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Femtosecond Laser Cataract Surgery: Improving Precision, Improving Results

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Femtosecond cataract surgery is considered to be one of the most significant advances in cataract surgery in 50 years. Laser cataract surgery has shown excellent results for accurate self-sealing corneal incisions, arcuate incisions to reduce astigmatism, highly circular, strong and well-positioned capsulorhexis, and safer and less technically difficult removal of the cataract with almost complete elimination of phacoemulsification. Laser technology may allow ophthalmologists to meet the demands of cataract patients to the same level that has been accomplished with laser vision correction. This issue of *Ophthalmology Rounds* reviews the features of this procedure that may significantly improve cataract surgery, its mechanism of action, and factors to consider for optimal use.

Cataract surgery is the most frequently performed surgical procedure in the world, with an estimated 15 million procedures per year and more than 250 000 procedures performed annually in Canada.[1,2] The evolution of modern cataract surgery has been from large-incision extracapsular extraction with a basic, monofocal intraocular lens to microincision surgeries with advanced lens technology. Improved safety and accuracy of the procedure has in general reduced the age at which most patients are undergoing the procedure. With many patients still active in their work and recreational activities, this has led to a corresponding increase in patient expectations with an emphasis on precise refractive and safety outcomes. The introduction of femtosecond lasers to cataract surgery represents a potentially significant advance in cataract technology.[3]

Dr. Charles Kelman introduced small-incision phacoemulsification in 1967. Over time, cataract wound size has gradually decreased to 2.2 mm.[4] Although the technique today of phacoemulsification is widely regarded as safe and effective, its outcome depends on the experience and skill of the surgeon. The next logical step in the evolutionary process of cataract surgery would be using laser technology to enhance the accuracy and safety of the procedure. In the early days of phacoemulsification, the ophthalmic community doubted not only the safety but also the efficacy of the procedure. At this stage in development, there is little reason to question the safety of the use of a femtosecond laser in cataract surgery. The efficacy of the procedure is rapidly being established through studies and peer review literature.

Femtosecond lasers have been used in ophthalmic surgery for a number of years.[5-7] The most common use of this technology has been in the area of refractive laser surgery with the creation of corneal flaps. Femtosecond lasers have enhanced precision and safety compared to mechanical microkeratomes that utilize a blade.

Clinical and technical developments in laser-assisted *in situ* keratomileusis (LASIK) have enhanced outcomes to the point at which 20/20 uncorrected acuity is now achieved in nearly 90% of cases.[8] This improvement was achieved in only 50%–60% of eyes with modern phacoemulsification using small incisions and the most sophisticated intraocular lens (IOL) measurements.[9] Increasing the percentage from 60% to 90% requires approximately a 2-fold reduction in the standard deviation in refractive outcomes. Examining the factors that affect refractive outcomes, 2 of the greatest contributors are the effective lens position and uncorrected astigmatism. A significant improvement in these factors could therefore increase the probability of enhancing uncorrected vision.

Similar to refractive laser surgery, femtosecond laser technology may be able to deliver improvements in reproducibility and safety to cataract surgery.[10] Femtosecond lasers may assist or replace several aspects of traditional cataract surgery, including a clear cornea incision,

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correction or reduction of astigmatism through arcuate corneal incisions, an anterior capsulotomy, and fragmentation of the lens.

Clear Corneal Incisions

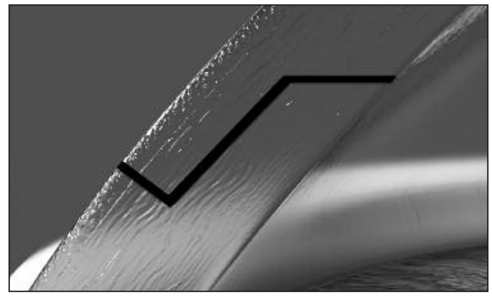
Clear corneal incisions are the preferred method for North American surgeons.[11] The benefits of clear corneal incisions are that they are well tolerated by patients, provide a rapid recovery of vision,[3] preserve the subconjunctival space for future filtering procedures, and allow improved visibility during phacoemulsification due to the shorter tunnel. There are reports of an increased incidence of endophthalmitis that may be related to the use of clear corneal incisions.[12] Although the incidence of endophthalmitis is only 0.13%,[12] this remains the most feared complication of cataract surgery with a potential devastating impact. Endophthalmitis after cataract surgery with a permanent decrease in vision can impact an individual's quality of life, including productivity.

