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LASIK/Laser Eye Surgery: What the PCP Should Know

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***Editor's Note**—Modern medicine increasingly promises to improve on mother nature's gifts, or to delay what father time takes. Body contouring surgery (liposuction, implants, etc.) and lifestyle drugs (e.g., Viagra) showcase medicine as one option for non-lifethreatening conditions. Refractive surgery promises to "get rid of glasses." The primary care physician (PCP) may wonder about the reality behind the hoopla of full-page advertisements and evidence of ongoing price wars for the latest in laser eye surgery.[1,2] Should the PCP also rush out to get rid of their glasses and contacts?[3-6]*

This article reviews the optical aberrations that result in poor vision (myopia, hyperopia, astigmatism, and presbyopia) and the surgical steps for laser vision correction. Although complications are infrequent, these complications, as well as the risks and contraindications, are emphasized to alert the PCP to their ocurrence. Laser eye surgery is highly technological, undergoing constant development and relentless change, much like what is occurring with computers. Although the techniques now available have demonstrated excellent results, they will most certainly continue to be refined.

Laser vision correction continues to increase. There are now more than 1100 lasers in the United States, with 350,000 procedures performed during the second quarter in 2000—a 40% increase over the previous year. This growth has resulted from wider availability, increased advertising, insurance coverage (Blue Cross in some regions), and competition, which has driven prices down.[7]

Does it work? What do patients say after having laser vision correction? One fairly typical report of patients with high degrees of myopia (mean preoperative, -10.7 D) showed that 76% of eyes (83% patients) achieved uncorrected visual acuity (UCVA) of 20/40 or better. Although 9% reported that they still experienced difficulty with nighttime driving, 96% felt the results were as good as they had anticipated. Only 2.1% were dissatisfied; and the speed of recovery was as important as the overall outcome.[5,8-11]

Almost every refractive error can now relatively, simply, and quickly be reduced and, in most cases, corrected by modifying the shape of the cornea. To understand in principle what the laser does, the following brief review of the fundamental terms and basic concepts of vision and refraction will help understand the procedures.

Normal Focusing Ability (emmetropia) vs. Nearsightedness (myopia), Farsightedness (hyperopia), Astigmatism, and Presbyopia

Emmetropia is the term for an eye that at distance viewing (by definition at 20 ft) does not require any optical correction (or accommodation) to see clearly. Thus, if a person sees what the average person can see at 20 ft, their acuity is 20/20. However, if at 20 ft they can only see twice larger letters (i.e., letters that ought to be legible from 40 ft away) the acuity is 20/40. 20/40 is the conventional minimum acuity for driving in most states.

At closer distances (e.g., for reading), there must be a greater focusing "power," which is provided by the lens changing its shape as a result of accommodation. Traditionally, the Snellen visual acuity chart has been used to evaluate visual results; while generally accepted, other modalities of testing may have to be used to better evaluate the results of surgical procedures (e.g., glare effect and contrast sensitivity).

Clear images are formed in the eye as a result of a combination of three factors: 1) the optical power of the cornea; 2) the optical power of the lens; and 3) the length of the eye (i.e., the distance to the retina). These factors are usually closely matched. Excessive power occurs when the eye is too long, or either cornea or lens has more focusing power. This results in a myopia, with best-uncorrected vision close-by and blurring at distance. The opposite applies when the eye lacks optical power, when the focusing power of the cornea and/or lens is insufficient, or when the eye is too short. This results in hyperopia, with more blurring close-up than at a greater distance. Seeing better at distance explains the term "farsighted."

Presbyopia is the problem that arises around 45 years of age when increasing rigidity in the lens prevents the eye from accommodating at a near distance. Astigmatism is when the optical power (curvature) of the cornea differs along various meridians resulting in defocus along given axes and is independent of the overall power (hyperopia and myopia) of the eye.

