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# Refractive Surgery for Myopia

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Dieudonne Kaimbo Wa Kaimbo

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## Abstract

This chapter describes current surgical techniques used to correct myopia, including laser correction (laser surgeries), incisional techniques, intrastromal corneal rings, phakic intraocular lenses, and refractive lensectomy. Contents are based on recent findings published in the medical literature and reflect the most advanced achievements in current refractive surgery for myopia. The chapter presents relevant information that patients, students, optometrists, orthoptists, ophthalmologists, as well as scientists involved in management of myopia need to know about this important topic.

**Keywords:** Myopia, Refractive Surgery, Correction, Laser correction, Photorefractive keratotomy, LASIK, Phakic intraocular lenses, Refractive lensectomy

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## 1. Introduction

Myopia is the most common eye disease and is one of the leading causes of vision impairment worldwide [124]. Prevalence of myopia is significantly different among racial groups, although its worldwide prevalence is approximately 30% (3–84%) [41]. The highest prevalence is found in East Asia, such as in mainland China [41]. The prevalence of myopia in the US population was estimated in the early 1970s to be 25% in persons aged 12–54 years [111]. A meta-analysis of population-based studies found a prevalence of 25% in persons over age 40 [61]. The World Health Organization has grouped myopia and uncorrected refractive error among the leading causes of blindness and vision impairment in the world [45].

Myopia (nearsightedness) is a refractive error, in which the eye possesses too much optical power (too much plus powers) for its axial length ; as a consequence, images of distant objects focus in front of the retina, when accommodation relaxed ([www.checdocs.org](http://www.checdocs.org)).

Myopia has been recognized as a distinct visual disability for millennia and has been known for more than 2000 years, first described by the ancient Greeks [54]. It was probably the ancient

Greeks who coined the term, using the roots *myein* (to close) and *ops* (eye) to characterize those individuals who narrow their eyelids to improve distance visual acuity, the pinhole effect. The focus of distant parallel rays of light falls anterior to the retinal plane and produces a blurred image in myopia. This situation can arise because either the primary refractive components are too powerful or the globe is too long. Thus, myopia can be due to increased corneal or lenticular curvature, or an increase in the lens index of refraction, as occurs with the development of nuclear sclerosis. More commonly, myopia is the result of axial elongation of the posterior segment of the eye.

Myopia is categorized into two groups: (1) low-to-moderate myopia ( $\leq 6.0$  D myopic spherical equivalent (SE) with or without astigmatism) and (2) high myopia ( $\geq 6.0$  D of myopic SE with or without astigmatism ([www.medpagetoday.com](http://www.medpagetoday.com))).

Low-to-moderate myopia, known as physiologic myopia, is generally defined as that state in which the eye is rendered myopic by a combination of its components of refraction. In this situation, the refractive power of the eye (corneal power plus lens power slightly modified by anterior chamber depth (ACD)) and the axial length are such that its posterior focal plane lies anterior to the retina. Each component has a value within its normal curve of distribution. These eyes demonstrate normal anatomy and physiology. Whether the absence of correlation among the elements of refraction occurs by chance or is a heritable trait is unknown at present. Low-to-moderate myopia is also considered as low-to-moderate refractive errors defined as myopia less than 6.0 diopters (D).

High myopia, also known as pathologic, degenerative or malignant myopia, is related to an eye with an axial length exceeding 25.5 or 26 mm, a refractive error of at least -5.0 D and characteristic degenerative changes ([eachers%20stangov.uk](http://eachers%20stangov.uk)).

Posterior pole abnormalities typical of high myopia include tessellated fundus, lacquer cracks, diffuse atrophy, patchy atrophy, choroidal neovascularization (CNV), macular atrophy, posterior staphyloma but also straightened and stretched vessels, temporal peripapillary atrophic crescent, hemorrhages, and tilting of the optic disk [48, 52]. Recently, high myopia has been defined as a SE refractive error of at least -6 D associated with characteristic degenerative changes which are more seen in eyes with myopic SE exceeding 8 D.

As elongation of the globe is a key feature of pathological myopia, an axial length of  $\geq 26.5$  mm has been adopted as a biometric definition in clinical trials [122], with recent studies reporting a mean of 29 mm (range 26.8–31.5 mm) [129, 130]. Limit of 25.5 mm of myopic eye has been arbitrarily fixed as 25, 25.5, or 26.5 mm [74] with an inferior limit of -6 to -10 D of refractive error, providing a cornea of +43.5 D as average refractive power, in the absence of spherophakia or nuclear cataract ([eachers%20stangov.uk](http://eachers%20stangov.uk)).

Of greater interest is the determination of the best cutoff for high myopia. Criteria for high myopia that have been used in previous studies include -5.0, -6.0, -10.0, and -12.0 D and there is no universal definition for high myopia [85, 132]. It is thought that at this level, the risks of secondary complications, such as retinal detachment and glaucoma may increase [103, 117, 132]. There may also be further deteriorations in visual field, central visual acuity, increased risks of irregular astigmatism, keratoconus, and peripheral visual field defects.

Most cases of myopia are in children of school age and young adults. The etiology of myopia is not clear, but there is evidence that genetic and environmental factors play a role. The chief complaint is difficult reading at a distance. The diagnosis is made by measurement of refractive errors by refraction [106].

The various modes of treatment of myopia (commonly used methods for correcting myopia) include medical therapy options and surgical therapy options (known as refractive surgery).

## **2. Medical therapy options**

Medical therapy options include eyeglasses (spectacles), contact lenses, and observation. Individuals with asymptomatic myopia may not need eyeglass correction except for activities such as driving or school work. Eyeglasses are the simplest and safest means of correcting myopia; therefore, eyeglasses should be considered before contact lenses or refractive surgery [12]. Contact lenses are used for many reasons. Contact lenses provide better, large field of vision, a greater comfort, and an improved quality of vision. Only contact lenses can give optimal visual function in some conditions such as high myopia, symptomatic anisometropia, aniseikonia, irregular corneal surface, or shape. Further, contact lenses are beneficial in managing unilateral myopia, and some special occupational needs ([www.rutzeneye.com](http://www.rutzeneye.com)).

