Cataract is the leading cause of world blindness with an incidence increasing each year. Fortunately, cataract surgery is highly effective and usually restores visual function with consequential improvements in quality of life. Like many surgical procedures, research and technological advances have improved surgical outcomes and patient satisfaction. This article discusses the management of cataract and describes the application of femtosecond lasers to assist cataract extraction.

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Learning objectives

(Group 2, 2.2.5) Be able to make decisions based on your own and previous findings including the significance of refractive change/ocular status and clinical findings (reduced VA)

(Group 6, 6.1.6) Be able to understand the impact of cataract on the patient’s lifestyle, show awareness of HES management, including types of surgery and risks, and know when to refer for cataract extraction

About the authors

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Despite modern phacoemulsification cataract surgery being a relatively safe and effective procedure, the risk of sight-threatening complications such as endophthalmitis, cystoid macular oedema, and retinal detachment still exists. Therefore, the quest for further improvements in cataract surgery continues. The new kid on the block when it comes to cataract extraction is the femtosecond laser. This type of laser is commonly used on the cornea when performing laser in situ keratomileusis (LASIK) to create a stromal flap prior to excimer laser ablation. However, new laser platforms have been developed which enable this femtosecond laser to operate in a similar fashion to perform lens fragmentation, anterior capsulorrhexis and corneal or limbal incisions at the time of cataract extraction.

The impact of cataract
Cataract can have a profound effect on visual function which may not be adequately elicited with simple visual acuity (VA) testing. The use of contrast sensitivity may yield a better objective understanding of the problem, while the use of subjective questionnaires can ascertain the effect of cataract on the patient’s everyday life. There have been many studies on the effect of cataract on quality of life, demonstrating the problems caused on a patient’s lifestyle such as reduced ability to read (e.g. with posterior subcapsular cataract – Figure 1) and increased glare from light scatter which can impair a patient’s ability to drive. Often in the early stages of cataract, an accurate and up-to-date refraction may provide an adequate improvement in sight, while advice on the need for additional lighting can improve reading. However, not all patients will be able to cope with such adjustments and referral for cataract extraction will therefore ensue.

When to refer
Within the NHS, referral for surgery should only be made when the patient is confident they wish to undergo surgery. Other factors to consider prior to referral include:
• The cataract is likely to be responsible for the visual impairment. There may be a reduction in VA since the last examination and this cannot be improved with an up-to-date refractive correction
• The cataract is affecting the patient’s ability to work, drive or quality of life. This might include symptoms such as glare which is debilitating
• Risks and benefits have been discussed including co-morbidities such as age-related macular degeneration (AMD), glaucoma, and uveitis etc., which may limit visual improvement, particularly if at advanced stages, and any disease/factors which may affect surgery such as pseudoexfoliation syndrome, shallow anterior chamber etc.
• Medications such as α,1-adrenergic blocking agents which can cause intra-operative complications
• The degree of refractive error and, in particular, amount of astigmatism

Local protocols may exist for referral of patients for cataract extraction, such as direct referral and specific referral criteria (e.g. VA of 6/12 or worse in the eye with cataract) which vary across the country. It is important to be familiar with the protocols in your area, but it is beyond the scope of this article to discuss such pathways and protocols.

Traditional phacoemulsification cataract surgery
In 1967, Charles Kelman from New York introduced phacoemulsification. Phacoemulsification uses an ultrasonic tip to firstly fragment the crystalline lens and secondly emulsify these fragments. The procedure of cataract surgery initially involves pupillary dilation and in cases of unresponsive miotic pupils, iris retractors may be used. To achieve access to the anterior chamber of the eye, between one and three incisions are performed, depending on a variety of factors. The main incision is often performed along the steepest axis of the cornea to avoid postoperative astigmatism. A viscoelastic agent (also known as an ophthalmic viscosurgical device – OVD) such as sodium hyaluronate is introduced into the eye. This stabilises the anterior chamber’s dimensions, provides protection of the intraocular structures, and reduces the risk of corneal endothelial damage. The next step involves the creation of a continuous curvilinear capsulorrhexis (CCC), which is a central opening created on the anterior capsule of the lens to enable the cataractous lens within to be removed. The manual CCC that is too small makes the next step of removing the nucleus a difficult task and it may also contract postoperatively (capsular phimosis). A CCC that is too large may cause the intraocular lens (IOL) implant to tilt or dislocate anteriorly.

The next stage of the procedure is hydrodissection, which involves the injection of fluid (usually balanced salt solution – BSS) between the capsule and the cortex of the lens. This dissects the cortex (and inner nucleus) from the capsule. This step enables the lens to be freely rotated within the capsular bag. Some surgeons follow this step with the injection of BSS into the nucleus to separate the nucleus into the central hard endonucleus and outer softer epitnucleus, in a process called hydrodelineation.
of Planck’s equation, $E = \frac{hc}{\lambda}$, where $E$ is the energy, $h$ is Planck’s constant ($= 6.626 \times 10^{-34}$ J·s), $c$ is the speed of light ($= 3 \times 10^8$ m/s), and $\lambda$ is the wavelength.

