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**REVIEW ARTICLE**

# Cataract surgery with femtosecond lasers

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**Abstract** Cataract surgery with femtosecond lasers is approaching its practical application in ophthalmology. These lasers, working in the near infrared wavelength (1030 nm) can penetrate the transparent and even opaque tissues of the anterior segment of the eye, with limitations related to vessels and mineral opacities. Femtosecond lasers, guided by image systems can precisely outline the anatomy of the anterior segment of the eye, acting in a very precise way, performing corneal incisions, capsulorhexis, softening and breaking of the nucleus, which are essential steps in cataract surgery.

In this article we summarize the four technologies available and approaching commercial application in the coming future. The main differences between the systems are based on the diagnostic imaging techniques, which might either be based on optical coherence tomography or the Scheimpflug principles. One model (the Technolas Femtec 520 F custom lens, 20/10 Perfect Vision), offers the possibility of combined use in corneal and intraocular surgery.

While clinical studies are being performed with all of them, and most probably becoming available on the market during 2011 and 2012, the main problem of this emerging technology is its practical application as the increase in costs will affect their availability in the market of cataract surgery.

Research is needed to confirm the practicality and the advantages of femtosecond laser cataract surgery over conventional surgery. Meanwhile, a new path for the future of cataract surgery is opening.



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## 1. Introduction

Femtosecond lasers and their application to cataract surgery constitute a major innovation in modern ophthalmic surgery. These lasers, which act on the near infrared wavelength (1030 nm) are capable of penetrating the transparent and even opaque cornea, with the only limitation of an eventual corneal vascularisation and the densely calcified plates. They are guided in their intraocular application by 3 dimensional image systems of the anatomy of the anterior segment of the eye. In this way they act in a very precise way, delivering energy to perform corneal incisions, capsulorhexis, softening or breaking the nucleus, thus enabling elimination of the cataract. The surgical procedure performed in this way, facilitates optimization of the surgical time, minimizing the surgeon's work (the least controllable variable of all those involved in cataract surgery) to the elimination of the cortical remains and the implantation of the intraocular lens (He et al., 2010).

For femtosecond lasers to be applied in cataract surgery, their numeric opening should be greatly reduced with the aim of penetrating the structures of the anterior chamber. Conversely, the diameter of focus of the laser should be larger than that of corneal surgery. This combination of physical elements leads to an increase in the energy limit needed to produce the adequate tissue photodysruption. This high energetic level needed to produce the crystalline lens lysis or fragmentation, results in a limitation of the repetition index of the laser to be maintained within the safety limits, due to the heat effect that the laser causes in this tissue.

The intraocular photodysruption is guided by image systems that use optical coherence tomography systems or optical technology in real time, such as the Scheimpflug, which is able to define with precision, the structures of the anterior segment up to the posterior capsule. Given that these elements are based on optical technology, they cannot penetrate the iris or the structures located behind the iris.

What is the importance of these lasers in cataract surgery during this initial stage of their application? It should be considered that the cataract surgery that is performed today begins with a small corneal incision which enables a manual capsulorhexis of the anterior capsule to be carried out followed by the phacoemulsification and the elimination of the lens fragments. At present, these procedures, although safe and efficient, are considered to depend greatly on the skill and experience of the surgeon.

Precise performance of the incisions is one of the immediate advantages of these lasers and for reason, the concept of Microincisional cataract surgery (MICS) plays and important and relevant role. MICS, a term coined by Prof. Jorge Alió and registered in 2003, embraces the principles of modern cataract surgery, which aims to perform the surgery through a minimal incision, with no refractive impact on the cornea (Naranjo-Tackman, 2010).