Spectacles and contact lenses are conservative optical methods. They each have functional limitations such as the problems encountered in wearing spectacles when showering or playing sports, such as individuals involved in certain sports and hazardous activities in which there is risk of eye trauma. Carrying contact lenses solutions and storage solutions can be inconvenient, and wearing contact lenses can increase the risk of corneal infection [106].

## **3. Surgical therapy options or surgical procedures (refractive surgery)**

The term refractive surgery describes various elective procedures that modify the refractive status of the eye [11]. The most commonly used methods for correcting myopia are spectacle correction and contact lens wear. These conservative optical methods provide temporary correction of myopia and remain the first choice, but refractive surgery is increasing significantly. There are a variety of reasons why patients with myopia request refractive surgery as an alternative to contact lenses or spectacles.

These reasons may include the following [28]: (1) contact lenses may be inconvenient, not tolerated, or may be deemed unsafe; (2) spectacles may be associated with unacceptable aberrations, glare, and/or reduction of visual field, and (3) spectacles may be cosmetically unacceptable or inconvenient.

Surgical procedures have been developed in an attempt to permanently correct myopia.

The goal of refractive surgery is to correct myopia by decreasing the refractive power of the eye and to obtain a safe, predictable, stable desired refractive state new optical problems. The

refractive power of the eye is reduced, by augmenting the anterior radius of curvature of the cornea (flattening the curvature of the anterior corneal surface) or by insertion of an appropriate synthetic intraocular lens (IOL). Several surgical techniques are available for the treatment of myopia ([www.medpagetoday.com](http://www.medpagetoday.com)).

Several effective options for laser refractive surgery are available to patients, which provide the opportunity to meet more of the needs of an individual patient. These techniques are divided into two groups: those involving surgery on the cornea (corneal refractive surgery) and those involving surgery on the lens (lenticular refractive surgery). Procedures that involve altering the cornea are collectively referred to as keratorefractive surgery, refractive keratoplasty, or refractive corneal surgery [28].

## 4. Corneal refractive surgery

Corneal refractive procedures used to correct myopia include excimer laser refractive surgery and corneal addition procedures.

Excimer laser refractive surgery for myopia works by removing corneal stroma to lessen the refractive power of the cornea and to bring the image of a viewed object into focus onto the retina rather than in front of it. Corneal addition procedures work by inserting ring segments, a donor lenticule or hydrogel lens inside the cornea, or using compression sutures to steepen the cornea.

### 4.1. Corneal ablation by excimer laser

This procedure includes lamellar procedures, such as LASIK, and procedures involving surface ablation:

- Laser-assisted stromal in situ keratomileusis (LASIK)
- Photorefractive keratectomy (PRK)
- Laser-assisted subepithelial keratomileusis (LASEK)
- Epithelial laser-assisted in situ keratomileusis (Epi-LASIK)

This is divided into two main procedure groups: surface treatments and flap treatments.

In surface treatments, the skin on the surface of the cornea is removed by physical scraping or peeling and the laser is applied to the surface of the stroma. The laser corrects myopia in modifying the shape of the corneal stroma. In PRK, the surface skin is left to heal naturally with the aid of a contact lens; in laser epithelial keratomileusis (LASEK) or epipolis (Greek for surface) LASIK, known as EpiLASIK, the removed dead skin is replaced and acts like a bandage, while new skin regenerates below it [106].

Flap treatment, called laser-assisted in situ keratomileusis (LASIK), employs a blade or a femtosecond laser to cut a thin flap on the surface of the cornea. The flap is peeled back, and

the excimer laser is applied within the body of the cornea stroma. At the end of the procedure, the flap is replaced. A variant of LASIK in sub-Bowman's keratomileusis (SBK), also referred to as "thin-flap LASIK", which differs from LASIK only in that the thickness of the flap is less [106].

#### 4.2. Laser-assisted stromal in situ keratomileusis (LASIK)

LASIK has become the single most common elective operation with over 35 million procedures performed worldwide by 2010 [1, 97]. Brilliant ideas with bioengineering accomplishments have led to correct about 90% of refractive errors in about a 10-min process with a less discomfort, a recovery time of a few hours and dramatic visual results overnight. [www.londonvisionclinic.com](http://www.londonvisionclinic.com))

The concept that refractive error could be corrected by sculpting corneal stromal tissue to change corneal curvature was the brainchild of Jose Ignacio Barraquer Moner in 1948 [24, 26, 27]. Barraquer developed a procedure he coined "keratomileusis" [25], which involved resecting a disc of anterior corneal tissue that was then frozen in liquid nitrogen, placed on a modified watchmaker's lathe, and milled to change corneal curvature. The word "keratomileusis," which is derived from the Greek roots *keras* (hornlike = cornea) and *smileusis* (carving), literally means "sculpting" of the "cornea" [97].

LASIK, the most common procedure for corneal refractive surgery to correct myopia [33, 114], combines lamellar corneal surgery with the accuracy of the excimer laser.

After immobilization of the eye by the positioning of a suction ring, a partial-thickness lamellar corneal flap is cut using a microkeratome (with an oscillating blade to shave 100–200  $\mu\text{m}$  corneal flap, ranging in size from 9 to 10.5 mm); the excimer laser ablation is then performed after the flap to expose the corneal stroma; the laser is then focused and centered over the pupil with the patient looking at fixation light and a preprogrammed excimer ablation of the stroma is performed. The flap is after reflected onto the treated corneal stromal bed [19].

One of the critical steps in this procedure is creation of the corneal flap. Traditionally, the flap was created using mechanical microkeratomes, but during the last few years there has been the emergence of the new ultrashort-pulse lasers (picosecond and femtosecond) [66, 77, 114, 125]. There have been a number of technological advancements to overcome the difficulties associated with intraoperative flap and microkeratome-related complications [33]. The femtosecond laser is one such technology. Current clinical applications of femtosecond lasers have been developed to create flaps for LASIK [59, 96]. The femtosecond laser is a focusable infrared (1053 nm) laser; it employs ultrafast pulses in the 100-fs ( $100 \times 10^{-15}$ -s) duration range and makes closely spaced spots which are focused at a preset depth to photodisrupt tissue within the corneal stroma without inflammation and collateral tissue damage. Each laser pulse generates a small amount of microplasma, which results in microscopic gas bubbles in the interface and creates the flap. During treatment, the cornea is flattened with a suction apposing lens to immobilize the eye and to allow treatment of a geometrically simpler planar cornea [77]. Adjacent pulses are scanned across the cornea in a controlled pattern without

causing significant inflammation or damage to the surrounding tissue, which possibly results in safer and more predictable flaps [125, 66].