The unit for measuring optical power is the diopter: a convex (plus) lens of one diopter focuses parallel light rays to a distance of 1 m, a lens 10 times stronger (+10 D) exerts 10 times greater effect and focuses at 1/10 of a meter. The same rule holds true for minus lenses, with the "virtual focus" following the same measurement rule.

The overall power of the eye is 60 D; the cornea contributes 44 D and the lens approximately 16 D. Any small change in the shape of the cornea will result in a major effect on the refractive power either way.

Development

One of the earliest successful refractive procedures used controlled incisions that weakened the cornea and the resulting change of shape changes the optical power. The procedure of radial keratotomy (RK) was developed first and was widely used, but it is limited in achieving correction of small amounts of myopia only. The maximum correction that can be achieved is about -6 D, depending on age. While occasionally still used, its best place seems to be for relatively low myopia. A related technique (astigmatic keratotomy [AK]) remains beneficial for managing astigmatism.[12,13] While RK has the longest track record, concerns remain about long-term weakening of the eye as well as a progressive increase in hyperopia. RK and AK, however, are inexpensive (no need for expensive lasers) but demand skillful surgeons.

An alternative method to change the corneal shape consists of directly removing some tissue, and this reshaping (keratomileusis) alters the optical power: flattening the cornea's center decreases its power and corrects myopia. Automated lamellar keratoplasty (ALK), which uses a mechanical removal of tissue, has a major problem with long-term stability, with the amount of tissue removed directly related to the long-term regression.[14] Although both procedures take advantage of lamellar keratoplasty techniques, the LASIK technique minimizes the depth of ablation while maximizing optical zone size that results in more accurate correction and better long-term stability.

Removing tissue from the periphery will result in a steepened center, thus adding power. Mechanical devices to remove tissue (keratomes) lack sufficient precision when dealing with living tissue to produce reproducible and finely adjusted outcomes. This problem was solved when the excimer laser became available. This intense ultraviolet laser (excimer = excited dimer, typically argon and fluorine) vaporizes proteins and each pulse removes precisely 0.25 microns of tissue. Complex mirrors, lenses, adjustable apertures, and ablatable masks that modify the broad laser beam can achieve a variety of effects to correct myopia, hyperopia, and astigmatism.[13-15]

Interfacing the laser with the topographic map of the surface of the cornea will allow a finer control of the laser to correct any defects.[16] The latest lasers now use scanning beams with smaller spots as well as automated trackers to correct for involuntary movement of the treated eye.[17]

The scanning laser takes more time but produces less shockwave effect and is associated with a lessened prevalence of optically damaging central islands. Numerous companies are developing and bringing scanning spot lasers to the market. There are other concepts yet in development that seem to have potential for further improving laser refractive surgery. These

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include the pico-second intra-stromal laser, which can take the place of a keratome and produce customized ablation deep within the corneal stroma. Also, sophisticated wavefront analysis technology allows for analysis and mapping of the optical behavior of the eye as a whole, to include all optical aberrations anywhere along the visual path.[18] By selectively modifying the cornea, it holds the promise of correcting even minor optical defects that could potentially produce better than "normal" vision (e.g., with visual acuities of 20/8).

From a practical point of view, there are two main lasers currently used in the United States for vision correction:

1. **The Excimer laser.** This is what most commonly is referred to in discussions of laser refractive surgery and will form the major portion of this article.[19]
2. **The Holmium laser.** This device was FDA approved in June 2000. It can be relatively briefly discussed since its sole function is to correct hyperopia. Infra-red heat applied to the stroma of the peripheral cornea causing collagen shrinkage that steepens the central cornea. The effect is modest at best, and the effect regresses within two years. Nevertheless, the manufacturers believe there is a large potential market.[20,21]

Laser Keratectomy

There are two ways in which the excimer laser can be used, both of which currently appear to have a place:[22-26]

