# Femtosecond laser–assisted cataract surgery

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Femtosecond laser–assisted cataract surgery provides surgeons an exciting new option to potentially improve patient outcomes and safety. Over the past 2 years, 4 unique laser platforms have been introduced into the marketplace. The introduction of this new technology has been accompanied by a host of new clinical, logistical, and financial challenges for surgeons. This article describes the evolution of femtosecond laser technology for use in cataract surgery. It reviews the available laser platforms and discusses the necessary modifications in cataract surgery technique and the logistics of incorporating a femtosecond laser into one's practice.

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Online Video

Cataract surgery is the most commonly performed surgical procedure in the world, with an estimated 19 million operations performed annually, nearly 3 million of which are performed in the United States.[1] The World Health Organization estimates this number will increase to 32 million by the year 2020 as the over-65 population doubles worldwide between 2000 and 2020.[2] Globally, more than 3000 eye surgeons (more than 1000 United States surgeons) have been trained. Femtosecond laser technology, introduced clinically for ophthalmic surgery in 2001 as a new technique for creating lamellar flaps in laser in situ keratomileusis (LASIK), has recently been developed into a tool for cataract surgery.[3]

Given the recent introduction of this technology, the conventional nomenclature for these procedures is inconsistent. At the 2012 American Society of Cataract and Refractive Surgery meeting, a survey of 30 practices revealed 29 different names used for this procedure. The more common acronyms include ReLACS (refractive laser–assisted cataract surgery), FLACS (femtosecond laser–assisted cataract surgery), and FALCS (femtosecond–assisted laser cataract surgery).[4] Agarwal proposes ReLACS and T-LACS (therapeutic laser–assisted cataract surgery) to refer to refractive procedures and therapeutic applications (surgically challenging cases—dense nuclei), respectively.[4]

While this technology has the potential to improve safety, accuracy, and clinical outcomes, the femtosecond laser–assisted cataract surgery procedure brings with it a host of new clinical and financial challenges. This article describes clinical aspects of the new surgical technique and discusses the currently available femtosecond laser–assisted cataract surgery equipment, the benefits and challenges of this new technology, and the logistics of incorporating these systems into a clinical practice.

## OVERVIEW

### Femtosecond Laser Technology

Current femtosecond laser technology systems use neodymium:glass 1053 nm (near-infrared) wavelength

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light. This feature allows the light to be focused at a 3 μm spot size, accurate within 5 μm in the anterior segment.[5] The critical aspect of femtosecond laser technology is the speed at which the light is fired. The focused ultrashort pulses ($10^{-15}$ seconds) eliminate the collateral damage of surrounding tissues and the heat generation associated with slower excimer and neodymium:YAG lasers.

## Photodisruption

Femtosecond laser energy is absorbed by the tissue, resulting in plasma formation. This plasma of free electrons and ionized molecules rapidly expands, creating cavitation bubbles. The force of the cavitation bubble creation separates the tissue. The process of converting laser energy into mechanical energy is known as photodisruption. The femtosecond laser technology virtually eliminates collateral damage and can therefore be used to dissect tissue on a microscopic scale (Figure 1).

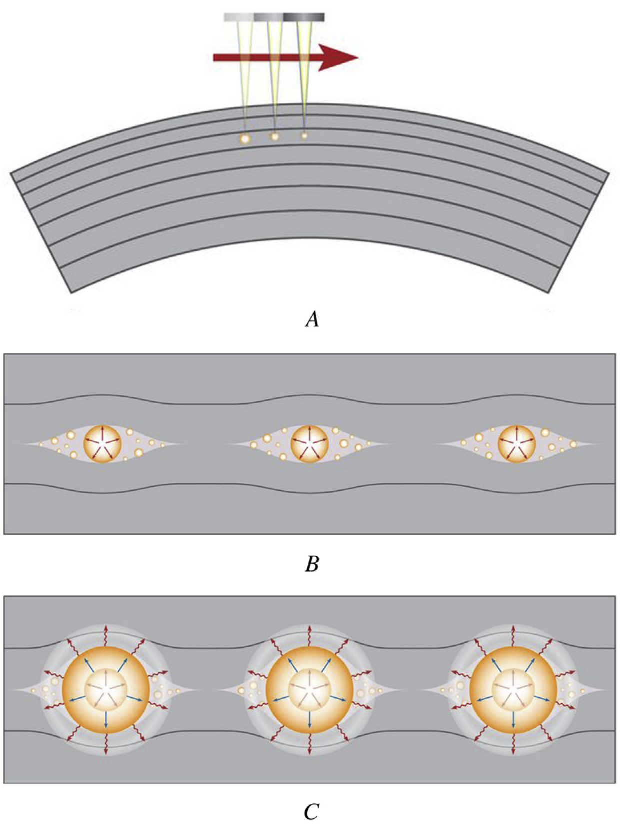



**Figure 1.** Highly focused femtosecond laser pulses create plasma that rapidly expands in a cavitation bubble, separating target tissue. *A*: Highly focused femtosecond laser pulses. *B*: Formation of cavitation bubbles. *C*: Cavitation bubbles enlarge and coalesce to allow separation of tissue (excerpt of Figure 2-1 reprinted with permission from Factorovich E. Femtodynamics; a Guide to Laser Settings and Procedure Techniques to Optimize Outcomes with Femtosecond Lasers. Thorofare NJ, Slack, 2009, courtesy of Slack, Inc.).