The femtosecond laser was developed as a replacement of the microkeratome; it permits surgeons to customize and create a partial-thickness lamellar corneal flap and customize its diameter within the corneal stroma, providing more accuracy in flap thickness than with previous methods.

#### 4.2.1. *Advantages of the femtosecond laser vs mechanical microkeratomes*

- Unlike mechanical microkeratomes, which can have variable flap thickness, the femtosecond laser minimizes irregular flap thickness and epithelial injury as it etches a lamellar flap at a desired corneal depth.
- Potential biomechanical and histopathological advantages with femtosecond laser flap creation.

In LASIK, a larger flap is desired (up to 9 or 10 mm in diameter), in high myopes and in patients with large pupils to compensate for any decentration.

With the femtosecond laser, a smaller flap is possible if centered over the optical zone.

- the femtosecond laser has been reported to minimize aberrations and to be less dependent on corneal curvature;

#### 4.2.2. *Disadvantages*

- increased cost,
- surgical time,
- risk of diffuse lamellar keratitis which is reduced with intensive perioperative topical corticosteroids [19, 33].

In recent studies, outcomes of a femtosecond laser for LASIK (IntraLase, IntraLase Corp., Irvine, CA) [29, 40, 62, 118;] demonstrated more predictable flap thickness, an insignificant increase in higher-order aberrations (HOAs) after flap creation, better uncorrected visual acuity (UCVA), and decreased epithelial injury relative to mechanical microkeratomes. The refractive outcomes after uncomplicated LASIK are relatively stable several years after surgery. The flap perimeter and interface undergo slow wound healing, which allows for early and stable refractive corrections [33, 101]. Although standard laser treatment eliminates conventional refractive errors, it can induce new HOAs that adversely affect the postoperative quality of vision, especially with respect to deterioration of the contrast functions [32, 81, 128]. A clinical refraction, composed of sphere, cylinder, and axis, describes what we now call lower-order aberrations. There exist other types of optical aberrations in the visual pathway of the eye, such as coma and spherical aberration, collectively called higher order. Change in the corneal shape after LASIK toward an oblate pattern is believed to be responsible for inducing spherical aberrations and HOAs after refractive surgery [15, 30].

Aspheric ablation profiles are designed to minimize further inducing spherical aberration by precompensating for its induction or by aiming to maintain the original Q value of the cornea. Wavefront-optimized LASIK compensates specifically for the induced spherical aberration by increasing the pulse energy in the periphery, with good reported visual outcomes [16, 33, 46, 94], and minimization of induced HOA. However, aspheric ablation profiles are not designed to decrease preoperative HOAs. Wavefront-guided ablation profiles are designed to customize the ablation pattern centered on the individual aberration profile of each eye to eliminate the preexisting HOAs and avoid inducing more aberrations. Limitation of such customized treatments in terms of induced changes in corneal asphericity and spherical aberration has been previously reported [30, 33]. There are contradicting reports comparing the results of visual outcome and HOAs between wavefront-guided and aspheric (wavefront-optimized) profiles [33, 43, 65, 69, 75, 82, 88, 100, 112].

#### 4.3. Photorefractive keratectomy (PRK)

PRK is a procedure in which the cornea is reshaped using an excimer laser. PRK evolves epithelial removal and photoablation of Bowman's layer and anterior corneal tissue. In contrast to LASIK, there is no need for flap creation with a microkeratome. PRK can be used in thinner corneas, where creation of a flap may leave less tissue than desired (usually 250  $\mu\text{m}$  of cornea tissue) remaining to the posterior stroma.

PRK was the most commonly performed surgical procedure until the introduction of laser in situ keratomileusis (LASIK) in the mid-1990s. PRK is safe and effective, but the risk of corneal haze, especially in high myopia, is significant. Postoperative pain and slow visual rehabilitation limit the use of PRK ([www.jaypeedigital.com](http://www.jaypeedigital.com)).

PRK was first introduced in 1987 [73], and the techniques have continually been modified since then.

The most frequently performed procedures for low-to-moderate myopia utilize the excimer laser, which was first approved for this purpose by the FDA in 1995. A surface ablation technique, PRK was the first procedure performed.

**Surgical procedure:** An optical zone of 6 mm with a transition zone up to 8 mm is used. The central 6–9 mm of epithelium is removed by one of the several methods: mechanical scraping with a spatula or blade with or without topical alcohol, scraping with an automated brush, using the laser to reduce the thickness and then scrape the residual or to remove epithelium to Bowman's layer, or removing the epithelium with a keratome. The exposed surface is then ablated with laser followed by the placement of a bandage contact lens. A multipass technique is also used for PRK: The total amount of correction is separated into multiple smaller treatments of equal values of sphere and cylinder [91].

The total of these small treatments is equal to the actual-targeted correction. The laser is stopped during 15 s between each pass. All passes are performed during the same surgical procedure. The passes are set so that the operating time at each pass is less than 20 s [91, 92]. Postoperatively, a soft contact lens is inserted on the eye. Corticosteroid drops (fluorometholone (FML)) and nonsteroidal anti-inflammatory drugs (ketorolac tromethamine (Acular)) are

given every 4 h for the first day and then thrice daily for the next 48 h. Antibiotic drops (ofloxacin 0.3%) are given every 4 h. For myopia more than  $-6$  D, corticosteroids are given twice daily for the first postoperative month, four times daily for the second month, thrice daily for the third month, twice daily for the fourth month, and once daily for the fifth month. Corticosteroids are tapered after the first month follow-up exam. For myopia less than  $-6$  D, corticosteroids are given only during the first week after surgery. Oral analgesics are also prescribed for pain during the first 72 h after surgery [91].

PRK is extremely useful in patients with thin corneas and in patients prone to flap dislocation such as military personnel or contact sports athletes.

Surface ablation techniques compared with LASIK have

#### **4.4. Advantage**

More residual posterior corneal stromal tissue is preserved

No stromal flap-related complications.