Given that the femtosecond lasers can today guarantee the stability, precision, length, shape and width of the corneal incisions, this step has considerably improved. The capsulorhexis, essential step for the so-called "Premium" intraocular lenses, requires an optimum size, shape and centration for its performance to have a positive effect on the lens stability and in this way contribute to the success of the accommodative, multifocal and toric lenses and also to a reduction in the risk of early development of posterior capsular opacity. The capsulorhexis is one of the steps which depends most on the ability and experience of the surgeon, and is the step in which the fewest technological advances have been incorporated into in the recent years, depending totally on the skill of the surgeon.

Finally, the energy delivered by the phacoemulsification tip (cavitation, shock waves and free radicals), damages the corneal endothelium. For all these reasons, a technology that can perfectly control the performance of the incisions and the capsulorhexis and minimize the use of the phacoemulsificator inside the eye should result in a better surgical outcome and greater control of cataract surgery (Kullman and Pineda, 2010).

There are current studies by the different companies involved in the development of the femtosecond lasers, applied to cataract surgery, with respect to the improvement in the safety and the precision of the surgery. All these aim to avoid

**Figure 1** LenSx laser.

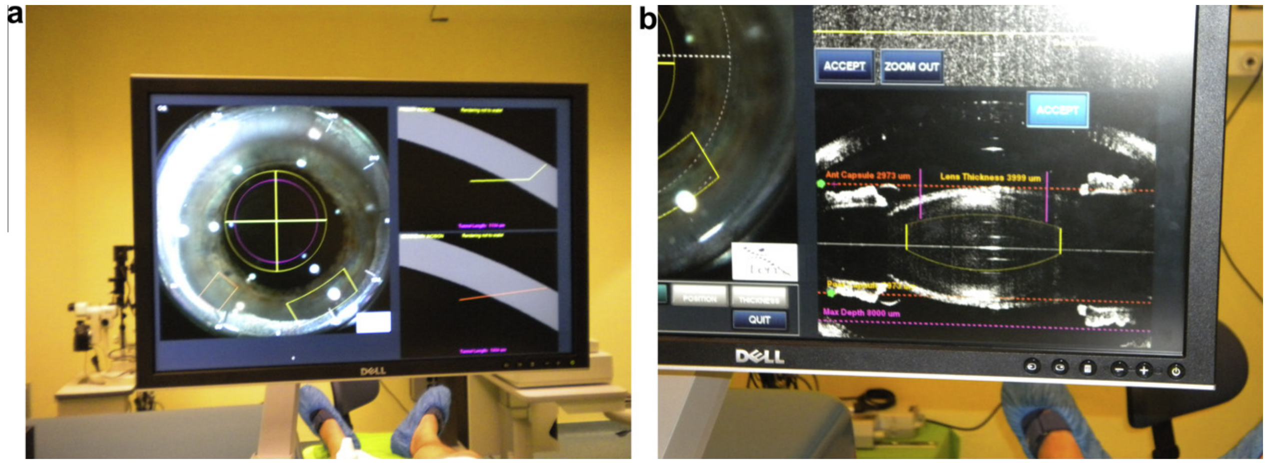


**Figure 2** Images of the LenSx laser monitor.


**Figure 3** Image of the incision drawing.

the collateral damage that the energy for the photodysruption may cause by controlling the length of the pulses and the levels of flow-limit of the energy delivered. In addition, the femtosecond lasers may enhance the outcome of the surgery by controlling and correcting preoperative corneal astigmatism using relaxing corneal incisions which have far greater precision and control than those that are performed with diamond knives available until now. In summary, the integrated systems of anterior segment image diagnosis, together with femtosecond lasers, modified for use in the structures of the anterior segment of the eye can provide multiple benefits for cataract surgery.

Different femtosecond technologies are currently being developed. All are technologically similar but differ basically in the way in which they capture the image of the anatomic structures of the anterior segment, in their versatility for surgical use and speed of action.

There are currently four international companies producing femtosecond lasers that are being applied to cataract surgery: LenSx-(ALCON), LenSar, Optimedica and Technolas FEMTEC.