This process of electrons changing energy levels may occur in three differing situations. The first is photo absorption, where an atom absorbs a photon enabling the electron to jump from a lower energy state to a higher energy state, probabilistically described by Einstein’s coefficient $B_{21}$. The second is spontaneous emission where an electron spontaneously decays to a lower energy level, described by Einstein’s coefficient $A_{12}$ and emits photons of light in a haphazard manner. The third is stimulated emission also described by Einstein’s coefficient $B_{12}$, where a photon of exactly the correct amount of energy passes an excited atom forcing an electron to drop down energy levels and in the process emitting a photon with the same phase, wavelength, frequency and direction of the passing photon. The passing photon remains undisturbed and the emitted photon follows it in the same pattern, thus providing two identical photons. This final scenario is employed in the use of lasers. Stimulated emission rarely occurs as few atoms are in an excited state; they tend to remain in ground state with lower energies. Therefore, in order to achieve a situation with many excited atoms to evoke stimulated emission, a large quantity of energy is required within the laser medium. When a photon is released from an electron dropping energy levels, it will induce stimulated emission in a neighbouring atom, which in turn will release an identical photon, which continues in a chain reaction. Laser systems also use internal mirrors that reflect photons which in turn induce further photon release. One of these mirrors is partially reflective enabling a small percentage of photons to be released, hence forming a coherent and monochromatic laser beam. This allows photons in phase and of equal wavelength to arrive at the same position in the target tissue at one time.

Lasers (light amplification by stimulated emission of radiation)

A laser is a device that emits electromagnetic radiation via stimulated emission. Theodore Maiman developed the first laser (a ruby laser). The emitted electromagnetic radiation is usually in waves of one wavelength, equal frequency and phase, which can be easily re-directed. An atom consists of a central nucleus with positively charged protons and neutral neutrons. The nucleus is surrounded by negatively charged electrons bound to the atom by electromagnetic forces. These electrons have both kinetic energy due to their motion and potential energy from electrostatic attraction to the nucleus. An atom has a defined set of energy levels with electrons able to receive or lose discrete packets of energy to move energy levels. When an electron receives the required energy it is able to move further from the atom’s nucleus, to a more distant excited state. When electrons return to a lower energy level, energy is released in the form of a photon of light. The wavelength of the emitted photon can be calculated by a rearrangement of Planck’s equation, $E = \frac{hc}{\lambda}$, where $E$ is the energy, $h$ is Planck’s constant ($= 6.626 \times 10^{-34}$ J·s), $c$ is the speed of light ($= 3 \times 10^8$ m/s), and $\lambda$ is the wavelength.

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Ophthalmic application of lasers

Since the advent of lasers, they have been closely associated with ophthalmology. In 1949, German ophthalmologist, Gerhard Meyer-Schwickerath suggested the use of lasers to photoagulate the retina. Following this, numerous devices were developed in attempts to achieve this, such as the xenon arc, pulsed ruby lasers, the argon laser and the krypton laser. In retinal photoagulation, photons of light cause molecular vibration, which in turn increases the temperature of the tissue causing protein denaturation. The transparent structures of the eye do not absorb electromagnetic radiation in the visible or near infrared wavelength range at low power densities. However, at higher power densities, this radiation is readily absorbed resulting in plasma generation and tissue disruption.

The neodymium: yttrium-aluminum-garnet (Nd:YAG) laser was introduced as the first non-thermal based laser used in ophthalmology. The Nd:YAG laser has a pulse duration in the nanosecond range (10^-9 seconds) and causes photodisruption at its focal point, such as on the posterior capsule in the treatment of posterior capsular opacification (PCO). The photodisruption causes a rapidly expanding cloud of free electrons and ionised molecules (plasma) leading to the formation of an acoustic shock wave and tissue damage. This vapourises tissue by gas bubble creation of water and carbon dioxide with significant collateral damage. This collateral damage is the reason why the Nd:YAG laser is not suitable for corneal surgery. The femtosecond laser is very similar to the Nd:YAG laser. By shortening the pulse duration to the femtosecond range (10^-15 seconds), the acoustic shock waves are reduced, which in turn reduces collateral tissue damage and improves precision.
The power delivered by a laser is a function of energy per unit time (power = energy / time), therefore reducing the pulse duration (time) increases the power of the delivered laser beam without an increase in energy and subsequent collateral damage. This allows the femtosecond laser to be focused anywhere either within or behind the cornea and enables very precise cuts to a precision of 1 μm. Contrast this to the excimer laser used in laser refractive surgery, which is absorbed by the cornea resulting in ablation. The characteristics of femtosecond lasers have led to their use in corneal refractive surgery and, more recently, cataract surgery.