##### *4.4.1. Disadvantages*

More discomfort

Slower recovery of vision (due to the longer re-epithelialization time and potential development of subepithelial haze) [19, 107].

##### *4.4.2. Complications*

The corneal wound healing response after PRK is usually more complex than after LASIK for the same amount of correction [76].

- Regression
- Overcorrection and undercorrection
- Haze or corneal scar formation
- Dry eyes
- Infectious keratitis

#### **4.5. Laser-assisted subepithelial keratomileusis**

LASEK is indicated in

- low-to-moderate myopia with or without astigmatism
- thin corneas without any signs of keratoconus,
- extreme keratometric values (as in steep or flat corneas),
- deep set eyes and small palpebral fissure,

- recurrent erosion syndrome,
- dry eye,
- glaucoma suspect,
- wide scotopic pupil,
- scleral buckle

LASEK is also indicated in patients and for patients who are prone to trauma, such as military personnel and athletes [116]. Although there is a newer method of creating the epithelial flap mechanically by an epikeratome, without the use of alcohol, LASEK is still considered by many surgeons, for a personal preference or because of the affordability of the mechanical epikeratome.

LASEK involves the creation of an epithelial flap that is put back in position after the laser treatment. Detachment of the epithelial flap is created with placement of a diluted solution of alcohol (typical 15–20%) in a well. Alcohol weakens the adhesions of the basal epithelial cells to the anterior stroma.

#### *4.5.1. Surgical procedure[20, 18, 116]*

In brief, after topical anesthesia and lid speculum application, positioning marks are used to mark the corneal surface, and then a semi-sharp circular well is used to administer 18% alcohol for 25–35 s on the corneal epithelial surface [18, 20, 116]. Using vannas scissors and jeweler's forceps, the margins of the delineated area are freed, leaving two to three clock-hours of intact margins for the hinge. Using a Merocel sponge, the loosened epithelium is then peeled back. After standard laser ablation, the epithelial sheet is gently repositioned with the aid of intermittent irrigation. The epithelium is carefully realigned using the preplaced positioning marks and allowed to dry for 3–5 min. Antibiotics and steroids eye drops are given and a bandage contact lens is placed to reduce the mechanical friction by the eyelid and to reduce postoperative pain [8, 91].

### **4.6. Epithelial laser-assisted in situ keratomileusis (Epi-LASIK)**

Epi-LASIK is an innovative new procedure designed to create a thin flap in the epithelium with an epikeratome. Epi-LASIK is also an excellent alternative for patients with thin and steep of flat cornea [84]. The layer is preserved and replaced following the reshaping of the cornea using the excimer laser. Unlike LASER, which uses alcohol to separate the epithelium and the process can kill epithelial cells, Epi-LASEK permits the cells to live and continue to survive following replacement [60]. Preliminary clinical results suggest that Epi-LASEK is a safe and efficient method for the correction of low myopia [14, 83].

#### *4.6.1. Complications*

Postoperative dry eye syndrome

Postoperative haze

#### 4.7. Corneal addition procedures

These procedures include the following:

- Intracorneal ring segments (e.g., INTACS); the most commonly used to treat keratoconus.
- Epikeratophakia (removal of epithelium and placement of a donor lenticule of Bowman's layer and anterior stroma). Epikeratophakia (also known as epikeratoplasty and onlay lamellar keratoplasty) was introduced by Werblin et al. It involves removal of the epithelium from the central cornea and preparation of a peripheral annular keratotomy. No microkeratome is used. A lyophilized donor lenticule (consisting of Bowman's layer and anterior stroma) is reconstituted and sewn into the annular keratotomy site.

The procedure is used to correct greater degrees of myopia. Complications include irregular astigmatism, delayed visual recovery, and prolonged epithelial defects.

- Keratophakia (intrastromal implantation (insertion) of a donor lenticule of corneal stroma that was previously frozen and reshaped)
- Intracorneal lens (implantation of hydrogel lens within the corneal stroma).
- Compression sutures (to modify refractive error by steepening the cornea and reducing astigmatism). Corneal addition procedures, except intracorneal ring segments, are not currently in widespread use ([www.medpagetoday.com](http://www.medpagetoday.com)).

#### 4.8. Corneal relaxation procedures

Radial keratotomy (peripheral deep stromal radial incisions) has been abandoned ([www.medpagetoday.com](http://www.medpagetoday.com)).

RK for myopia involves deep, radial corneal stroma incisions, which weaken the paracentral and peripheral cornea and flatten the central cornea. Patients with low-to-moderate myopia (up to 5 D) achieve the best results with RK in terms of the highest levels of UCVA. Stability of refraction after RK is lower than with many other refractive surgical procedures. The procedure was abandoned because of the long-term complication of bullous keratopathy secondary to endothelial cell loss.

Arcuate keratotomy (paired peripheral stromal incisions parallel to the limbus); the most often used to treat astigmatism after corneal graft surgery.

- Limbal relaxing incisions (deep limbal incisions of varying arc) are used during cataract surgery to reduce preexisting corneal astigmatism. These incisions are a valuable tool for correcting mild astigmatism. There are several nomograms for determining the number and length of peripheral corneal relaxing incisions (PCRIs). For example, [www.lricalculator.com](http://www.lricalculator.com) features Nichamin and Donnenfeld nomograms; *Cataract and Refractive Surgery* (Kohnen and Koch, 2006) features Koch's nomogram. A PCRI is performed by creating a deep (usually about 600  $\mu\text{m}$ ) incision or pair of incisions in the peripheral cornea anterior to the corneal limbus and vascular arcade. The length and placement of the incision(s) depend upon the axis and amount of cylinder. PCRIs work well if the SE is close

to plano (due to the coupling effect), and the astigmatism is less than 2.00 D. If necessary, it is possible to add or lengthen a PCRI at a later date. Patients with more significant astigmatism (>2.00 D) typically have greater success with LASIK or PRK than with PCRI (Focal Point, 2014).

#### 4.8.1. Corneal thermocoagulation

Thermokeratoplasty (heating the peripheral cornea to shrink collagen and steepen the central corneal curvature) can be used to treat hyperopia or presbyopia.