Manually created incisions have potential for leakage because of difficulty in controlling the ideal length and architecture of the incision. Surgeons tend to vary their angle of incision depending on the ergonomics of the situation. Other potential causes of leakage include thickening of the incision site and detachment of Descemet's membrane. Masket et al[13] were able to demonstrate in cadaver eyes the advantages of a clear corneal incision using a femtosecond laser with a more reproducible square incision and a multiplanar configuration of the corneal wound.

A clear corneal incision that is poorly constructed may result in leakage, hypotony, iris prolapse, or endophthalmitis. Cataract incisions created with a blade will typically have a simple uniplanar configuration, with a suboptimal construction, and fluids may leak in and out of the eye. This increases the risk of endophthalmitis, as bacteria from the tear film may enter the anterior chamber of the eye. Future studies will address the ideal architecture of the corneal incision to prevent leakage and minimize astigmatism induction. The femtosecond laser has the potential to create a more square architecture using complex multiplanar incisions (Figure 1) such as a tongue in groove or interlocking zigzag design, which could provide a more stable wound configuration that is more resistant to leakage.

A study utilizing optical coherence tomography (OCT) imaging of the anterior segment after standard cataract surgery demonstrated that the majority of eyes had an internally gaping corneal wound and detachment of Descemet's membrane.[14] It is hypothesized that these clear corneal wound abnormalities may be a factor in increasing the risk of postoperative endophthalmitis. Palanker et al[15] demonstrated that a femtosecond laser can create a one-way, self-sealing, watertight valve under normal intraocular pressure (IOP). An unpublished study of 75 eyes by Steinert and Nagy[16] showed that 30 of 33 eyes in which a manual incision was constructed required wound hydration. In contrast, of the 42 eyes with a 2-plane laser-assisted incision, all were resistant to external pressure and none required wound hydration.

Figure 1: Customized corneal wound architecture with a multiplanar configuration to reduce leakage and induced astigmatism.



It is important to research the difference in postoperative endophthalmitis rates after laser-assisted corneal incisions. This is the essential question because postoperative endophthalmitis is the outcome measure that will ultimately justify laser incisions as the preferred method of corneal wound construction. This research will require the undertaking of very large patient populations because of the relatively low incidences of endophthalmitis.

Astigmatism Correction

The ability of the femtosecond laser to perform intrastromal-relaxing incisions to reduce preexisting astigmatism is a potentially significant benefit. Nearly 70% of cataract patients have ≥0.5 D of astigmatism preoperatively; relatively few surgeons take this into account to correct preexisting astigmatism.[17] Surgeons utilizing an excimer laser correct as low as 0.25 D of astigmatism. In order for cataract refractive outcomes to advance to the same degree as LASIK or photorefractive keratectomy (PRK) it is important for surgeons to address all levels of astigmatism.

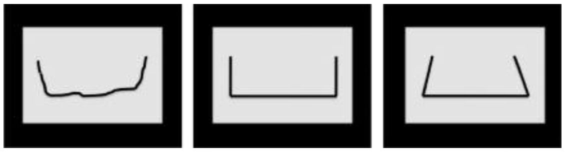
Peripheral relaxing incisions that are performed manually often lack consistency as the cuts may suffer from an imprecise depth, length, position, and shape (Figure 2). Most surgeons utilize a blade with a fixed depth of 600 µm instead of modifying the depth based on pachymetry. Even if a customized blade depth is utilized, the outcomes depend on surgical expertise, the quality of the cutting blade, resistance of the corneal tissue, and patient cooperation.

Reproducible and precisely placed laser incisions have the potential to improve outcomes compared to manually performed incisions. Femtosecond laser systems can deliver reproducible cuts at a precise location, depth, angular orientation, and length.[18] These intrastromal incisions do not penetrate the corneal epithelium or posterior surface of the cornea. By leaving the epithelium intact, the femtosecond laser can potentially minimize postoperative discomfort, epithelial wound healing, infection, and tear film disruption. Surgeons have the option to titrate the treatment by opening the cuts either intraoperatively or postoperatively.