Femtosecond laser technology systems use photodissection to create tissue planes and side cuts for LASIK flaps in the cornea. For this application, the parameters are typically set so neighboring shots do not entirely overlap, leaving tissue bridges that must be bluntly dissected. Femtosecond laser technology systems used to perform certain steps of cataract surgery may use closer spot settings to overlap these cavitation regions, eliminating tissue bridges (ie, during capsulorhexis creation) (Figure 2). As with any new technology, software upgrades to the systems improve energy delivery and stability.

## The Four Laser Platforms: Similarities and Differences

Currently, 4 femtosecond laser technology platforms are commercially available for cataract surgery: Catalys (Optimedica), Lensx (Alcon Laboratories, Inc.), Lensar (Lensar, Inc.), Victus (Technolas). The baseline characteristics of the 4 platforms are shown in Table 1 and Videos 1 to 4 (available at http://jcrsjournal.org).

# PROCEDURE

## Docking

Proper docking requires the patient to be flat on the table with minimal neck support. This may represent a contraindication for older patients with significant kyphosis or scoliosis. The head must be secured with a slight tilt so the operated eye is in a higher plane to clear the nose and achieve proper applanation. The patient must be able to remain still for the several minutes required for accurate imaging followed by application of laser energy.

The 4 available laser platforms have varying patient-interface systems (Table 1, Figure 3), which can be divided into contact (applanating) and noncontact (nonapplanating). Contact systems tend to have a smaller diameter and may fit a smaller orbit better. They also provide a separate reference plane for anterior cuts such as a flap. Noncontact devices, in addition to less increase in intraocular pressure (IOP), cause less subconjunctival hemorrhage and offer a wider field of view. Schultz et al.[6] evaluated the increase in pressure using a fluid-filled interface. They found a small mean increase in IOP from 15.6 mm Hg ± 2.5 (SD) preoperatively to 25.9 ± 5 mm Hg during laser application. This has been compared to the increase with corneal contact applanation platforms; however, much of the data was acquired from flat applanation devices used in LASIK or from earlier curved applanation interfaces in femtosecond laser–assisted cataract surgery.

Talamo et al.[7] recently compared the 2 optical interface designs used for femtosecond laser–assisted