#### 4.9. Criteria for corneal refractive surgery [8, 53]:

Inclusion criteria (10 [53]):

- Age of patient (years):  $\geq 18$
- Myopia (up to  $-12.00$  D), with astigmatism, up to 3.00 D
- Refraction with a  $<0.50$  D change of  $<0.50$  D during prior 6 months
- Best correctable visual acuity of  $>20/20$  in both eyes
- No use of soft contact lens use for  $>7$  days before the preoperative visit
- Normal fundus peripheral retina or previously treated with photocoagulation

Informed consent must be obtained from all patients after they receive a detailed description of surgical procedure and a thorough review of its known risks.

To be a candidate for either type of refractive procedure, the patient must have adequate central cornea thickness, regular topography, adequate pupil size, healthy and adequate tear film, and no absolute or relative contraindications to the procedure. LASIK is generally avoided in patients with previous corneal surgery, including PCRI, in favor of surface ablation. With either procedure, the ablation can be a standard conventional, a wavefront-guided or a wavefront-optimized treatment. Conventional ablation treats lower-order or spherocylindrical aberrations. Wavefront-guided treatment reduces preexisting HOAs and reduces induction of new aberrations by creating a customized ablation profile. Wavefront-optimized ablation provides a customized treatment profile based on the patient's refraction and only treats the HOAs that would be induced by the alteration of this refraction.

Exclusion criteria [8, 53]:

- Age younger than 18 years
- Excessively thin corneas ( $<500$   $\mu$ m central corneal thickness)
- Topographic evidence of keratoconus [56]
- Eyes with ectatic disorders [99]
- Histories of autoimmune diseases, pregnancy, or current nursing of an infant

- Greater than 2.5 D of difference in sphere and cylinder between eyes
- Previous ocular surgery, corneal diseases, glaucoma, or history of ocular trauma
- Active ocular or systemic disease likely to affect corneal wound healing

#### 4.10. Preoperative evaluation

The preoperative evaluation, a comprehensive medical eye evaluation includes history, examination, diagnosis, and initiation of management ([www.rutzeneye.com](http://www.rutzeneye.com)).

The history should incorporate the elements of the comprehensive medical eye evaluation in order to consider the patient's visual needs and any ocular pathology. In general, a thorough **history may include the following items:**

- Demographic data including name, date of birth, gender, ethnicity, race, occupation, address
- Chief complaint
- History of present ocular disease
- Present status of visual function (e.g., patient's self-assessment of visual status, visual needs, any recent or current ocular symptoms, and use of eyeglasses or contact lenses)
- Ocular history (e.g., prior eye diseases, injuries, surgery, including refractive surgery, or other treatments and medications)
- Systemic history, allergies and adverse reactions to medications,
- Family and social histories: pertinent familial ocular and systemic disease
- Social history such as occupation, smoking history, alcohol use, family and living
- Review of systems

**The comprehensive eye examination evaluates an evaluation of the physiologic function and the anatomic status of the eye, visual system, and its related structures. This includes the following elements ([www.corneasociety.ca](http://www.corneasociety.ca)):**

- Visual acuity UCVA, with current correction (the power of the present correction recorded) at distance and when appropriate at near
- Measurement of best spectacle-corrected visual acuity (BSCVA) (with refraction when indicated)
- Manifest and cyclogenic refractions
- Ocular dominance
- External examination (e.g., lids, lashes, and lacrimal apparatus; orbit; and pertinent facial features)
- Ocular alignment and motility

- Pupillary function; mesopic pupil size measurement using a pupillometer
- Keratometry
- Visual fields by confrontation
- Slit-lamp biomicroscopic examination: eyelid margins and lashes, tear film, conjunctiva, sclera, cornea, anterior chamber, and assessment of peripheral ACD, iris, lens, and anterior vitreous
- Pachymetry
- Corneal topography; computerized videokeratography
- Haze measurement
- Tonometry with Goldmann tonometer
- The fundus ophthalmoscopy: vitreous, retina (including posterior pole and periphery), vasculature, and optic nerve
- Haze measurement
- Assessment of patient's mental and physical status

Anterior segment structures examination includes a close inspection and biomicroscopic evaluation before and after dilation. Posterior segment structures evaluation (examination) requires (needs) a dilated pupil. The peripheral retina examination needs the use of the indirect fundus ophthalmoscopy or slit lamp fundus biomicroscopy. The examination of the macula and optic nerve needs the use of the slit lamp biomicroscope, with diagnostic lenses and OCT.

([www.rutzeneye.com](http://www.rutzeneye.com))

The evaluation of myopia requires an assessment of both the refractive status of the eye, the patient's current mode of correction, symptoms, and visual needs. Refraction is often performed in conjunction with a comprehensive medical eye (American Academy of Ophthalmology Preferred Practice Patterns Committee. Preferred Practice Patterns Guidelines. Comprehensive Adult Medical Eye Evaluation, 2005). Evaluations of myopia include visual acuity, refraction, and refinement. The depth of the corneal lesion can be measured using an optical pachymeter [31]. The combination of manifest refraction, slit-lamp examination, and keratometry is generally sufficient for detecting the most anterior abnormalities.

#### **4.11. Postoperative care**

Postoperatively, antibiotics such as tobramycin (Tobrex; Alcon Laboratories, Inc, Fort Worth, Texas, USA), diclofenac 0.1% drops (Basel, Switzerland), and corticosteroids such as dexamethasone 0.1% or prednisolone acetate 1% eyedrops

1. is given four times a day during the first week
2. FML 0.2% is then applied four times daily for four weeks (minimum), based (depending on) on the refraction and IOP;

3. The drops of FML are tapered gradually three times a day for two weeks and switched to two times a day for two weeks [8]. Lubrication is prescribed as required [91]. After a LASIK, a shield is placed on the eye and taped to the forehead. Patients are instructed to wear their eye shield at night during the week, and not to rub the eyes or swim underwater in order to prevent flap displacement or infectious keratitis.

#### 4.12. Postoperative evaluation [8]

After surgical procedure, the postevaluation includes:

- Measurement of manifest refraction
- Cycloplegic refraction
- UCVA
- BSCVA
- Slit-lamp biomicroscopy
- Dilated funduscopy
- Applanation tonometry
- Corneal topography
- Visual acuity is measured using a standard Snellen acuity chart at 6 m.