Clinical outcomes reported by Zaldivar[19] in 35 eyes treated with a pair of femtosecond arcuate incisions

Figure 2: Astigmatic keratotomy

A B C



A. Manually created astigmatic keratotomy often lacks consistent depth

B. Laser created astigmatic keratotomy allows for a precise location, depth, length, and angle

C. Laser created astigmatic keratotomy can be customized to produce a reverse bevel design

showed a mean change in astigmatism of 1.22 D, with a minimum of 0.50 D and a maximum of 2.5 D. All patients had reduced astigmatism with nearly 50% of eyes having less than 0.25 D, with no eyes having this degree preoperatively. Future studies will evaluate the effects of variables such as patient age, IOP, corneal diameter, corneal thickness, and programmable laser options (optical zones, angle of cuts, length, and diameter).

Anterior Capsulotomy

A continuous curvilinear capsulotomy is a critical step in cataract surgery (Figures 3 and 4). Creating a successful capsulorhexis can be difficult in a variety of clinical situations, including corneal haze or scarring, a shallow anterior chamber, a small pupil, weak zonules, a fibrotic anterior capsule, a poor red reflex, and an intumescent white cataract. A properly sized, shaped and centred capsulorhexis enhances surgical safety, hydrodissection of the lens, nuclear disassembly and removal, clean-up of the remaining cortex, IOL position and centration, and inhibition of posterior capsule opacification.

Using a manual technique, the incidence of anterior capsular tears in the hands of experienced surgeons has been suggested to be 0.79%–3.8% in the general ophthalmic community.[20,21] Of those with an anterior capsular tear, 40% were reported to extend to the posterior capsule and 20% required a vitrectomy;[20] this

Figure 3: This image illustrates the precision of a femtosecond laser anterior capsulotomy

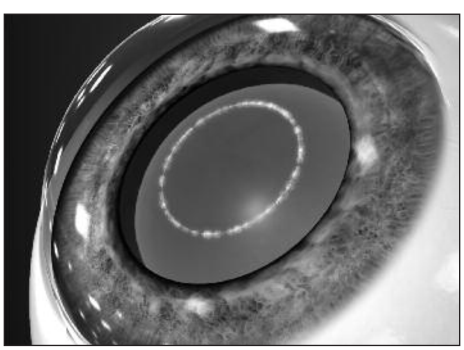
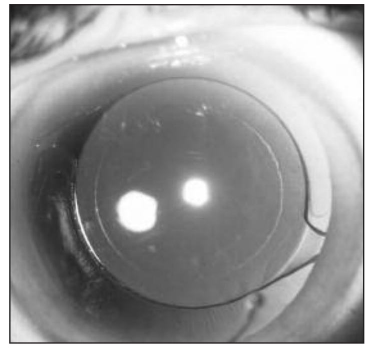


Figure 4: Clinical example of the precise size, shape, and centration of a femtosecond laser anterior capsulotomy



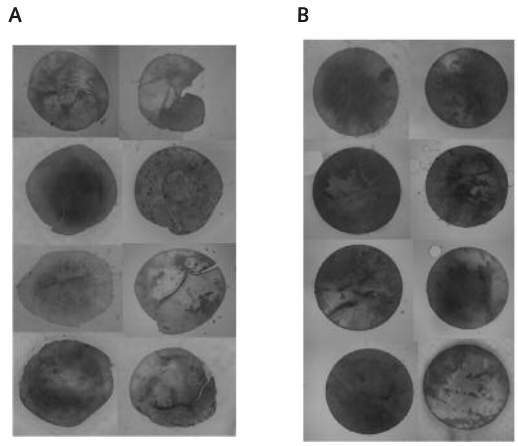
equates to 6346 vitrectomies annually in North America. Unal et al[22] studied resident cataract surgery in the United States and showed an anterior capsular tear rate of 5.3%, irregular capsulotomy 9.3%, and posterior tear with vitreous loss 6.6%. An irregular capsulotomy may lead to a reduction in visual results, including higher order aberrations due to possible optical decentration and lens tilt.[23] Anterior capsular tears can lead to significant problems. A posterior extension of a tear has been associated with retained lens material, persistent uveitis, cystoid macular edema (CME), and a secondary retinal detachment.