Photo refractive keratectomy (PRK).[26,27] This method directly treats the front surface of the cornea and removes a specified amount of the uppermost layer of the stroma. The specific surgical steps will be discussed. Its chief drawbacks include the fact that the surface then has to heal back, which is usually associated with a few days of discomfort and blurry vision.[28] Scarring with development of haze as well as regression can occur, all of which are amenable to topical steroids.[29,30] Using the laser directly on the surface will treat many ocular surface problems, including superficial scars and recurrent corneal erosions.[31]

LASIK is an acronym for laser assisted in situ keratomileusis. It performs PRK under a flap of tissue that, when replaced, minimizes pain and blurred vision immediately after the surgery. It has become the procedure of choice for the majority of refractive procedures. This procedure has a significant "wow" effect, with many thousands of procedures now being performed annually. Its success and low rate of complications has resulted in bilateral procedures being performed simultaneously.[32,33]

Surgical Steps

Both PRK and LASIK are performed using topical lidocaine drops along with minimal sedation (oral diazepam).

In the case of PRK, the laser may be applied directly to remove the epithelium first, or various mechanical or chemical means may be used.[34-38] Then the laser beam is applied to the stroma to achieve the desired optical effect. The epithelium is then allowed to heal back; a recent innovation simply loosens the epithelium and folds it out of the way until after the laser has been applied. The partially detached epithelial flap may then be replaced and heals back sooner than had it been totally removed.

In the case of LASIK, a flap of tissue must be sectioned with the microkeratome to expose the deeper layers of the corneal stroma to the laser. This additional step adds complexity to the procedure but reduces pain, healing time, and scarring.[39,40] First, a suction ring is applied around the edge of the cornea. It will increase the intraocular pressure to three or more times the normal pressure in order to cut the flap precisely. During this high-pressure phase, the patient experiences a total "blackout" since the circulation in the eye is interrupted. (There are only isolated reports of possible damage. The absence of damage may be due to the brief pressure increase or the fact that most eyes are young and resilient.[41-44]) A mechanized keratome lifts a flap of usually 160 micrometer thick (approximately one-third of the average corneal thickness of 500 micrometer) while leaving one edge attached with a small peripheral hinge. Then the pressure is reduced and the flap folded over to the side to expose the corneal stroma. If problems occur with the keratome incision (including irregular or eccentric flaps, buttonholes, etc.), the flap may be replaced without using the laser. It usually heals back innocuously and the procedure may be repeated later.[45] Whether different designs of microkeratome are beneficial is debated.[45-47]

Then the excimer laser is applied exactly as with PRK but using a different calculation. Care is taken to only remove enough tissue to achieve the desired curvature modification. With a small diameter area treated, only a relatively small amount of tissue needs to be removed. However, the limited area of optical change may be smaller than the pupil and, thus, be associated with severe nighttime blur. Treating a larger area will result in removing more tissue; consequently, the remaining stroma becomes too thin and weakened. At least 250 micrometers of central posterior stromal tissue should be preserved to maintain long-term corneal integrity and to avoid postoperative corneal ectasia. If a 160-micrometer flap is created for LASIK, the average 550-micrometer cornea will have 140 micrometers of corneal stroma available for ablation. The maximal LASIK correction for the average cornea ranges from 9.8 D to 15.0 D since 10-24 micrometers of tissue is removed per diopter of correction.[48-54] Obviously, since PRK starts with the full thickness of 550 micrometer, more tissue can be removed and, thus, a greater refractive effect can be achieved.[48] Then the surface is carefully cleaned of any debris, moistened, and the flap returned to its normal position. Any material left in the interface can result in inflammation and scarring—the "sands of the Sahara" syndrome, which will be discussed.[55-58] The flap does not require sutures, since it reattaches firmly due to the strong tissue suction from the innermost endothelial layer. However, flap striae (vide infra) can occur if the flap is not carefully replaced.[59] The patient should wear a clear shield at night, to prevent inadvertently rubbing the eye during sleep—avoid dislodging the flap.