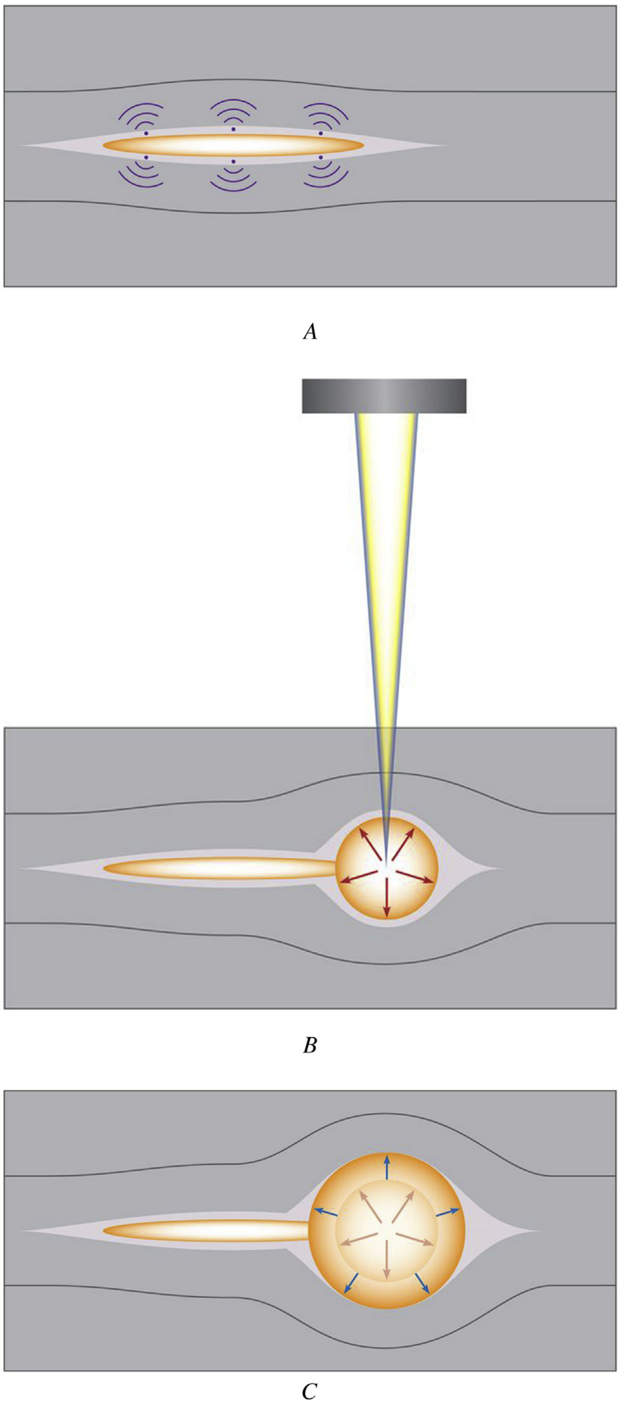



**Figure 2.** Adjacent femtosecond laser pulses may be placed close together to virtually eliminate intervening tissue bridges, aiding in the free dissection of the capsulorhexis, for example. *A*: Adjacent femtosecond laser pulses placed in close proximity. *B*: Expansion of cavitation bubbles. *C*: Separation of tissue as cavitation bubbles expand. (excerpt of Figure 2-1 reprinted with permission from Factorovich E. Femtodynamics; A Guide to Laser Settings and Procedure Techniques to Optimize Outcomes with Femtosecond Lasers. Thorofare NJ, Slack, 2009, courtesy of Slack, Inc.).

cataract surgery: contact corneal applanation and liquid immersion. They found that the curved contact interface induced corneal folds that resulted in areas of incomplete capsulotomies beneath the folds. Folds were not seen in the liquid immersion group. Talamo et al. also found greater eye movement in the contact applanation group than in the liquid optics group. Greater IOP rise and increased subconjunctival hemorrhage were also seen in the contact applanation group.

Improvements in the contact corneal immersion interfaces have occurred over the past 2 years, decreasing the incidence of corneal folds and resultant incomplete capsulotomies. The evolution of the patient interface is rapidly occurring, with new designs in the pipeline to provide better, safer, and more reproducible results.[8]

## Imaging

All the femtosecond laser platforms use either spectral-domain optical coherence tomography (OCT) or ray-tracing reconstruction (3-dimensional confocal structural illumination [3-D CSI]) to image and map the treatment plan (Table 1). The cornea must be centered within the applanated area to adequately center the treatment. If the cornea is decentered, the primary clear corneal incision and arcuate incisions will not be appropriately positioned. This centration is important in all eyes but crucial in astigmatic patients in whom decentration could result in arcuate incisions within the visual axis or a wound posterior to the limbus. Additionally, the capsulorhexis could be decentered, potentially resulting in decentration of the intraocular lens (IOL).

To optimally image the anterior segment, the cornea must be clear. Any scarring, edema, or corneal folds may diminish the quality of the image and cause the laser application to be incomplete.[6] Therefore, care must be taken to minimize folds while docking, particularly with a contact applanation patient interface in patients with steeper corneas (average keratometry greater than 47 D). Guttae without significant edema generally allow adequate imaging, providing the opportunity to preserve endothelial integrity with the use of decreased ultrasound (US) energy during phacoemulsification. In systems with an air–fluid interface, the fluid must be clear with no bubbles. The applanating lens must be clear with no smudges, condensation, fog, or haze. During the acquisition phase, the patient must remain still for up to a few minutes while the image is being captured.

The surgeon evaluates the images to ensure the anterior segment structures are correctly identified by the imaging system for proper refractive

**Table 1.** Currently available femtosecond laser platforms for cataract surgery. All information reported as of February 1, 2013.