Hatch et al[24] showed that the incidence of endophthalmitis is significantly higher when a capsular rupture occurs. Endophthalmitis was 9.56 times more likely to develop following a capsular rupture than with uncomplicated cataract surgery. Bhagwandien et al[25] found an even higher relationship (16 times more likely). If femtosecond laser surgery can result in consistent round, centred and intact capsule this would be a significant advance for patients.

The position and centration of the IOL depend on a properly shaped and sized anterior capsulotomy. Nagy et al[26] demonstrated in porcine eyes that femtosecond laser capsulotomies were more precise and rounder than with a manual technique (Figure 5). The chance of achieving a capsulotomy diameter within 0.1 mm of the intended size was 100% in the laser capsulotomy group compared to only 10% in the manual group. Similar findings were noted by several authors.[15,27-29] Kranitz et al[27] compared a manual capsulorhexis to a femtosecond laser-assisted capsulorhexis with 1 year of follow up. The authors concluded that decentration of the IOL was 6 times more likely to occur in the setting of a manual capsulorhexis. Palanker et al[15] confirmed the accuracy of capsulotomy with a mean circularity of 0.942 in 29 lasered eyes, compared to 0.774 in 30 manual eyes. Friedman et al[29] demonstrated that the deviation from intended diameter was 29±26 µm for laser capsulotomies and 337±258 µm for a manual technique; the mean deviations from circularity were 6% and 20%, respectively.

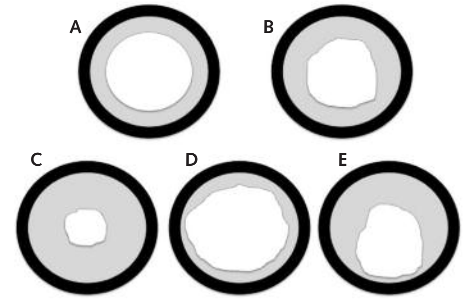
Femtosecond lasers have the potential to centre the capsulotomy over the dilated pupil, the nondilated pupil, the geometric centre of the lens, or the visual axis. The

Figure 5: Capsule disc morphology



Manual (A) and laser (B) capsulotomy stained with trypan blue, demonstrating superior precision in size and shape with the laser method.

Figure 6: Anterior capsulotomy



A. Laser anterior capsulotomy with a reproducible shape, size, and centration. Capsulorhexis influences the effective lens position, which affects the postoperative refractive error.
B. Manual anterior capsulotomy often lacks a consistent shape, size, and centration.
C. A small anterior capsulotomy can push the implant posteriorly leading to a hyperopic shift.
D. A large anterior capsulotomy can result in the implant vaulting forward leading to a myopic shift.
E. An irregular anterior capsulotomy can result in tilting or subluxation of the implant and induced higher-order aberrations.

implant can then be positioned with respect to the capsulotomy. Refractive outcomes as well as measurement of higher-order aberrations will ultimately allow us to determine the ideal position of the capsulorhexis. Currently, most surgeons believe that centring the capsulotomy over the visual axis can provide the best quality of vision. The ideal position of the anterior capsulotomy will be established with future studies.

Tackman et al reported when using a femtosecond laser for an anterior capsulotomy that the majority of cases had free-floating capsular buttons, which reduces the incidence of capsular tears.[28]

The size of the capsulotomy and its construction has a direct relationship to the effective lens position (Figure 6).[30] A large capsulorhexis allows the implant to rest anteriorly, where as a smaller capsulorhexis pushes the implant more posteriorly. The final resting position of the implant can result in either a myopic or hyperopic shift if the capsulorhexis created is larger or smaller than intended.[30] An irregular capsulorhexis can induce higher-order aberrations by tilt or decentration of the implant.[23] Preliminary studies have shown that laser-treated eyes had less vertical tilt and coma aberrations than eyes treated with a manual capsulotomy.[31] The variability and predictability in effective lens position has been shown to be superior for laser-assisted anterior capsulotomies for monofocal, multifocal, and toric implants.[32] A minority of surgeons using a manual technique consistently perform sized and positioned capsulotomies.[31]