Outcomes

The overall results are excellent and patients are ecstatic about the "instant" improvement of vision. However, up to 18% of patients do not achieve 20/40; 9.5% lost two lines; 19% outside 1 D of the spherical equivalent target.[60-64]

Complications

While appearing deceptively simple with excellent overall results,[61,62] these procedures are not without problems.[63-97] The complication rate is low (0.5-2.5%) and while many authors claim reduced complication with greater experience, a comparative outcome was found in novice and experienced surgeons.[61]

The complications include the following:

Poor visual result (either due to optical complications or to scarring). Fortunately, incorrect optical outcomes are amenable to further treatments, either with more laser or using alternative approaches, including RK, AK, and implantable devices such as the INTACS ring.[68] Retreatments, though simple and easier than the original, are often required and adds to complexity and risk.[69-74] The lower the correction required, the less need there is for additional treatments.[70,72] Irregular astigmatism as well as abnormal contours that may result are all amenable to retreatments.[73-76]

Folds. Microscopic folds ("striae") can result in poor visual outcome. This has been blamed on insufficient smoothing of the flap. If recognized and managed early, the problem seems to be correctible.[59]

Sands of Sahara. Debris (including lid secretions) left in the interface may result in an inflammatory process and the granular appearance of the interface scarring that explains the term "sands of Sahara."[55-58]

Lifting the flap and scraping away the material can correct the problem.

Keratectasia. The problem of too thin a residual stromal bed causing progressive ectasia has been mentioned.[49-54] Similar appearances may result from scarring as well.[77-78] The problems with IOL power calculation and/or contact lens fitting will be discussed below.

Scarring. While usually far less in LASIK than with PRK, scarring at the interface does occur. This can result in haze and loss of contrast sensitivity; however, this problem appears to be temporary and recovers by six months.[79-84]

Epithelial ingrowth. The edge of the flap may not be firmly attached with a layer of epithelial cells growing into the potential space under the flap.[85] Alternately, displaced epithelial cells may multiply in the interface. The layer of epithelial cells result in progressive melting of the overlying stroma.[86] If recognized early and aggressively managed (lifting the flap, scraping the interface and replacing the flap), the problem can be dealt with.[85-87]

Infection. This problem is fortunately uncommon. Patients present with pain, loss of vision, and visible infiltrates as well as ulceration of the cornea. Unfortunately, the causative organism is often an unusual opportunist, including atypical mycobacteria.[88-91]

Problems with cataract surgical planning. Corneal topography is no longer simple and measurable for IOL calculation; thus, after cataract sugery, there may be significant errors in the optical outcome.[92,93]

While contact lens fitting may be difficult, the corneal shape change does not preclude a successful fitting.[94,95]

Sensation. Removing tissue affects the corneal nerves and temporarily reduces the sensitivity of the cornea.[96] While not a significant risk, it may confuse neurological evaluation, as well as potentially result in greater risk for damage.

Intraocular pressure measurements. Since the cornea is thinner, it will not respond in the same way to devices that measure the intraocular pressure. This artifactual reduction can adversely affect the management of glaucoma.[97,98]

Hyperopia. Since a more complex shape must be created to correct for hyperopia, the results have been less predictable than with myopia. More complex laser technology is required to produce the appropriate change in configuration, including erodible masks.[100-101] However, more experience has improved the calculations and delivery of laser energy, with gratifyingly improved results.

Patient Selection: Who Should *Not* Have Laser Refractive Surgery

Patient selection is as critical as meticulous technique to avoiding problems.[102,103]

Unrealistic expectations. While these procedures are effective, laser or any other refractive procedure is not perfect. Thus, between 5% and 15% of patients do not achieve 20/40 or better without glasses, which may be disappointing to some. In any event, even if the distance vision is perfect, then the patient will still (once they reach the age of presbyopia) have to use reading glasses. Furthermore, some patients will have haze and scarring that may result in some loss of best vision that may not be corrected with glasses or other means.[104,105]