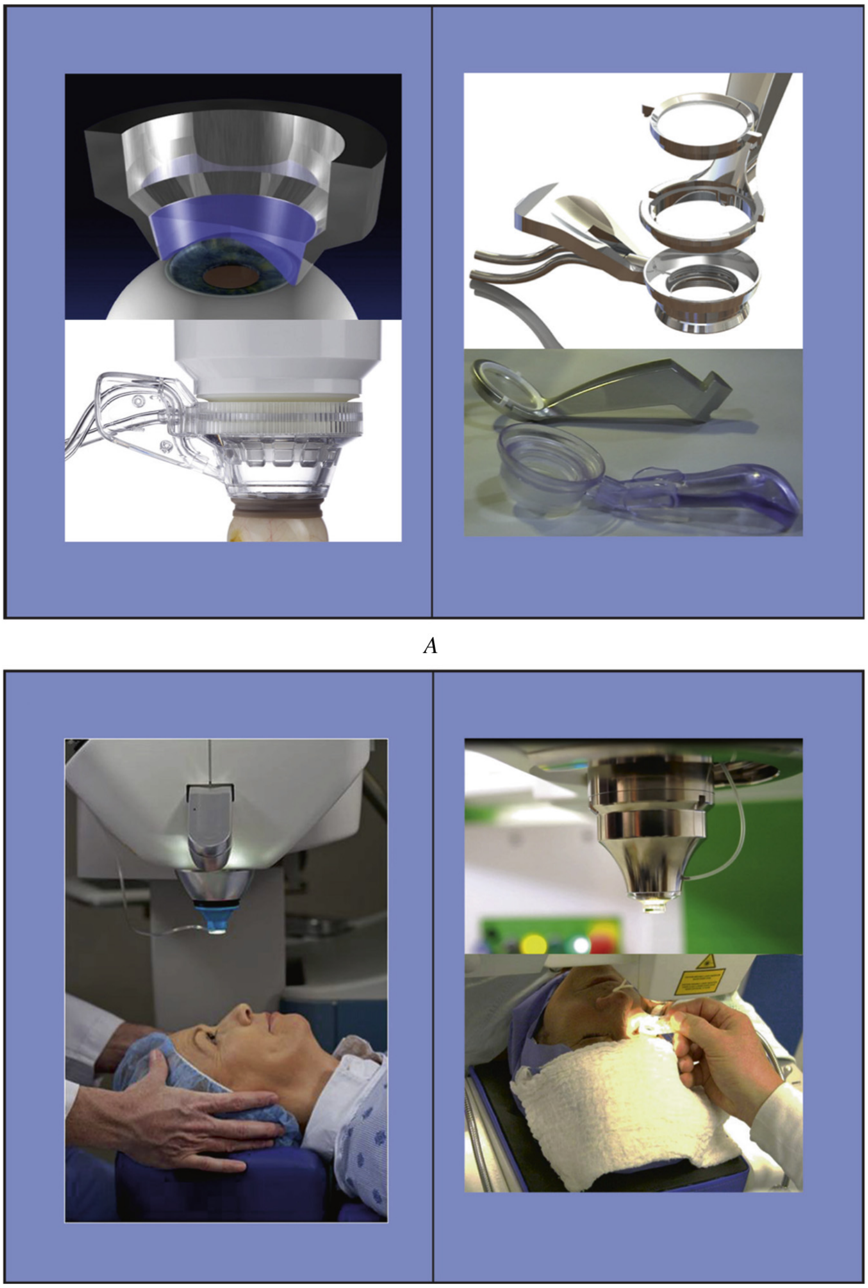
| Femtolaser | Catalys | Lensx | Lensar | Victus |
|---|---|---|---|---|
| Pulse frequency (KHz) | 120 | 50 | 80 | Up to 160 |
| FDA approvals | Corneal + arcuate incisions, ant capsulotomy, lens fragmentation | Corneal + arcuate incisions, ant capsulotomy, lens fragmentation, corneal flap | Corneal + arcuate incisions, ant capsulotomy, lens fragmentation | Corneal + arcuate incisions, ant capsulotomy, corneal flap |
| CE mark | same as FDA approvals | Same as FDA approvals | Same as FDA approvals | Corneal +arcuate incisions, ant capsulotomy, lens fragmentation, corneal flap |
| Arcuate incisions (type) | Surface and intrastromal | Surface and intrastromal | Surface and intrastromal | Capable of surface or stromal (approved for surface) |
| Patient interface design | Liquid Optics, nonapplanating, liquid interface, 2-piece, vacuum docking | Softfit, curved lens, applanating, 1-piece, vacuum docking | Robocone, nonapplanating, fluid interface, 2-piece, vacuum docking | "Dual modality," curved lens applanating 2-piece, spherical, solid + liquid, vacuum docking |
| Patient interface dimensions | Inner diameter, 13.5 mm; inner suction skirt, 14.1 mm; outer suction skirt, 23.0 mm | Inner diameter, 12.5 mm; outer diameter, 19.8 mm | Inner diameter > 12.7 mm; outer diameter, 24.0 mm | Curved PI > 12 mm; inner diameter suction clip, 15.5 mm; outer diameter suction clip, 21 mm |
| Docking | Ocular surface bathed in saline solution, no corneal applanation, no glaucoma contraindication | Curved applanation, no glaucoma contraindication (since Softfit PI) | No corneal applanation | Soft docking for capsulotomy and lens fragmentation, regular docking for corneal incisions † |
| IOP rise | 10.3 mm Hg rise[6,31] | 16.4 mm Hg rise (Cionni, ASCRS 2012 presentation) | Unknown (currently under evaluation) | Unknown (currently under evaluation) |
| Ocular surface visualization | Automatic + user adjustable (integral guidance) | Manual | Automatic (augmented reality camera) | Manual |
| Imaging type | 3D spectral domain OCT, video microscope and FS laser to enable image-guided cataract surgery | 3D spectral domain OCT, video microscope and FS laser to enable image-guided cataract surgery | 3D ray–tracing CSI* | 3D spectral domain OCT, video microscope and FS laser to enable image-guided cataract surgery |
| Integrated bed | Yes | No | No | Yes |
| laser dimensions | 0.68 m × 0.87 m (on floor; without patient bed) | 1.524 m × 1.828 m | 1.65 m × 1.97 m | 2.075 m × 0.825 m (without patient bed) |

*3D-CSI (confocal structural illumintation) uses a super luminescent diode to create the infrared light which illuminates the eye. The illumination beam scans the structures of the eye and a video camera records the image, employing the Scheimpflug principle to maintain focus throughout.