Residual stromal bed (RSB) is estimated by two methods: (1) preoperative pachymetry minus predicted flap thickness (according to Pérez-Santonja and associates [86, 87]) minus calculated ablation depth and (2) postoperative pachymetry (using the latest available pachymetry data) minus predicted flap thickness. If enhancement procedures were performed, the RSB is estimated using the sum of the calculated ablation depths for all procedures including the safety and efficacy indexes: Safety = (BCVA postoperative/BCVA preoperative); Efficacy = (UCVA postoperative/BCVA preoperative).

#### 4.13. Results and outcome measures[53, 116]

Primary outcome measures include uncorrected visual acuity, refractive stability, predictability, loss of the best spectacle-corrected visual acuity, aberrometry, contrast sensitivity, and adverse event profile. Evaluation is based on measurement of [53, 116]:

**Efficacy** measured by the mean postoperative UCVA and the efficacy index, which is the ratio of mean postoperative UCVA to mean preoperative BSCVA.

**Predictability** measured by the mean postoperative SE within  $\pm 0.50$  D, and within  $\pm 1.00$  D of the intended correction; and the percentages of eyes within  $\pm 0.50$  D and  $\pm 1.00$  D of emmetropia (target refraction); a lesser likelihood of undercorrection and on the other hand, the more overcorrection seen postoperatively.

**Safety** measured by lost of two or more lines of BSCVA and the mean postoperative BSCVA; and the safety index, which is the ratio of mean postoperative BSCVA to mean preoperative

BSCVA. The percentage of eyes that lost 1 or more lines of BSCVA at a period of time (six and 12 months) posttreatment [116].

**Retreatment and complications** percentage of treated eyes retreated for residual myopia and overcorrection.

#### 4.14. LASIK complications [8]

Keratome and flap complications (miscreated flaps, flap striae, interface inflammation, traumatic flap tears with initial flap lift, loss of suction, and epithelial defects, etc.)

Intraoperative complications such as ectasia, flap striae, flap dislocation ;Laser complications such as misinformation/improper ablation, decentered or improperly registered ablation, reduced quality of vision ; complications of healing/infection/inflammation such as recurrent corneal erosions, Infectious keratitis, epithelial ingrowth, diffuse lamellar keratitis (DLK), post-LASIK dry eye syndrome ; other complications of LASIK such as intraocular pressure measurement after LASIK optic neuropathy and glaucoma ([www.operationauge.com](http://www.operationauge.com)).

## 5. Lenticular refractive surgery

Phakic IOLs for the treatment of myopia work by diverging light rays so light rays from a distant object are focused sharply on the retina rather than in front of the retina. Phakic IOLs, therefore, can be inserted in the anterior chamber of the eye in front of the iris or placed in the posterior chamber of the eye behind the iris in front of the natural lens in the ciliary sulcus ([www.meddpagetoday.com](http://www.meddpagetoday.com)).

### 5.1. Refractive lens exchange

This is extraction of the natural lens and insertion of a posterior chamber IOL, that is, “cataract surgery” in the absence of a visually significant cataract.

The technique is a variety of standard cataract surgery. The elements involved are the transparency and softness of the crystalline lens in the absence of cataract and the elongation of the globe, an axial length of  $\geq 26.5$  mm associated to high myopia, which in this particular case is the indication for RLE [10].

The ideal technical elements for successful RLE surgery include the following [10]:

- Minimal invasive surgery with minimal trauma to intraocular structures (specially corneal endothelium, iris and other intraocular structures).
- A watertight sub-2.2-mm clear corneal microincision, located optimally less than 1 mm from the limbus on the steepest corneal meridian to minimize surgically induced astigmatism or/and to reduce preexisting corneal astigmatism [10].
- Capsular bag fixation of an appropriate posterior chamber IOL proven to be associated to a low incidence of posterior capsular pacification (PCO).

Special considerations in cases selected for RLE include the following:

The best approach to RLE surgery includes minimally invasive surgery, through the smallest possible incision.

Specific informed consent for RLE different to different to the one used for cataract surgery must be provided and will include information about potential refractive benefits and complications, and the problem of pseudophakic presbyopia [10].

## **5.2. Surgical technique [10]**

### *5.2.1. Topical anesthesia*

A clear corneal incision and continuous curvilinear capsulorhexis (CCC)

Hydrodissection: cortical cleaving hydrodissection is performed in two separate distal quadrants with decompression of the anterior chamber in order to avoid capsular block syndrome

Prechopping (optional): although the nucleus is not hard in RLE, prechopping facilitates further surgical maneuvers and reduces surgical time

### *5.2.2. Phacoemulsification*

The nucleus is divided based on the technique used: prechopping, chopping, or grooving, Irrigation/aspiration

An adequate viscoelastic is injected deep in the capsular bag to reform the bag and prepare it for IOL insertion

IOL insertion. After IOL insertion, bimanual

Irrigation/aspiration is performed to remove all viscoelastic material

A preservative-free antibiotic is injected into the anterior chamber, and then the stroma at the incisions is hydrated to assist self-sealing.

### *5.2.3. Complications*

Post-RLE retinal detachment

Cystoid macular edema in the first few weeks after surgery

PCO, which can develop from months to years after the surgical procedure

A decrease in twilight vision (with halo perception and glare) after implantation of multifocal IOLs.

Choroidal neovascular membrane (CNV) formation

Myopic macular degeneration

RLE is indicated in high refractive error in the absence of cataract. RLE, however, is specifically only indicated in presbyopic eye [10]. In general, due to the fact that at present for restoration of near intermediate, and distance vision, multifocal IOLs are at present superior to the available accommodating IOLs. The main challenge involved is to reach emmetropia with rapid recovery using the astigmatically neutral incisions of modern cataract surgery [10].

## 6. Phakic IOL

This is the insertion of an additional synthetic lens in front of the natural lens, placed either behind the iris in the ciliary sulcus or clipped to the iris in the anterior chamber.

Implantation of IOLs in the phakic eye (phakic intraocular lense, pIOL) is a relatively new technique to correct high ametropia.

pIOLs are used for correcting moderate and high ametropias and allowing maintenance of accommodation while offering good quality of vision, some reversibility of the procedure, and possible management of postoperative error [21, 39, 50, 72, 79, 123]. Among the IOLs are the implantable Collamer lens (ICL, Staar Surgical, Monrovia, CA), a foldable posterior chamber IOL, the veriflex lens (Verflex Phakic IOL), an iris-claw lens with hydrophobic polysiloxane foldable design. Implantation of both types of pIOLs is increasingly popular because it is technically undemanding while offering high predictability and a good safety profile.