Age. Young patients are more likely to have unstable refractive errors and are also not able to fully comprehend the informed consent. Therefore, the patient must have attained an age of 18 years or more.[106]

Unstable refractive error. The refractive error must have remained relatively stable for at least the last year. Therefore, pregnant women or women who are nursing should defer the procedure until after their hormonal status has stabilized. Wearing contact lenses can induce changes of corneal curvature that could result in inaccurate refractive findings; hence, patients should stop wearing soft lenses for at least three days before undergoing refractive measurements and corneal topography. While two weeks may be sufficient in the case of hard lenses, there are corneas that take longer to recover a stable contour.[107]

Some occupations or avocations (e.g., violent contact sports such as boxing) may place the eye at greater risk for blunt injury.

Collagen autoimmune disease. In these eyes, the healing response is extremely unpredictable and the patients may suffer complications such as corneal melting.[108]

Herpes simplex keratitis. Corneas that have previously suffered herpes infection may experience reactivation from the laser. Treatment with antivirals before and after may avoid the problem.[109]

Keratoconus. Since these corneas are thinner, they may not be good candidates. More important is the risk of natural progression and the patient mistakenly blaming the problem on the laser. Therefore, preoperative corneal topography must be used to identify these patients.[110-112]

Drug Interactions. Patients taking isotretinoin (Acutane) or amiodarone hydrochloride (Cordarone) should defer this procedure.

Unknown Interactions

The long-term effects of laser vision correction have not been elucidated. The epithelium has been shown to have major modulating effect on the corneal stroma.[113] The wound-healing cascade in the cornea may be different than elsewhere, and topical medications further modify the response.[114,115] Epithelial injury can activate keratocytes deep in the stroma, with some entering a phase leading to apoptosis.[116,117] While the technological refinements of the lasers show no sign of cessation, the increasing precision may outstrip the variability in tissue healing responses; biology is less precise than physics.

Other Alternatives

Other options being evaluated include surgery on the crystalline lens and implantation of an intraocular lens, as is being performed for cataracts, but when there is no lens opacity per se.[118]

An artificial lens may indeed be implanted (with preservation of the normal crystalline lens) to achieve optical correction, including using LASIK to further enhance the outcome.[119]

Another option under evaluation includes intra-ocular contact lenses (ICLs), which are under investigation and should be approved by the FDA in 2-3 years.

Conclusions

Refractive eye surgery is remarkably effective, and while reducing the refractive error, it does not forever eliminate the need for spectacles in all patients. However, the vast majority of patients will achieve their goals of no longer being spectacle or contact lens-dependent. Myopia and astigmatism of almost any degree can be corrected with good precision; although hyperopia can be improved, there is still marked variability of outcomes and long-term stability.

The high precision of the laser has resulted in predictable outcomes and, therefore, extremely satisfied patients. This has led to a rapid spread of the technology. The ongoing advances and refinements have produced hyper-specialized practitioners, who (due to the investment required) are market oriented. Long-term clinical studies are now becoming available.

Current techniques are amazingly free from major complications, which has led to simultaneous bilateral surgery in most cases. Nevertheless, complications can and do occur. Nothing is perfect. Refractive laser eye surgery remains surgery, and the eye is irrevocably altered. This may affect the measurement of pressures and temporary loss of corneal sensitivity.

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CME Questions

1. Refractive laser surgery can correct all visual defects, so patients will not ever have to wear glasses.
   a. True
   b. False

2. With generally available LASIK, there is no longer any place for RK or PRK.
   a. True
   b. False

3. The following are complications of laser vision correction *except*:
   a. keratoconus or corneal ectasia.
   b. retinal detachment.
   c. glaucoma.
   d. scarring of the cornea.

4. Patients at high risk for complications include all of the following *except*:
   a. too thin corneas.
   b. collagen vascular disease.
   c. diabetes.
   d. age younger than 18.

In Future Issues:

Complementary and Alternative Medicine—
Felise Milan, MD