**Femtosecond assisted cataract surgery**
Zoltan Nagy performed the first femtosecond laser assisted cataract surgery in Budapest, Hungary in August 2008 using the Alcon LenSx laser. The technology is quickly becoming popular across the world with many hospitals and clinics investing in laser platforms to assist cataract surgery. The femtosecond laser is used in cataract surgery for three main purposes, as described below.

**Corneal and limbal incisions**
The exact number and characteristics of the incisions will invariably depend on surgeon preference and the individual patient. Incisions can be corneal or limbal relaxing and it is possible to correct up to 3.50D of corneal astigmatism. Incisions along the steepest corneal meridian will result in an overall flattening effect. In order to achieve effective astigmatic correction, precision is the key. Manual incisions are not comparable to the accuracy achievable with the femtosecond laser, with the former resulting in a 17% reduction in effect if the axis is misaligned by 5° during their creation. Clear corneal incisions are the preferred option for most cataract surgeons, but this has been met with an increased risk of endophthalmitis. With corneal incisions made by laser, there is less need to hydrate the wound as the incisions are self-sealing. Furthermore, it has been suggested that better constructed wounds with the femtosecond laser result in quick healing times, less tissue damage and are likely to reduce the risk of endophthalmitis.

**Capsulorrhexis**
The laser is able to create a precise CCC of a specific diameter, which will depend on various factors such as the optic diameter of the IOL. The advantage of a laser-created capsulorrhexis is the precision of the shape, diameter and centration. A well performed capsulorrhexis will ensure IOL stability, consistent effective lens position, refractive predictability, and minimises the risk of PCO. The precision of the capsulorrhexis is particularly important for multifocal, toric and aspheric IOLs, as poor positioning is likely to result in a sub-optimal visual outcome. There are a number of studies in the literature demonstrating improved precision of a capsulorrhexis created with the femtosecond laser over a manually created capsulorrhexis. A capsule strength study using a capsule stretching instrument (maximum force exerted until capsular tear), found that capsulotomies created with the femtosecond laser required two to three times more force to tear the capsule compared with the manually created capsulotomies.

**Lens fragmentation**
Laser assisted lens fragmentation (Figure 2) allows the surgeon to skip the sculpting and chopping steps in traditional cataract surgery – steps which can lead to capsular bag complications and corneal endothelial injury. In turn this makes the process faster. The use of

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**Figure 4: The Technolas Victus femtosecond laser system and its graphic user interface (images courtesy of Lindsay Brooks from Technolas)**
laser also reduces the amount of ultrasound energy required from the phacoemulsification probe as well as reduced temperature and free radical production.27,28 There may be additional safety benefits too, since there is less use of intraocular instruments and manipulation of the lens, which can lead to injury. The treatments may be optimised for the irrigation/aspiration phacodynamics to reduce flow, trampolining, and iris prolapse.17 Nagy and colleagues15 reported that the use of the femtosecond laser resulted in a 43% reduction in phacoemulsification power and a 51% reduction in phacoemulsification time.

Laser systems
There are a number of laser systems on the market such as the Alcon LenSx, LensAR (Figure 3), Technolas Victus (Figure 4), Optimedica Catalys, and the Abbott Medical Optics (AMO) iFS (for corneal incisions only) (Figure 5). Some systems utilise anterior optical coherence tomography (OCT) whereas others use confocal or Scheimpflug imaging. The systems also differ in a variety of other parameters, including the pattern of fragmentation cuts (Figure 6) and the order of incision delivery. For example, the Alcon LenSx starts with lens fragmentation, followed by the capsulorhexis and lastly the corneal incisions. However, they all employ the same principle of femtosecond assisted incisions.

Contraindications
It is not possible to use the femtosecond laser for cataract surgery in patients with small pupils and corneal scars. It is also important to consider the relative risk of increased intraocular pressure (IOP), which occurs during the procedure, particularly in the elderly. The increases in IOP vary between laser systems but are not as high as those encountered during femtosecond LASKI surgery. Patient selection and counselling is therefore of great importance when making referral decisions.

Figure 5: The Abbott Medical Optics (AMO) IFS femtosecond laser system for corneal incisions (image courtesy of Daniel Wawrzyn from AMO)

Figure 6: The different lens fragmentation patterns possible on the Technolas Victus laser system (image courtesy of Lindsay Brooks from Technolas)

Conclusion
Femtosecond laser-assisted cataract surgery is in its infancy at present and there is likely to be an increase in its use as more hospitals and clinics purchase this technology and more surgeons gain experience with it. It provides improved precision and reduces the human error associated with some of the steps. In turn, this may potentially limit intraoperative complications. Initial results of these laser systems appear promising and larger clinical trials are currently underway, the results of which are eagerly awaited.

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References Visit www.optometry.co.uk/clinical, click on the article title and then on ‘references’ to download.

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