Implantation of pIOLs is a reversible refractive procedure, preserving the patient's accommodative function with minimal induction of HOAs compared with corneal photoablative procedures [86].

Corneal ablation surgical procedures such as PRK or LASIK laser are usually the preferred options by refractive surgeons for correcting refractive errors [86]. However, the range of safe dioptric correction for these procedures has been progressively limited due to the mid- and long-term complications observed, particularly in cases of high refractive error, such as keratectasia [95], corneal haze [105], regression [8], dry eye [119], or poor postoperative visual quality [55, 89]. It has been shown that photoablative refractive surgery in high ametropia can lead to a significant increase in ocular aberrations [89] and decrease in visual performance [55]. Furthermore, corneal photoablation has a decreased predictability for the correction of high refractive error because of the unknown and unpredictable effects on corneal biomechanics [98].

Intraocular refractive procedures have become a safe, efficient, and predictable alternative for treating high ametropias when the use of corneal photoablative procedures is not possible or high risk [86].

The progress of intraocular refractive surgery is due to advances made in IOL designs, surgical tools and procedures, and viscoelastic substances, [7].

The advantages of implantation of pIOLs are:

- a reversible refractive procedure and

- a preservation of the accommodative function with
- a minimal induction of HOAs compared with corneal photoablative procedures [86, 102].

pIOLs may be divided into anterior chamber and posterior chamber lenses, with anterior chamber lenses being further divided into angle-supported and iris-fixated [86].

Angle-supported pIOLs were first implanted in 1986. Initial designs induced significant rates of complications (corneal endothelial cell loss, chronic uveitis or pupil ovalization). These lenses have shown good refractive results in the long term [58, 86, 87].

Despite this, as an intraocular procedure, it has potential-associated complications such as cataract, chronic uveitis, pupil ovalization, corneal endothelial cell loss, pigmentary dispersion syndrome, pupillary block glaucoma, astigmatism, or endophthalmitis [34].

### 6.1. Indications of phakic lenses

Patients with high myopia and who are poor candidates for laser correction.

#### 6.1.1. Criteria

Age: 21–45 years with ACD of 3.0 mm or greater and Shaffer grade II as determined by gonioscopy

Myopia ranging from −3 to −20 D

Astigmatism less than or equal to 2.5 D

Stable refraction (less than 0.5 D change for 6 months)

Clear crystalline lens

Ametropia not suitable, appropriate for excimer laser surgery

Unsatisfactory vision, intolerance of contact lenses, or spectacles

A minimum endothelial cell density

No ocular pathology such as corneal disorders, glaucoma, uveitis, maculopathy

#### 6.1.2. Surgical procedure for anterior chamber angle-supported phakic IOL

Anterior chamber phakic IOL implantation can be performed under topical or peribulbar anesthesia

Pilocarpine is instilled in the eye 30 min before surgery to protect the crystalline lens at the time of IOL implantation

Creating a superior scleral tunnel or a temporal clear corneal incision (2–6.5 mm, of size, according to the IOL model)

The anterior chamber is filled with cohesive viscoelastic

The lens is introduced toward the angle from the incision (the first footplace is inserted in the iridocorneal angle, the second haptic is then placed, avoiding having their folding over the haptic)

The lens is then rotated with a lens dialer to the meridian in which the pupil is best centered in relation to the IOL optic

A peripheral iridectomy is performed

The incision is closed

Removal of the viscoelastic

Topical antibiotics and corticosteroids are applied for times daily for 4–6 weeks

#### *6.1.3. Surgical procedure for iris-fixated phakic IOLs*

Preoperative application of topical pilocarpine

Corneal, limbal, or scleral tunnel incision (at least 5.3 or 6.3 mm)

The “claw” haptics are fixated to the iris by enclavation by two side-port incisions at 10 and 2 o'clock

The lens is implanted vertically through the incision, and rotated and centered in front of the pupil with haptics at 3 and 9 o'clock positions

The anterior chamber is filled cohesive OVD material

Watertight wound closure

Removing of the OVD material

Antibiotics and corticosteroids are prescribed for 2–4 weeks.

#### *6.1.4. Surgical technique for posterior chamber phakic IOLs*

Topical mydriatics (combination cyclopentolate and phenylephrine), 30 min before surgery

Topical or peribulbar anesthesia

A 2.0–3.0 mm temporal clear corneal tunnel

Placement of cohesive OVD

The posterior chamber IOL is introduced into the anterior chamber

Each footplace is then placed one after the other beneath the iris

Intraoperative iridectomy (or 2 peripheral Nd:YAG laser iridotomies 2 weeks before surgery)

Removing of the OVD material

Acetylcholine chloride is injected

Antibiotics and steroids eyedrops are used three times a day for 1 week with tapered doses for 3 weeks and tropicamide 0.5% two times a day for 2 days.

There are a number of studies evaluating the outcomes obtained with the different models of ICL, and therefore, there is a complete characterization of the refractive outcomes and complications resulting from the implantation of this pIOL [2, 3, 4, 5, 47, 70, 90, 104].

## 6.2. Preoperative assessment and patient selection for pIOLs implantation [86]

A complete ophthalmological examination is performed before the surgery and will include:

- a comprehensive clinical history;
- Visual acuities (uncorrected and best-corrected) visual acuity (using preferably optotypes in logMAR scale under photopic conditions, 85 cd/m<sup>2</sup>);
- Refraction (objective, subjective, and cycloplegic);
- Biomicroscopy of anterior segment
- Intraocular pressure measurement (preferably Goldmann tonometry); scotopic pupillometry; corneal topography; biometric analysis (axial length, white-to-white (WTW) distance, and ACD); corneal endothelial analysis by means of a specular microscopy; binocularity evaluation; and fundus evaluation.

