of cells.[47]

In conclusion, at present, FLACS is considered as a great revolution in cataract surgery over standard cataract surgery with many studies have shown better reproducibility in terms of capsulorrhexis diameter and centration, corneal wound construction, and decreased ultrasound energy and decreased endothelial cell loss. FLACS had passed through long period of evolution with high refinement but still has different complications and limitations.

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