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EDITORIAL

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Cataract surgery: historical devices, modern innovations, and future perspectives

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1. Introduction

Cataract is the most prevalent cause of reversible blindness and it is defined as loss of transparency of the crystalline lens [1,2]. The World Health Organization (WHO) has estimated the global occurrence of cataract to be 65.2 million, with the majority being in developing countries [3]. The age-standardized prevalence rate of visual impairment caused by cataract was 1207.9 per 100 000 people in 2019 with a 5% increased prevalence in the past 29 years according to a report by Global Burden of Disease Study 2019 [4,5]. Cataract has a long list of etiologies and may be congenital or acquired. Age-related cataract is the most common with multiple factors like ultraviolet light exposure, poor nutrition, diabetes, smoking, alcohol, and severe dehydration accelerating it. Trauma, toxins, drugs, radiation, and systemic diseases being other important causes [1–5].

The only *therapy* for clouding of the lens or cataract is surgical removal of part of the anterior capsule, cortex, and nucleus, and implantation of an intraocular lens (IOL) to provide refractive power, hence improving the quality of life (Qol) of individuals suffering from it. With an estimated 25 million operations performed worldwide each year, cataract surgery ranks second in terms of surgical procedures performed worldwide [1–4]. This editorial will outline the devices used for cataract surgery in the past, present, and what do we expect in the future.

2. History of cataract surgery: device evolution from the beginnings to the current standard of practice

Historically, the earliest known procedure for cataract removal dates back to 800 BCE, *couching*, where a sharp needle via the pars plana was used to dislocate the lens into the vitreous, usually without anesthesia or proper asepsis with many associated complications: inflammation, glaucoma, posterior synechiae, capsular opacification, pupillary block, and endophthalmitis [2,6,7] (Figure 1).

The first known *extracapsular cataract extraction* (ECCE) was performed by Jacques Daviel in mid 1700s in which the cataract was removed by an incision in the lower cornea, puncturing the anterior capsule, and cortex removal by curettage [2,6,7].

Intracapsular cataract extraction (ICCE) was first devised by Samuel Sharp in 1753 using his thumb to extract the whole lens with its capsule after zonule fracture. ICCE later evolved with accompanying devices like the muscle hook for zonular disruption, the capsular forceps; the suction erysiphake, and eventually the cryo probe [2,6,7]. ICCE was associated with many complications in addition to aphakia. Modern day ICCE is limited to severely subluxated lenses where conventional surgery is impossible [2,8].

Sutures in cataract surgery were used for the first time in 1865 but got mixed reviews from primitive surgeons. General anesthesia was avoided by most and topical anesthesia was introduced in 1884 [6].

In 1965, Charles Kelman proposed that ultrasonic dental drills for scaling purpose could be used to fragment the lens nucleus via a small incision. He subsequently performed the first *phacoemulsification*. In the 1970s and 1980s, with the development of modern devices for phaco, a continuous curvilinear capsulorrhexis (CCC), and invention of foldable IOLs, the modern day phacoemulsification found its way into the heart of cataract surgeons [1,2,6–9].

The first *intraocular lens* (IOL) device was created by Sir Harold Ridley after observing that windshield fragments were considerably inert in traumatized eyes of injured World War II pilots [1]. He subsequently designed and implanted a biconvex polymethyl methacrylate (PMMA) disc to counter aphakia, in 1949 after ECCE. Better IOLs were later reintroduced in mid 1970s to 1980s, the Ridey IOL being prone to glaucoma, uveitis, and dislocation [2]. The IOL has revolutionized the lives of cataract patients and has evolved over the years; with anterior chamber IOLs being developed in the 1950s, to iris-supported IOLs in 1971; to foldable IOLs (acrylic or silicon) in 1984 [1,2,7].

Capsular tension rings (CTRs) were first developed in 1991 in Japan to counter zonular weakness, which can cause numerous problems including capsular tears, vitreous prolapse, nucleus drop, IOL decentration, subluxation and dislocation. These are implanted in the capsular bag to provide support and IOL centration. Cionni, Morcher, and Ahmed are different designs to provide capsular stability [1,2,9].