The patient must be properly informed about the procedure and risks of the surgery. Spherical hydrophilic contact lenses, toric hydrophilic and rigid gas permeable contact lenses must be discontinued during a period of at least 1 week before the preoperative examination, [80]. The refractive error stability during at least 1 year before the intervention must be confirmed. The principal indication for pIOL implantation includes prior contraindication of corneal refractive surgery for myopic or hyperopic refractive error correction (including postsurgical central keratometry below 36 D, RSB of <250  $\mu$ m or residual central corneal thickness below 400  $\mu$ m after the programmed laser ablation) [86].

Contraindications of this type of implant for refractive error correction include the following:

Age under 18 years old (except in certain cases of anisometropic amblyopia with intolerance to contact lenses and noncompliance with other less invasive treatment options) [9], previous intraocular surgery, ACD (corneal endothelium-anterior surface of the crystalline lens) <3 mm, glaucoma, history of uveitis, lenticular opacity, nontreated peripheral retinal lesions, scotopic pupillary diameter of >7 mm, neuro-ophthalmological disease, pregnancy or breastfeeding, and unrealistic expectations [17, 57].

Also, any condition associated to a potential zonular weakening and fragility of the ciliary processes should be also considered as a contraindication for the implantation of PRL, such as history of ocular trauma with secondary zonular damage, Marfan's syndrome diagnosis [42]. A preoperative evaluation of the zonule by means of ultrasound technology is indicated [86].

## 6.3. Results

### 6.3.1. Results of angle-supported anterior chamber pIOLs [64]

Anterior chamber pIOLs generally demonstrate good predictability, efficacy, and safety. However, there is a tendency toward undercorrection of the refractive error [58, 120].

### 6.3.2. Results of iris-fixated anterior chamber pIOLs [64]

Several studies with long follow-up demonstrated good predictability, efficacy, and safety of the nontoric and toric pIOL models. With the toric pIOL models, larger amount of preoperative astigmatism can be managed successfully [6, 38, 49, 51, 121].

### 6.3.3. Results of posterior chamber pIOLs [64]

Visual acuity, predictability, efficacy, and safety of the ICL (Staar Surgical Co.) and the phakic refractive lens (PRL; Carl Zeiss Meditec) posterior chamber pIOL models are good. In a United States Food and Drug Administration (FDA) study, the ICL pIOL showed good functional results with a low complication rate (ICL, 2004). In a prospective study comparing matched populations of laser in situ keratomileusis (LASIK) and Visian ICL implantation, the ICL performed better than LASIK in almost all measures of safety, efficacy, predictability, and stability (Sanders, 2007). In a few case reports, results with the toric posterior chamber pIOL have been shown [63, 64]. Schallhorn et al. [64] report better results with the toric ICL than with conventional PRK in a randomized prospective comparison of safety, efficacy, predictability, and stability. In summary, pIOLs show good refractive and clinical results. They demonstrate reversibility, high optical quality, potential gain in visual acuity in myopic patients due to retinal magnification, and correction is not limited by corneal thickness or topography. With proper anatomical conditions (especially sufficient ACD), pIOLs also show good refractive and clinical results in hyperopic patients [22]. Phakic IOLs preserve corneal architecture, asphericity, and accommodation. With recent innovations in the design of toric pIOLs, spherocylindrical correction is also feasible. However, pIOL implantation is not without complications. The spectrum of common and rare complications with each type of pIOL is presented in the following section.

## 6.4. Complications

### 6.4.1. General complications of intraocular surgery [64]

With the increasing use of topical or parabolbar anesthesia, complications due to anesthesia such as retrobulbar hemorrhage, penetration of the globe, or life-threatening systemic side effects from accidental injection into the optic nerve are very rare.

Because implantation of a pIOL is an intraocular procedure, it bears a potential risk for the development of postoperative endophthalmitis. The risk for this complication in general

cataract surgery with implantation of a posterior chamber IOL is 0.1–0.7% with an optimal antiseptic perioperative treatment regimen.

#### *6.4.2. Complications of angle-supported anterior chamber pIOL*

Loss of corneal endothelial cells

Pupil ovalization/iris retraction

Optical quality, glare, halos

Surgically induced astigmatism

Pigment dispersion or IOL deposits

Chronic inflammation or uveitis

Intraocular pressure elevation/pupillary block glaucoma

pIOL rotation

Cataractogenesis

Retinal detachment

Oddities

#### *6.4.3. Complications of iris-fixated anterior chamber pIOL*

Optical quality, glare, halos

Surgically induced astigmatism

Loss of corneal endothelial cells

Pigment dispersion/lens deposits

Intraocular pressure elevation

pIOL rotation

Cataractogenesis

Retinal detachment

Oddities

#### *6.4.4. Complications of posterior chamber pIOL*

Complications for the ICL and PRL are similar and are related to the position of the pIOL between the rear surface of the iris and the front surface of the crystalline lens. Complications such as cataractogenesis, pupillary block, and glaucoma are due to pIOL design materials ([www.ecavolunteer.org](http://www.ecavolunteer.org)).

Optical quality, glare, halos

Surgically induced astigmatism

Loss of corneal endothelial cells

Pigment dispersion/IOL deposits/intraocular pressure elevation

Chronic inflammation/uveitis

Pupil ovalization/iris retraction

Pupillary block/malignant glaucoma

Decentration/incorrect size/pIOL rotation

Cataractogenesis

Retinal detachment

Oddity: zonular dehiscence

## 7. Multifocal lens

These lenses have concentric ring segments that have two different focal lengths for distance and near vision.

### 7.1. Toric lens

These lenses have a cylindrical power to address astigmatism.

## 8. Conclusion

The prevalence of refractive errors is high, affecting approximately one-third of persons 40 years or older in the United States and Western Europe. Myopia is the most common eye disease and is one of the leading causes of vision impairment.

This chapter describes current surgical techniques used to correct myopia, including laser correction (laser surgeries), incisional techniques, intrastromal corneal rings, pIOLs, and refractive lensectomy.

Spectacles and contact lenses remain the first choice for correcting refractive error, but refractive surgery, especially LASIK, is increasing significantly.

There are now several surgical techniques available for the treatment of myopia. The excimer laser, and pIOLs and RLE are promising tools for refractive surgery. The techniques are still developing, and it is certain that there will be significant advances in the future.

## Author details

Dieudonne Kaimbo Wa Kaimbo\*

Address all correspondence to: dieudonne\_kaimbo@yahoo.com

University of Kinshasa, Kinshasa, Congo (DRC)

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