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Major review

Femtosecond laser—assisted cataract surgery—current status and future directions



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ABSTRACT

Femtosecond laser—assisted cataract surgery (FLACS) putatively offers several advantages over conventional phacoemulsification. We review the current status of FLACS and discuss the evolution of femtosecond lasers in cataract surgery and the currently available femtosecond laser platforms. We summarize the outcomes of FLACS for corneal wound creation, limbal relaxing incisions, capsulotomy, and lens fragmentation. We discuss surgical planning, preoperative considerations, clinical experiences including the learning curve and postoperative outcomes with FLACS, and also the cost effectiveness of FLACS. We present the intraoperative complications and management of challenging cases where FLACS offers an advantage and also speculate on the future directions with FLACS. Further advancements in laser technology to refine its efficacy, advancement in intraocular lens design to harness the potential benefits of FLACS, and a reduction in cost are needed to establish a clear superiority over conventional phacoemulsification.

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1. Introduction

1.1. Evolution of femtosecond lasers in cataract surgery

During the 1970s, lasers began to be investigated for applications in cataract surgery. These lasers were initially tested with the goal of achieving aphakia without surgery.^{98,141} One of the early challenges was to minimize damage to the surrounding tissue. An important breakthrough was the design of a Q-switched laser that delivered extremely short duration pulses and thus was able to minimize thermal damage.^{97,99} Krasnov in 1975 described the use of a Q-switched laser unit for laser phakopuncture or rupture of the anterior lens capsule.⁹⁸ Aron-Rosa and colleagues demonstrated the efficacy of the neodymium-doped yttrium-aluminum-garnet (Nd:YAG) laser for posterior capsulotomy in pseudophakic patients with posterior capsular opacification.¹⁷ Another milestone was a use of a picosecond laser Neodymium: Yttrium Lithium Fluoride for performing anterior capsulotomy and lens fragmentation in the late 1980s.^{77,165}

Although this research showed a proof of the concept, one of the early commercially available lasers for cataract surgery was an erbium:YAG (Er:YAG) laser. Manufacturers of Er:YAG lasers included the Centauri system (Premier Laser Systems, Irvine, CA); Phacolase or MCL 29 (Asclepion-Meditec, Jena, Germany)^{54,82}; and Adagio (Wavelight Laser Technologie GmbH, Germany) (Fig. 1).^{1,2} These lasers were broadly categorized into direct and indirect acting systems based on whether laser energy directly made contact with the lens.

Er:YAG, introduced in 1993 for cataract surgery, was a direct acting mid-infrared 2940 nm laser, a wavelength with a strong water absorption peak.⁶⁹ Because the crystalline lens is about 63% water, the Er:YAG laser was thought to be well suited for lens phacovaporization.⁶⁹ The delivery system for Er:YAG lasers comprised silica, zirconium fluoride, sapphire,

and germanium oxide crystals. The explosive evaporation on delivery of the laser formed a cavitation bubble and microspikes within the laser pulse traversed this cavitation bubble, creating microfractures and breakup of lens material that was then aspirated.^{125,151}

The Photon system (Paradigm Medical Industries, Salt Lake City, Utah, USA), introduced in 1999 for cataract surgery, was designed to deliver laser energy with an absorption coefficient lower than that required for phacovaporization. It was a direct acting system with a 1064 nm Nd:YAG laser through a 1.8 mm diameter ski shaped tip, which allowed for lens fragmentation in a 2.5 mm photofragmentation zone.¹ The nuclear fragments were removed by aspiration and irrigation. Nd:YAG laser-based systems for cataract surgery have the potential for deep penetration, a limitation as they may cause damage to nontargeted ocular tissue. To overcome this, the tip had a backstop design that prevented the laser beam from damaging nontarget tissues.

Dodick pioneered the development an indirect system using the Nd:YAG laser (1064 nm) in 1989.^{60–62} The Dodick Laser Photolysis Surgical System marketed by ARC Laser Corp (Salt Lake City, UT) received FDA marketing approval in July, 2000. Using this system, pulsed Nd:YAG laser energy struck a titanium target within the mouth of the laser probe causing optical breakdown and plasma formation. This caused shock waves to emanate toward the distal opening of the probe where they made contact with the lens material, which was held with the tip of the probe using suction. The shock waves disrupted this lens material at the mouth of the probe, and the fragmented material was aspirated.⁶⁰ This system was able to prevent direct exposure of the Nd:YAG laser to the surrounding tissues. The Nd:YAG lasers used a Quartz delivery system. Although these systems confirmed that lasers could perform several steps of cataract surgery, their clinical use was limited because they were inefficient in their delivery of laser energy and lens fragmentation.



Fig. 1 – The early commercially available lasers for cataract surgery. **A:** WaveLight Adagio laser, **B:** ARC Laser Dodick Photolysis, **C:** Paradigm Photon, and **D:** Asclepion-Meditec Phacolase.

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