Iris hooks were also used first in 1991 for expanding small pupils to aid in cataract extraction. Pupil expansion rings like Graether pupil expander, Siepser's hydrogel ring, Morcher PMMA ring, Milvella, and Malyugin also have been evolved to achieve a larger pupil size for ease of surgery [10]. *Manual small-incision cataract surgery* (MSICS) introduced in 1994, is similar to ECCE but with a smaller, scleral self-sealing incision (6–8 mm), less astigmatism, and manual nuclear

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Figure 1. Demonstrates the couching procedure. (Reproduced from System of Ophthalmology; vol II, Duke-Elder S, Diseases of the Lens and Vitreous; Glaucoma and Hypotony, Copyright Mosby, Elsevier 1969).

fragmentation. Often called the poor-man's phaco and is popular in small centers in low to moderate income countries with non-availablilty of the phaco machine [1,2,7].

Table 1 describes cataract surgery evolution and evolving techniques.

Ophthalmic viscosurgical devices (OVDs) found their place in cataract surgery in 1970s when sodium hyaluronate 1% was used to maintain the anterior chamber, protect the endothelium, iris, and posterior capsule, and to provide a controlled, smooth surgical manipulation and prevent globe deflation. These are clear, gel-like materials with elastic and viscous properties, that have evolved tremendously over the years and are currently classified as *cohesive*, *dispersive*, or *viscoadaptive* [1,2].

3. Modern innovations in cataract surgery

Modern phacoemulsification provides a small incision (1.9–3.2 mm), a stable ocular environment during surgery, lesser complications than ICCE and ECCE, and the insertion of a foldable IOL. The phacoemulsification technique involves creation of a continuous curvilinear capsulorrhexis of about 5.5 mm either with a cystitome or Utrata forceps which are cheap and also used in developing countries. However, a more precise capsulotomy which is accurate in size, completely circular in shape, centered over the IOL with adequate overlap and less chance of IOL tilt or decentration is achieved with the femto- or nano-second lasers, plasma Fugo blade, pulsed-electron avalanche knife, CAPSULaser selective laser capsulectomy, or precision pulse capsulotomy (Zepto), which are modern innovations to achieve perfection and stability in current cataract surgery [2,11].

Nucleus removal techniques in phacoemulsification are varied and depend on surgeon preference, with *carousel, chip and flip,* or *phacofracture* techniques involving *divide-and-conquer* (Gimbel), *four-quadrant pregrooved* (Shepherd), *nonstop chop* (Nagahara), *stop-and-chop* (Koch) or *double chop* (Kammann) techniques [2]. Alternative approaches to cataract surgery used in conjunction with phacoemulsification are the laser photolysis in which a *Q-switched Nd:YAG laser system* developed in 2000 uses a system to generate 200–400 ns shock waves against a titanium handpiece to fragment the lens nucleus [1,2].

The clear corneal incision has paved the way for *refractive correction* in phacoemulsification, with a smaller incision, placing the incision 'on-axis,' limbal relaxing incisions, astigmatic keratotomy, all aiding in reducing astigmatism [1,2,7,8]. In addition to regular monofocal IOLs, modern-day IOLs include the toric IOLs invented in 1992, multifocal IOLs in the 1990s, and accommodating IOLs in 2000. These correct astigmatism and presbyopia respectively. Extended depth of focus (EDOF) IOLs, potentially accommodative IOLs, and the light-adjustable lens (LAL) are newer technologies to treat various refractive errors. Refractive indexing and softening of IOLs with the femtosecond laser to correct refractive error are also being evolved [2,7,8].

Femtosecond laser assisted cataract surgery (FLACs) uses the Nd:glass lasers to create focused, ultrashort pulses (10–15 s) at a 1053 nm wavelength to photodisrupt tissue by creation of cavitation bubbles. This laser can be used to create corneal incisions, relaxing incisions, capsulotomy, and lens fragmentation, which can be later removed by phaco. It was performed in the first human eye in Hungary in 2008, and it integrates artificial intelligence (AI), and promises to revolutionize cataract surgery, in terms of precision, reproducibility, accuracy, safety, and limiting collateral damage and inflammation [1,2,8,12,13].

Ophthalmic microscopes have evolved tremendously since their first use in 1946. Improvement in microscope design has provided variable illuminations, magnifications, red reflex, beam splitting, depth of field, less phototoxicity, precise motorized zoom focus, ergonomics, and teaching facility; they are a necessity for intraocular surgery. Newer stereo coaxial systems with Xenon light provides natural light, whereas the light emitting diode (LED) source provides

Table 1. Cataract surgery evolution and devices.