Inaccurate preoperative lens prediction of the effective lens position has been identified as the largest source of error in IOL power calculations.[33] A difference of 0.5 mm in the final resting position of the intraocular lens can lead to a 1.00 D change in the refractive error;[34-36] 1 D of spherical refractive error is the difference between a patient seeing 20/20 and 20/40. For multifocal and toric IOLs the window for an acceptable error is smaller. Tilt and decentration with these IOLs can cause not only a significant deviation from the desired refractive outcome, but also visual aberrations that may be difficult to tolerate.[37,38]

The effective lens position of the IOL may vary depending of whether the capsulorhexis completely or incompletely overlaps the optic. Most accommodating IOLs should not be implanted in the presence of a suboptimal capsulorhexis. The dual optic accommodating IOL is designed to have the anterior optic move forward during the accommodative effort. This relies on the overlapping capsulorhexis to prevent prolapse of the anterior optics of the capsular bag.[39] With the advent of the femtosecond laser with a precisely sized and centred capsulotomy, this should enhance the predictability of this IOL in the future.

Nagy et al[26] demonstrated in porcine eyes that the capsule strength was as good or greater with the femtosecond laser than a manual capsulorhexis enabling a greater force of stretch before rupture. Their study compared 12 laser-treated eyes and 12 eyes with a manual capsulorhexis performed by an experienced cataract surgeon. The average strength of the capsule after manual capsulorhexis was 66±22 mN; after laser capsulotomy, it was more than twice as high (152±21 mN). The creation of a stronger capsulotomy edge may help reduce the probability of rupture of the capsule during lens emulsification, as well as insertion of an IOL. The authors found similar results in enucleated human eyes.

In the future, if a lens refilling procedure can be developed to restore accommodation a small consistent capsulotomy with the use of a femtosecond laser will be a significant advantage. Future long-term studies will be necessary to determine the long-term superiority for visual outcomes and reduced posterior capsular opacification with the laser-assisted capsulotomy. This is critical because the effective lens position is the most significant contributor to visual error after cataract surgery.[31]

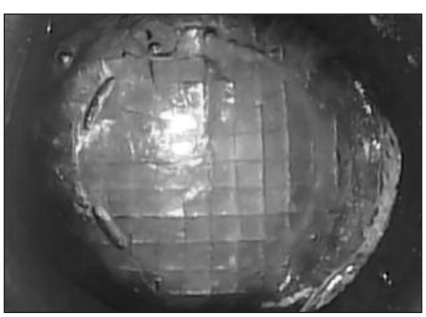
Lens Fragmentation

The femtosecond laser can fragment the nucleus, reducing the energy required and time during phacoemulsification (Figure 7). Several authors have confirmed that laser cataract surgery can significantly reduce the effective phacoemulsification time and power compared to standard surgery.[26,40] Nagy et al[26] showed that laser phacofragmentation resulted in a 43 % reduction in phacoemulsification power required.[26] Dick's paper at the 2012 European Society of Cataract and Refractive Surgery Winter Meeting demonstrated a 96% reduction in phacoenergy even with 4+ nuclear cataracts.[40] The reported differences in the degree of fragmentation of the nucleus with the different lasers may be secondary to the treatment patterns and different pulse energies that have been utilized.

Excessive use of ultrasound energy during phacoemulsification can result in corneal endothelial damage, as well as thermal injury to the corneal wound. In cases of weak zonules, techniques to fracture the nucleus in pieces may result in a further zonular dehiscence or subluxation.

An increase in endothelial cell loss and corneal thickness have been reported with longer phacoemulsification time.[41,42] CME is thought to have a greater incidence when the phacoemulsification levels are greater than 1 joule;[43] however, von Jagow et al[44] described no correlation between CME and phacoemulsification parameters. Clinical studies suggest that a variety of factors contribute to endothelial cell loss and CME. It makes sense that a reduction in phacoemulsification time and energy may reduce intraocular complications. This reduction in energy may be advantageous for patients at high risk for corneal decompensation, such as those with shallow anterior chambers, dense cataracts, Fuch dystrophy, prior corneal transplants, or those with marginal corneal endothelial function. Further studies with laser cataract surgery will confirm the significance of a reduction in phacoemulsification.