## 2. LenSx technology (ALCON, Aliso Viejo – California, USA)

This platform uses a femtosecond laser with an optical coherence tomography diagnostic unit with the capacity for real time analysis of the intraocular structures (Fig. 1).

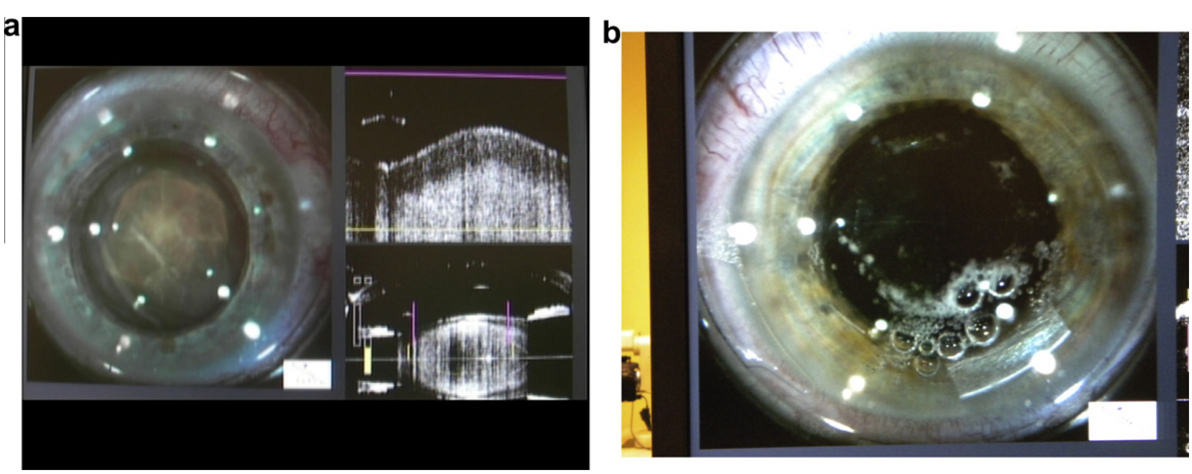


**Figure 4** Final stage of the nucleus dysruption.


**Figure 5** LensAR Laser.

The surgical procedure with this technology begins with the fitting of a suction ring in the eye which in turn is attached to the optical system of the laser. At this moment, the OCT image captures the anterior segment in a single image, projected onto the screen with the capacity for 3 dimensional manipulation of the image (Fig. 2). Using the software of the device, the incisions are located regarding their width, depth, profile and length (Fig. 3). In addition, the location of the capsulorhexis and the volume of the laser action inside the crystalline lens are determined by the use of the image software. With this data, determined by the software, the procedure is initiated by pressing the pedal.

The procedure is visible in real time while it is being carried out and lasts less than a minute (Fig. 4). The group that has acquired the most experience in the use of this laser is the group from the University of Budapest, directed by Dr. Zoltan Nagy. The application of this laser using MICS has already been performed by this team and Prof. Jorge Alió in June 2010.

In Fig. 5 the results obtained can be observed, regarding the precision of the incisions observing the comparison between femtosecond laser surgery incisions that are sub 2 mm and 2.75 mm, in which the full impact on the cornea with respect to the induction of corneal aberrations or astigmatic changes can be seen.

This group has also studied the precision of the capsulorhexis performed with this instrument and its clear superiority with respect to the manual capsulorhexis.

The LenSx instrument can soften grade 1 and even grade 2 cataracts. Grade 2+ and 3 can be partially segmented, allowing in this way a more efficient division prior to phacoemulsification. Advanced grade 3 cataracts and over cannot be tackled at the moment by this technology (Nagy et al., 2009).

The LenSx technology will probably be available mid 2011 in Europe, once the CE mark is obtained.