†Soft docking: less applanation (thus lower vacuum) needed for capsulotomy and lens fragmentation; hard docking: full corneal applanation (higher vacuum) necessary for corneal and arcuate incisions

alignment and safety. It is critical that the imaging system be able to detect lens tilt to avoid hitting the anterior or posterior capsule during application of the laser pattern to the lens nucleus.[4] Because it is dependent on accurate detection of these structures, the grid pattern must be modified and reoriented, as needed, to ensure a safety zone around the lens capsule. The capsulorhexis is then centered within the pupillary border. The diameter of the capsulorhexis is typically defined in settings prior to the procedure (approximately 5.0 mm in most cases) but can be modified according to pupillary dilation and IOL selection.

The surgeon chooses a lens fragmentation pattern based on the density of the nucleus and surgeon preference. He or she may choose the number of segments as well as the degree of lens softening depending on the lens grade. Commonly used patterns include 4, 6, or 8 segments with or without the use of lens softening. Lens softening is performed in a cylinder pattern by some platforms and in a grid pattern by others. A surgeon-defined safety zone from the posterior



A

B

**Figure 3.** Four patient-interface designs. *A*: Nonapplanating (Catalys [*left*], Lensar [*right*]). B: Applanating (Lensx [*left*], Victus [*right*]). Reprinted with permission from Springer.[4]

capsule (typically 500 to 800 μm) is automatically applied by the imaging platform and visualized on the OCT guidance for approval by the surgeon before the laser is applied. The systems allow surgical adjustment of this zone based on the evaluation of the OCT or 3-D CSI images.

## Laser Treatment

The IOP increase is minimal during laser treatment but may induce a mild circumferential subconjunctival hemorrhage, which generally resolves within a couple of days. The hemorrhage may be more pronounced with anticoagulation; however, there is no need to discontinue anticoagulant medications. Although suction levels generally remain lower than those during femtosecond LASIK procedures, it may be prudent to eliminate high-risk patients (such as those with advanced glaucoma or retinal vascular disease), particularly if using a laser with a contact applanation patient interface. The laser treatment can last from 30 seconds to 3 minutes depending on the laser platform and the degree of lens softening selected by the surgeon.

The capsulorhexis is performed first and takes 1.5 to 18.0 seconds (depending on the laser platform), followed by lens fragmentation and ultimately corneal wound creation. If suction is lost during the procedure, the suction ring can be reapplied and the procedure completed (unless anterior chamber gas bubbles prevent imaging). However, if suction is lost during the capsulorhexis, the capsulorhexis must be completed manually.

Lens fragmentation is then performed based on the segmentation pattern selected by the surgeon. For higher degrees of lens softening, the length of laser time may be significantly increased, from 30 to 60 seconds.[9]

Finally, the arcuate incisions, paracentesis, and clear corneal wound are created. Relaxing incisions can be made on the surface or created in an intrastromal location (by some platforms) (Table 1). The arcuate incisions are generally set at a default depth of 80% at the peripheral limbus, but depth, optical zone size, and placement can be customized.[1] Some surgeons choose to open the incisions at the time of surgery; however, many open the incisions either partially or fully during the postoperative period (up to 1 month after surgery), depending on the patient's vision, refraction, and topography. Nomograms to gauge the effects of these incisions better are being developed, but it is hypothesized that intrastromal incisions will yield greater precision and better postoperative comfort.

Once the laser treatment has been completed, the suction is released, the patient interface is removed, and the patient is slowly undocked from the laser. Depending on whether the laser is located in the operating room or in another location, the surgeon can proceed with phacoemulsification immediately or wait up to 2 to 3 hours between the 2 stages of the procedure. Some systems use an integrated bed, which is advantageous for head positioning and stabilization during image acquisition and treatment. However, this necessitates moving the patient to a different bed to be transported to and from the room. The laser-created wounds have been found to be stable and watertight with minimal anterior chamber reaction for up to a few hours after the procedure, although the pupil becomes progressively more miotic with increased time between laser and phacoemulsification. Due to progressive pupillary miosis, it is recommended that phacoemulsification occur within 30 to 40 minutes of the femtosecond laser procedure.