Year	Technique/Device	Region	Surgeon
800 BCE	*Couching*	India	Sushruta
1015	*Needle aspiration*	Iraq	Unknown
1100	*Needle aspiration*	Syria	Unknown
1500	*Couching*	Europe	Unknown
1745	*ECCE inferior incision*	France	Daviel
1753	*ICCE by thumb expression*	England	Sharp
1860	*ECCE superior incision*	Germany	von Graefe
1880	*ICCE by muscle-hook zonulysis and lens tumble*	India	Smith
1900	*ICCE by capsule forceps*	Germany	Verhoeff Kalt
1940	*ICCE capsule suction erysiphake*	Europe	Stoewer I. Barraquer
1949	*ECCE posterior chamber IOL and operating microscope*	England	Ridley
1951	*Anterior chamber IOLs*	Italy Germany	Strampelli Dannheim
1957	*1957 ICCE by enzyme zonulysis*	Spain	J. Barraquer
1961	*ICCE by capsule cryoadhesion*	Poland	Krwawicz
1967	*ECCE by phacoemulsification*	United States	Kelman J. Shock
1975	*Iris-pupil supported IOLs*	Netherlands	Binkhorst Worst
1984	*Foldable IOLs*	United States South Africa	Mazzocco Epstein
1991	*Capsular tension ring*	Japan	Nagamoto Hara
1991	*Iris hooks/retractors*	USA	De Juan Hickingbotham
2000	*Q-switched Nd:YAG laser*	Europe USA	Jack Dodick
2008	*Femtosecond laser assisted cataract surgery (FLACs)*	Hungary	Zoltan Nagy

ECCE, Extracapsular cataract extraction; ICCE, intracapsular cataract extraction; IOL, intraocular lens; Nd: YAG, neodymium yttrium aluminum garnet.
(Adapted from Ophthalmology, 6th edition, Yanoff M, Duker JS, Indications for Lens Surgery/Indications for Application of Different Lens Surgery Techniques, p 332, Copyright Elsevier, 2023).

variable light, excellent retroillumination, and less heat production. *Eye tracking systems* provide perfect centration, size, and position for automated cataract procedures [2,14].

4. Future perspectives in cataract therapy

The future of cataract surgery is ever promising as newer technology is introduced in various countries on a regular basis. The *Capsulaser device (Excel-Len)* is a new laser device in the pipeline for capsulotomy without the need for docking. *Aperture continuous thermal capsulotomy (CTC)* is currently being developed to deliver a millisecond of thermal energy for CCC. The development of *premium IOLs* will continue in the quest of perfect vision at all distances, improved contrast, reduced glare and aberrations. Fluid filled IOLs, small aperture, pinhole IOLs, modular IOLs, and mixed EDOF/multifocal IOLs are also being produced. Newer OVDs are being developed to provide smooth and safer surgery. *AI integrated biometry formulas* to minimize residual refractive errors are continuously being studied and improved. Compact and faster phaco systems, FLACs, Femtomatrix®, are being developed to minimize ultrasonic energy and heat. Development of drugs to treat cataract without surgery are also being studied. Head-mounted 3D visualization system with operating microscopes which also provide a stereoscopic view on a screen, provide better visualization, teaching and training, and integrated intraoperative OCT systems are also being developed for better monitoring of surgery. Robotic assisted surgery is also an innovation which is predicted to gain momentum in future [1,2,11,15]. All these advances and smart operating theaters are all good things in the pipeline, that all of us ophthalmic surgeons look forward to.

5. Expert opinion

Although laser cataract surgery has been developed, phacoemulsification remains the gold standard for cataract removal because various meta-analyses show that there are no discernible advantages to utilizing an expensive technology over conventional ultrasonography for cataract removal. Even though a laser can theoretically reduce ultrasonic power, cause less endothelial damage, better IOL centration, and less inflammation, phacoemulsification – when done correctly and with the right OVD and safety measures – remains the best option for both developed and developing nations. However, IOLs should provide best possible vision not only for distance, but for all distances. Many surgeons believe that there are no significant differences in visual outcomes, complications, safety, QoI between FLACs and conventional phaco, and FLACs is not superior, especially in terms of cost-effectiveness [12,13].

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