## 3. LenSar technology (Winter Park – Florida, USA)

This technology (Fig. 5) uses an integrated confocal 3 dimensional platform which uses Scheimpflug technology (CSI Technology) to create the image of the anterior segment. In contrast to the optical coherence technology (OCT) the object plane, the lenticular plane and the planar image, are not parallel to each other but intersect in a joint straight line. The theoretical advantage is a greater depth of field which allows greater precision in the laser focalization. The laser is fitted to the cornea using a suction ring below. As with the previous platform, the image obtained of the anterior segment structures, which is observed in a monitor allow adjustment of the corneal incisions, the capsulorhexis and the fragmentation of the crystalline lens. This platform allows the lenticular fibers to be cut with multiple possible forms, including quadrangles, making it different from the others. This technology claims to be able to fragment even grade 4 and grade 5 cataracts, using the nuclear fragmentation in small cubes to facilitate the elimination of hard nuclei.

The CSI technology (3D Confocal Structure Illumination) using modified Scheimpflug image, according to the data provided by the company, allows much more precise nuclear fragmentation than with the other technologies. The first experiences with this instrument were carried out in May 2010, and an experimental platform is aimed to be established in Europe during 2010.

## 4. Optimedica technology (Catalys system) (Optimedica corporation – Santa Clara, California, USA)

This technology has developed a femtosecond laser platform for cataract surgery. It incorporates an optical coherence tomography (OCT) image to draw the image of the anterior segment anatomic structures. This is known as the CATALYST system for lens surgery. The experiences with this laser, similar to the previous ones regarding the capacity to create precise corneal incisions, controlled capsulorhexis with respect to diameter, location and shape, and nucleus fragmentation, have been satisfactory in the preliminary clinical trials (Fig. 6).

As with the previous laser, this laser can perform multiple options for fragmentation of the nucleus, with diverse possible forms.

## 5. Technolas FEMTEC technology (520F, Customlens) (2010 Perfect vision, Munich – Germany) Fig. 7

This company has adapted its femtosecond corneal laser for cataract surgery (CUSTOMLENS Techology). They have

**Figure 6** The Catalys femtosecond cataract system (Optimedica).


**Figure 7** Femtec Laser image.

initiated clinical studies in Europe, in Heidelberg University, and these are expected to be extended to other countries during this year. This is the only technology that offers a combined instrument capable to perform both corneal and intraocular surgery.

## 6. Differences among the technologies

The femtosecond lasers for use in cataract surgery, require different parameters to those used for cornea surgery. These lasers need to penetrate more deeply into the eye (approximately 7500 microns compared to 1200 microns required for cornea surgery), and the four companies LenSx, LenSar, Optimedica and FEMTEC have developed very similarly with respect to the creation of an efficient photodysruption for the creation of the capsulorhexis and the softening and fragmentation of the nucleus.

The four technologies use anterior segment diagnostic technology capable of drawing the anterior segment of the eye with precision. The LenSar technology uses an optic system which requires the extraction of data for the complete reconstruction of the posterior capsule, apparently similar to OCT technologies, which in theory can imply a limitation to its clinical application, although the initial clinical results confirm its precision.

At the moment, there are no comparative studies that can determine which of these technologies is better than the others, although all three are different in terms of ergonomics, size and probably cost. 2011 will open a new era for the application of this technology in cataract surgery given that these three platforms will provide clinical results which will lead to their introduction, to cataract surgery, in the near or long term as a new reality. In any case, femtosecond technology will not eliminate the need for a modern phacoemulficator, as this is necessary to emulsify hard nuclei and the cataract fragments created from grade 2 and 2+ of hardness.

An important question raised by most of the surgeons and administration interested in these technologies is cost. An increase in about 600 US$ per operated eye is expected when introducing femtosecond laser technology in cataract surgery (approx. cost of the unit will be about 500,000 US$ plus 150–300 US$ for disposables, plus taxes, loans and hidden costs). How this extra cost, very significant in today's worldwide financial environment, will be absorbed by the practice is going to be the unresolved question for the cataract surgeon.

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