## Phacoemulsification

**Learning Curve** Multiple reports have documented a learning curve when incorporating femtosecond laser cataract technology into a practice.[10,11] In addition to slowing down the surgery day (particularly during the first 10 to 20 cases), the structures of the eye behave differently after laser application. One should be aware of many changes necessary in the phacoemulsification technique and adjustment of IOL constants that must be made for successful surgery.

**Incisions and Capsulorhexis** When the patient is under the operating microscope, the paracentesis and primary incision can be created or opened (if laser created) and an ophthalmic viscosurgical device (OVD) should be injected, as usual, into the anterior chamber. As the OVD enters the anterior chamber, close attention should be paid to the movement of the anterior capsule. A Utrata forceps or microforceps can be used in a circular (continuous curvilinear) motion to remove the anterior capsule if the laser capsulorhexis is incomplete or a radial tear has formed. Alternatively, a cystotome can be used to pull the tissue centrally, preventing extension of radial tears that may be present. Fortunately, as software has improved, radial tears have become less common, but they may occur.[7]

**Changes in Hydrodissection** The air bubbles should be gently decompressed from behind the lens before more aggressive hydrodissection is performed.[12] Generally, by tapping gently on the anterior surface of the lens (tilting the lens slightly) with the hydrodissection cannula and gently injecting balanced salt solution beneath the anterior capsule during hydrodissection, the bubbles come forward into the anterior chamber. If performed too aggressively, rapid hydrodissection could lead to a posterior capsule rupture, as described by Roberts et al.[12,13] and Yeoh.[14]

**Divide-and-Conquer Versus Chopping** With any technique, it is best to remove the superficial cortex first. This allows clear visualization of the segmentation and softening pattern of the nucleus below. At this time, the standard divide-and-conquer technique can be used; however, creating the grooves will expend additional US energy. The grooves made by the laser will crack easily and then less energy will be used to remove the softened nuclear material. Standard chopping or stop-and-chop may also be very effective. Since the grooves created by the laser are extremely narrow, the second instrument selected should be very narrow, such as an Akahoshi chopper (Katena Products, Inc.), a Nagahara chopper (Storz Ophthalmics), a Cionni chopper (Duckworth & Kent), or a Neuhann chopper (Geuder AG).

**Changes in Cortical Removal** Once the nuclear material has been removed, the surgeon may find that the removal of cortical material is slightly more challenging than with traditional phacoemulsification. When the laser creates the capsulorhexis, it also cuts a circular disk of cortex, which exactly matches the diameter of the capsulorhexis. At times, it may be difficult to visualize the edge of the cortex because the edge may correspond to the edge of the capsulorhexis. Although this perfect safety zone ideally protects the capsule, it may be more difficult to extract the residual cortical material from the bag, the most challenging area being the subincisional cortex. The ease of cortical removal improves during the learning curve and appears to be an insignificant issue for experienced users. Bimanual techniques can be useful when faced with subincisional cortex or with cortex that is thicker than usual and is flush with the underlying capsule.

## COMPLICATIONS AND CHALLENGING CASES

### Orbit, Neck, and Back Issues

The orbit must be able to accommodate the suction ring to allow placement of the patient interface and proper docking. Patients with severe neck and back problems may not be positioned adequately on the flat table used by some laser platforms to achieve a parallel surface for applanation. In contrast to traditional phacoemulsification, soft cushions cannot be placed under or around the patient's head during applanation and the imaging will be compromised if the patient is not properly positioned with stability. Some laser platforms are not associated with an integrated bed and can be used with a traditional operating room bed/chair, which may give surgeons additional flexibility with positioning; however, severely kyphotic patients will be problematic.

### Small Pupils

Small pupil cases present a challenge for femtosecond cataract surgeons, particularly during the early learning curve. The pupil must be able to dilate sufficiently to make an adequately sized capsulorhexis. The default diameter for the capsulorhexis is generally 5.0 mm; however, the diameter can be reduced to compensate for the smaller pupil. The case may become significantly more challenging if the capsulorhexis diameter is decreased below 4.6 mm. Applanation with the patient interface may slightly decrease pupil size. In addition, application of laser energy induces further pupillary miosis, sometimes resulting in a pupil constricting more than 2.0 to 3.0 mm between applanation with the patient interface and initiation of phacoemulsification. It is important to monitor the pupil carefully during laser treatment to ensure that miosis does not cause the pupillary border to be damaged by laser application during the treatment. This phenomenon is more pronounced in cases in which there is a lapse of time between the laser and the phacoemulsification portions of the procedure. It is also more noticeable in cases in which the capsulorhexis is created in close proximity to the iris border.