Figure 7: Femtosecond lasers can fragment the nucleus resulting in a significant reduction in phacoemulsification energy



Femtosecond Lasers: *Mechanism of Action*

The femtosecond laser used in ophthalmic applications is in the near-infrared wavelength of light (1030 nm) similar to the neodymium:yttrium aluminum garnet (Nd:YAG) laser, with the exception that it has significantly shorter pulse duration. This enables a different way of laser-tissue interaction called laser-induced optical breakdown, which means that the laser produces smaller shockwaves and cavitation bubbles affecting tissue volumes at 10^3 less than what is seen with a picosecond laser such as the Nd:YAG. Ultrashort laser pulses used in femtosecond lasers can ablate a very small fraction of tissue. No heat is generated during the ablation process. The femtosecond laser can be focused with precise accuracy at different depths, using a guidance system to create the corneal incisions, astigmatic keratotomy, capsulotomy, and nuclear fragmentation. The focused laser energy increases to a level where plasma is generated. The plasma expands and causes a shockwave, cavitation, and bubble formation. The bubble then expands and collapses, leading to separation of the tissue.

Because femtosecond lasers function at nearly an infrared wavelength, they are not absorbed by optically clear tissues. This allows the femtosecond laser to be used to the anterior segment of the eye as the anterior chamber provides an optically clear tissue pathway. This wavelength of light is not absorbed by the cornea. The shock waves generated by femtosecond photodisruption dissipate within approximately 30 µm of the targeted tissue thus protecting the posterior capsule and corneal endothelium.[45] The surgical effect is achieved by delivering thousands of individual laser pulses per second to produce tissue separation or continuous incisions.

Optical imaging is critical for the development of the femtosecond laser for cataract surgery. There is a significant difference in requirements of corneal lasers compared to a laser that targets tissue as deep as 8 mm from the corneal surface (Table 1).[45] The exact position of the target area is critical. A higher laser energy level is required for fragmentation of the crystalline lens compared to cuts within the cornea. The average power of a cataract laser engine is several times higher than that of a corneal laser.

Femtosecond Technology

Femtosecond lasers have been successfully used in the creation of the LASIK flap. The development of laser cataract surgery using 3-dimensional segmentation of the crystalline lens requires different laser parameters. Because of the large focal depth required, the beam diameter must be increased compared to that required in corneal surgery. This requires a higher threshold energy for fragmentation of the lens.

Four femtosecond lasers have been developed. These systems include LenSx® laser (Alcon, Fort Worth, Texas), Catalys (OptiMedica Corporation, Santa Clara, California), LENSAR™ laser (LENSAR Inc., Orlando, Florida), and VICTUS™ (Bausch + Lomb and Technolas Perfect Vision GmbH). Each platform appears to have good underlying

Table 1: Comparison of corneal and cataract femtosecond laser technologies

	Cornea Lasers	Cataract Lasers
Wavelength	1030–1060 nm	1030–1060 nm
Pulse duration	200–800 fs	600–800 fs
Pulse energy	≤1 μJ	8–15 μJ
Repetition rate	60–250 kHz	33–80 kHz
Scanning range	10 mm in diameter 1 mm in depth	12 mm in diameter 8 mm in depth
3D imaging	No	Yes

Reprinted with permission from Juhasz T. Femtosecond laser technologies for anterior segment surgery. In: Slade S, ed. *Laser Refractive Cataract Surgery: Science, Medicine, and Industry.* Copyright © Bryn Mawr Communications LLC. 2012.

technology with slight differences distinguishing the units. It is not the scope of this paper to review the differences with these femtosecond technologies.