In predetermined small pupil cases, a Malyugin ring can be placed before the femtosecond laser is used for the capsulorhexis and nucleus fragmentation. Care should be taken to ensure strict adherence to sterility. In addition, the OVD should fully inflate the anterior chamber without bubbles in the anterior chamber that may block laser energy. Some surgeons have advocated the removal of OVD before docking the femtosecond laser. Using an intense dilating regimen or adding atropine 1.0% drops to the regimen has been critical in limiting this problem, but does not solve it entirely. Alternatively, if significant pupillary miosis is noted following laser application, a Malyugin ring can be placed after the laser treatment has been completed. In such cases, one must be careful not to incorporate the edge of the anterior capsule under the ring as this may induce an anterior capsule tear. Additionally, intracameral mydriatics (eg, preservative-free bisulfite-free phenylephrine 1.5%) may be a useful adjunct for improved pupillary dilation.

### Suction Loss

Suction loss can be experienced with femtosecond laser LASIK surgery but appears to be less of a problem in femtosecond laser–assisted cataract surgery. Low level suction is required to maintain applanation during the femtosecond laser technology portion of the procedure. The IOP increase during suction is very small (approximately 10 to 20 mm Hg) and therefore does not cause discomfort or induce vision loss during the procedure (Table 1). The patient is able to maintain fixation throughout the procedure. Nonetheless, the patient must remain still or suction will be lost. A patient with nystagmus or an attention disorder may not be able to comply. Some surgeons have successfully performed femtosecond laser–assisted cataract surgery with a peribulbar or retrobulbar block; however, chemosis from the block can make suction difficult or impossible. The creation of corneal wounds and the capsulorhexis takes only a few seconds, so it is rare to have suction loss during this portion of the procedure. If suction loss were to occur during capsulorhexis creation, the surgeon should proceed with traditional phacoemulsification because bubbles induced during laser application could obstruct further imaging and laser application. If suction loss were to occur after capsulorhexis creation, bubbles would most likely obstruct adequate imaging; therefore, one should revert to traditional cataract surgery to complete the procedure. The patient could then be redocked for corneal incisions, if desired.

### Incomplete Capsulotomy

An incomplete capsulotomy may be created at times. Fortunately, software and hardware improvements have decreased the incidence of this problem from approximately 10.5% to less than 1.0%.[11,13] Since radial tears can sometimes be difficult to identify immediately following the capsulotomy, it is recommended that the surgeon ensure the capsule is entirely free before proceeding with phacoemulsification. In this way, he or she is prepared for any unexpected residual adhesions in the capsule. One should be particularly diligent in high-risk cases, which include patients with significant lens tilt or with steep corneas (average keratometry greater than 47 D) that may induce corneal folds on applanation.

### Computer Issues

One complication unique to femtosecond laser–assisted cataract surgery is system/computer failure. For this reason, surgeons must be prepared to revert to traditional phacoemulsification at any time. No cataract surgeon can rely entirely on the femtosecond laser to perform all cases. Ideally, the consent form should carefully state that the surgeon may revert to traditional phacoemulsification if that is most appropriate or if the situation warrants a change in procedure intraoperatively.

## OUTCOMES

### Capsulotomy

Several clinical studies (in vitro and in vivo) indicate that capsulotomies created with the femtosecond laser are significantly more precise in size and reproducibility and that a continuous curvilinear capsulorhexis (CCC) created with a femtosecond laser results in a more stable refractive result with less IOL tilt and decentration than a manual CCC.[15–21]

### Lens Fragmentation

The ability for the femtosecond laser to fragment the lens results in the need for less US energy to be expended inside the eye. Several studies indicate that less effective phacoemulsification time is needed to emulsify the lens following lens fragmentation by the femtosecond laser.[21] This translates into less endothelial cell loss due to the shorter phacoemulsification times and less fluid entering and exiting the eye during surgery.[9] The femtosecond laser may be particularly beneficial in complex cases such as hypermature cataracts or loose zonular fibers in which less energy expenditure would potentially provide a much better patient outcome. However, caution is advised as release of liquefied lens material may shield tissue from laser energy, resulting in an incomplete capsulotomy and poor penetration of laser energy for nuclear fragmentation. Use of an OVD prior to treatment may prevent this from occurring. However, there may be an increased risk for complications in this scenario, potentially resulting in posterior capsule rupture due to changes in capsule position as liquefied lens material is released.

### Incisions

Masket et al.[22] demonstrated greater architectural stability and reproducibility with femtosecond laser–assisted corneal incisions in cadaver eyes. Whether femtosecond laser corneal incisions are better than standard temporal clear corneal cataract incisions has to be determined. Areas of investigation include whether the laser-created corneal incisions result in lower rates of infections such as endophthalmitis. Additional studies are determining whether the integrity of these incisions are stronger than those created manually.[23,24,A]

### Visual Acuity

Good visual and optical quality outcomes have been reported by several studies, but the differences between femtosecond laser–assisted cataract surgery and conventional surgery are not universally statistically significant.[25,26] Long-term outcomes and rate of corneal edema should be investigated prospectively.

### Macular Edema

Nagy et al.[27] compared subclinical macular edema after uneventful femtosecond laser–assisted cataract surgery versus conventional surgery. The study demonstrated small but statistically significantly less thickening of the outer nuclear layer of the retina following femtosecond laser–assisted cataract surgery than following conventional phacoemulsification. Further studies with long-term follow-up and high-resolution imaging are needed to confirm these early outcomes.

## LOCATION, LOGISTICS, AND SCHEDULING

### Operating Room

The location of the femtosecond laser for cataract surgery directly affects patient flow and volumes. Two basic models are used currently: laser in the operating room and laser out of the operating room (in a separate laser room). The advantages to having the femtosecond laser in the operating room include patient convenience and the ability to create full-thickness corneal incisions without the hypothetical concern of anterior chamber instability during patient transport. Many studies have now shown the incisions to be stable for several hours after the femtosecond portion of the procedure.[26] The laser in the operating room model can also slow down a busy surgical day as it ties up the operating room during the femtosecond laser procedure, not allowing conventional cataract surgery to take place during that time.

Another model is to have the femtosecond laser outside the operating room. The femtosecond laser should be in a "clean" room similar to a refractive surgery suite, but it does not have to be in a sterile operating room since the corneal incisions created will not be entered. Multiple surgeons can use the femtosecond laser in rapid succession, or 1 femtosecond laser operator can perform this portion of the procedure for multiple surgeons in an efficient manner.

Of the 4 femtosecond laser platforms for cataract surgery, 2 (Victus and Catalys) have an integrated bed and 2 (Lensx and Lensar) do not.

### Staffing

In a stand-alone setting, at least 1 dedicated trained laser technician responsible for laser calibration, patient information uploading, and patient flow is needed. In cases in which the laser is set up in the operating room, the circulating operating room nurses may be trained to use the femtosecond laser to assist during both stages of the cataract procedure. This alleviates the need for additional staff members.

### Length of Femtosecond Laser–Assisted Cases Compared with Traditional Phacoemulsification Cases

Femtosecond laser–assisted cataract surgery is a 2-step procedure and therefore the time required to complete the case will be longer than the time required for conventional cataract surgery; the time needed for surgery greatly depends on the operating room setup (stand-alone setup or combined). Although this surgical procedure may add to the length of time needed for surgery, as surgeons progress through their learning curves, the time will decrease. In our experience (for beginning surgeons), the time in the operating room increases 20% to 30% over the time in the operating room for traditional phacoemulsification; in absolute numbers, the extra time typically does not exceed 6 minutes. On average, single-surgeon cases can be performed at 2 to 4 cases an hour; however, several new models are being created to increase patient flow. One example is having 2 surgeons operating at the same time, with 1 surgeon performing the femtosecond portion of the cataract procedure and the other surgeon performing lens removal and IOL implantation in a separate room. With this model, surgeons can perform up to 6 to 8 cases an hour.

## SUMMARY

Femtosecond laser–assisted cataract surgery presents a unique set of clinical and financial challenges to the cataract surgeon. During the early evolution of this new technology, questions arise as to whether the clinical value of the technique justifies the substantial capital investment required for acquisition and maintenance of these systems. In a survey performed by Dalton[B] that involved 1047 ophthalmologists, 72% stated that financial issues were their most important concern about adopting this technology. Reduced workflow efficiency, patient dissatisfaction, and increased patient expectations were also noted.

There is no doubt that this technology has added costs and ultimately it is the patients who will pay for this addition to the procedure.[C] With premium IOLs, we have seen that patients are willing to pay out of pocket for new technology if they view it as being safer or offering better results. Similarly, patients will likely be willing to pay extra if they perceive that they will achieve better results with laser-assisted cataract surgery. The average laser costs between $400 000 and $550 000 to acquire, excluding the service cost after the first year, which traditionally ranges from $40 000 to $50 000 per year. Disposable interface costs range from $300 to $450 per eye. Additional costs are associated with incorporating this technology, which may include office or surgery center construction and hiring of new personnel. Therefore, as Uy et al.[16] mentions in a recent article, individual practices must assess surgical volume, surgical pricing structure, patients' willingness to pay, and the cost of space and personnel to develop a business plan that demonstrates a positive return on their investment before investing in this technology. Recently, companies have begun to mobilize these platforms and bring the laser to the individual surgeon.

Femtosecond laser–assisted cataract surgery seems to be a safe, efficient, and reproducible procedure but further prospective randomized studies will demonstrate the potential clinical benefits of this emerging technology.

Patients often will not understand what "laser cataract surgery" is and what benefits it may provide them. In a time of evolving technology, it is our role as their providers to guide them with proper informed consent and appropriate information to allow them to make the best decision for their particular situation. As clinicians, this is a tremendous responsibility that brings with it technical, ethical, and financial challenges.[4,28–31,C] We are only beginning to comprehend the benefits and complexities of this exciting new technology.

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