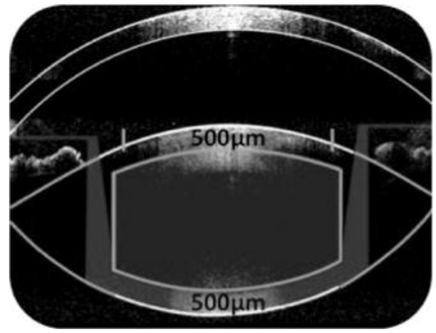
Technique

Laser cataract surgery requires dilatation of the pupil and topical anesthesia, followed by applanation of the cornea with a docking system that distributes pressure evenly on the cornea. The docking system minimally distorts anterior segment anatomy and increases IOP. Friedman et al[29] reported with the Catalys platform, which has a liquid optic interface, that the average rise in IOP is 10 mm Hg and avoids corneal folds. The other laser platforms have not reported a degree of IOP rise. Once the docking has been completed then imaging of the anterior segment is performed.

The accuracy of OCT imaging is critical to specify boundaries, including the iris and the posterior surface of the lens (Figure 8). Imaging of the posterior surface of the lens is essential in order to avoid rupture of the posterior capsule. The surgeon can program the location of the corneal incisions for the wound, paracentesis, and any limbal relaxing incisions. Laser-assisted anterior capsulotomy is performed before lens fragmentation because gas bubbles form during lens fragmentation. This could potentially stretch and displace the lens capsule from its original position, causing the laser pattern to miss the capsule. After the capsulotomy step, the lens fragmentation patterns are applied starting from the posterior part of the lens and moving anteriorly. Gas formation during lens fragmentation can help separate the horizontal lens lamella, which can further enhance the softening of the nucleus. Expansion of the lens as a result of gas formation occasionally can lead to lifting of the capsulotomy disk.

Corneal incisions are performed as the last step prior to moving the patient into surgery. In the operating room, the corneal wound and paracentesis are opened. The anterior capsulotomy is removed with forceps using a circular movement similar to a capsulorhexis. This technique is safer than just pulling it out in case there are any remaining bridges connecting the central disk to the capsular bag. This is followed by removal of the cataract using significantly less ultrasound energy.

Figure 8: Optical coherence tomography imaging of the anterior segment showing the cornea, anterior chamber, iris, and lens. Fragmentation of the nucleus is planned for a safe zone of 500 μm away from the anterior and posterior capsules.



Patient Selection

Femtosecond cataract surgery is relatively contraindicated in patients in whom the initial docking can be difficult, including those with deep-set orbits, small fissures, or who suffer from significant tremors. Since patient cooperation is required, patients with dementia may not be satisfactory candidates. The risk of IOP induced by the docking device – which has not been quantified with all systems – may preclude its use in patients with glaucoma or optic neuropathies. Patients with poor dilatation, such as those on chronic miotic medications or with posterior synechiae, are also poor candidates. High-quality images of the posterior lens capsule are critical for safe fragmentation. Eyes with zonular dialysis or phacodonesis may not be ideal candidates because of instability of the lens during docking.

It is unlikely that mild corneal opacification will preclude the use of the laser in cataract surgery. The femtosecond laser with a near-infrared wavelength of 1030 nm is scattered much less than visible light (400–700 nm). Significant central corneal scarring may be a limiting factor.

Education and Training

Surgeons are concerned about the transition from the more familiar standard phacoemulsification to laser cataract surgery. The learning curve with laser cataract surgery will make the procedure, at least initially, slower and more difficult. Although the surgeon will spend time utilizing the femtosecond laser, this will result in saving time in the operating room having already performed many of the critical steps with the laser. Surgeons who have adopted this technology have made the transition because of the potential for greater safety, reproducibility, and precision in creating the corneal incisions, capsulotomy, and nuclear removal.

In the future, ophthalmologists will still need to learn manual techniques to deal with challenging cases such as white intumescent cataracts, zonular dehiscence, perforated globes with cataracts following trauma, and ectopic lenses.

Complications

As with the introduction of any new technology, complications can develop that need to be managed. Suction breaks can potentially occur at any stage of the laser procedure, which include the capsulotomy, fragmentation of the nucleus, corneal wound incisions, or limbal relaxing incisions. If this occurs, the procedure can be stopped and the rest of the procedure performed manually. An anterior capsular tag requires careful surgical management to prevent these tags from extending and becoming an anterior capsular tear. The incidence of free-floating capsulotomies has increased in recent years and is related to improved docking, changed energy settings, and refined spot layer separation.[28]

A capsular block syndrome is a rare complication specific to laser cataract surgery. This complication can be eliminated by proper technique. It is hypothesized that gas is trapped within the crystallized lens during fragmentation, which increases the intracapsular pressure. Subsequent hydrodissection can further increase the pressure within the capsular bag resulting in a posterior capsular rupture. It is believed that cataracts of increasing density are more likely to have gas trapped within the capsular bag, increasing the risk of this complication. Hydrodissection should only be performed after adequate decompression of the anterior chamber. The hydrodissection should be relatively gentle in terms of volume of fluid delivered and force.

Docking technique is essential for excellent surgery. Poor quality docking can lead to tilting of the capsule and lens. Good quality docking technique leads to a more certain capsulotomy and nuclear fragmentation. Complications can occur with a poor docking technique, which may result in an incomplete capsulotomy, capsular tags, and a secondary anterior capsule tear formation. It is important for the surgeon only to proceed when there is satisfactory docking.

Small petechial conjunctival hemorrhages and vasodilatation in a ring pattern represent a common postoperative complication secondary to the suction ring that is applied during the docking procedure. These subconjunctival hemorrhages are similar to LASIK during flap creation and typically resolve in 7–14 days.

CME is the most common cause of decreased vision following standard cataract surgery, with 1%–2.5% of patients experiencing vision loss, and approximately 20% exhibiting thickness of the macula detectable with OCT.[46] Nagy et al[47] evaluated the central, inner, and outer macular regions of 20 laser-treated eyes versus 20 eyes that underwent a manual procedure. The macular thickness in the inner retinal ring was thicker in the manual group by 21.68 μm at 1 month and 17.56 μm at 4 months. There were no significant differences between the macular thickness of the central and outer areas. Femtosecond technology may be particularly advantageous for patients who are at greater risk for developing postoperative CME, such as those with uveitis or diabetic retinopathy.

Corneal endothelial cell loss, which occurs with standard phacoemulsification, can occasionally lead to bullous keratopathy. A reduction in ultrasound energy with laser cataract surgery can lead to clearer corneas postoperatively and potentially a reduction in endothelial cell loss. Knorz[48] reported a 25% decrease in endothelial cell loss in laser cases compared with manual cases at 1 month postoperatively.

Posterior capsular rupture and vitreous loss range from 2% to 6% of all standard phacoemulsification cases.[21] Femtosecond cataract surgery performed with a precise capsulotomy, a reduction in phaco energy, and a decrease in intraocular maneuvers especially when dealing with a dense nucleus may reduce the incidence of posterior capsule rupture and vitreous loss.

Summary

We are at the beginning of a new era in cataract surgery that may be similar to the transition from ECCE to phacoemulsification in the 1980s and 1990s. It is probable that femtosecond lasers will revolutionize the technique of cataract surgery. The method has shown excellent results for accurate self-sealing corneal incisions, arcuate incisions to reduce astigmatism, highly circular, strong and well-positioned capsulorhexis, and safer and less technically difficult removal of the cataract with almost complete elimination of phacoemulsification. An improvement in the predicted final resting position of the intraocular lens can significantly enhance the refractive outcome. A precise capsulotomy can reduce implant tilt or decentration and as a consequence reduce higher-order aberrations. The laser technology may allow ophthalmologists to meet the demands of cataract patients to the same level that has been accomplished with laser vision correction.

The surgery should be more reproducible from patient to patient and surgeon to surgeon. It is likely that future new procedures, techniques, and intraocular implants will be developed as a consequence of the capabilities of the femtosecond laser. It is also possible that a combined machine may be built that includes a femtosecond laser and phacoemulsification.

There is a surgical learning curve with laser cataract surgery, and initially it will be more technically demanding and a longer procedure. Despite these factors, the benefits to patients are significant. Although the procedure is more expensive for an individual patient, it may turn out to be cost effective for society. The implementation of laser cataract surgery into clinical practice should not be viewed as a step towards "robotic" cataract surgery, but rather an effort to raise our surgery standards to a new higher level of safety and clinical results. The technology is continuing to evolve but in its current state is offering patients clinical advantages.

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