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Correction of myopia using Laser-Assisted in Situ Keratomileusis (LASIK)

I. A. Vrabii

Department of Ophthalmology, Nicolae Testemitsanu State University of Medicine and Pharmacy
Chisinau, the Republic of Moldova

Corresponding author: ivrabii@gmail.com, manuscript received May 21, 2014, accepted July 05, 2014

Abstract

Background: The article provides an overview of current trends in refractive laser correction of myopia. Development of refractive laser correction is on the way to improve procedures for the production of thinner flaps. However, it is known that the formation of excessively thin flap can cause flap torn, buttonhole, while a thicker flap can significantly change the tectonic stability of the corneal thickness and also the predictability of thickness of the formed flap is important. Priority directions of refractive laser eye surgery are: identifying patients at risk for the possible development of corneal ectasia, holding correction with maximum preservation of corneal tissue, forming the widest zone of ablation, the optimal correction of refractive errors, and their predictability of clinical stability.

Conclusion: Summarizing the analytical review of modern methods of correction of myopia and astigmatism it should be noted that the technique with a thin flap Laser-Assisted in Situ Keratomileusis preserves natural balance of anatomical structures of the cornea, significantly reduces postoperative recovery period, reduces the incidence of complications, in some cases, provides an opportunity to reoperation in case of regression of refractive effect, thereby opening up new opportunities for the correction of myopia and astigmatism.

Key words: visual acuity, myopia, ablation, cornea flap, Laser-Assisted in Situ Keratomileusis.

Introduction

The number of patients wishing to hold refractive laser correction is steadily increasing. Rate of growth is associated with the professional needs of patients, problems of rational optical correction. In recent decades, the greatest progress in the correction of myopia and astigmatism was achieved through the establishment and improvement of methods of refractive laser surgery, based on modeling of corneal tissue by its ablation with the excimer laser wavelength of 193 nm [1, 2]. Excimer laser interventions in our days are the leading trend in modern ophthalmology. Today, using an excimer laser with minimal impact on the eye it is possible to model the shape of the cornea, making its surface curvature with the parameters of refraction, which, combined with the geometry of the eye, will provide normal vision that will relieve the patient from having to use glasses or contact lenses [3]. Application of the excimer laser has helped reduce the invasiveness and increase the accuracy of impact on the structure of the cornea, allowing the use of excimer laser for astigmatism. Throughout the world LASIK (Laser-Assisted in Situ Keratomileusis) surgery is considered the most secure technology with excellent functional results; the main advantage of the technology is not only high accuracy, but also predictable refractive effect and bactericidal effect of ultraviolet radiation. It is important to note that the bulk of the operated patients are young people of working age, so the demands on the results of the correction are continuously increasing [4, 5]. The priority areas in order to meet the increasing requirements are:

1. Careful preoperative assessment, aimed primarily to identify patients at risk for possible development of ectasia.
2. Formation of a minimal thickness of the corneal flap.
3. Conduct correction with maximum preservation of corneal stroma.
4. Formation of a wider ablation zone.
5. Optimal correction of refractive error, reaching the maximum corrected preoperative visual acuity.
6. Achieving predictable, clinically stable results.

Thinning of the cornea after LASIK changes corneal biomechanical properties, causing different strength response, which is characterized by a shift of anterior corneal layers, which may manifest in refractive effect regression, distortion of applanation IOP measurements and in rare cases (1:10 000) ectasia [6,7, 8, 9,10, 11]. Ectasia after LASIK procedure is described in the literature as depending largely on the predictability of the thickness of the corneal flap and residual stroma [12, 13, 14]. It is known that for the prevention of postoperative ectasia, minimum thickness of the residual corneal stroma should be 250 microns [6]. For more accurate calculations of residual corneal stroma a preoperative and intraoperative pachymetry of cornea is necessary [15]. Performing LASIK procedure in patients with thin corneas (less than 500 microns) is possible assuming there is a normal topographic data and the formation of a thin flap of the cornea.

Development of refractive laser correction is on the way to improve procedures for the production of thinner flaps [16]. However, it is known that the formation of excessively thin flap can cause flap torn, buttonhole [17], while a thicker flap can significantly change the tectonic stability of the corneal thickness and also the predictability of thickness of the formed flap is important. According to the C. Roberts' theory, after the formation of the flap, there is a change of biomechanical properties of the cornea in which the crossed fibers of cornea shifted to the limb, and the central area of the cornea flattens. The result is the so-called «hyperopic shift» of the refraction [18]. When forming the corneal flaps of thickness to 130 microns of corneal curvature changes are minor and can be neglected in the calculations. It was also found that the relaxation of the corneal tissues depends on the thickness of corneal flap is formed and may be from 14-33% [19]. Obtaining various thickness flaps is associated with the head size of the keratome, the size of vacuum ring, corneal thickness, keratometry, refraction and age. Some authors attribute the changes in the thickness of the flap to vacuum pressure, the degree of sharpened blade length of cut (longer holding cutting leads to the formation of a thicker flap and larger cutting angle on the swine eye) [20]. It should be noted that the resulting thickness of the flap in one eye does not guarantee receipt of the same thickness of the flap on the other eye due to the fact that the variability of apparently identical parameters is very high [16].

Normally, the highest density of keratocytes is in the anterior stroma, about 40% higher than the density of cells in the middle and posterior stroma [21]. Consequently, conducting the correction in the surface layers of the stroma is more preferable since the cornea is biomechanically more durable. In this regard, considerable interest is the work of Michael Smolek, which showed that the collagen fibers in the front of the stroma have interlamellar bridging fibers, contributing to the preservation of structural integrity of the cornea [22, 23, 24]. These fibers ramify at different depths in front of the stroma that helps tie all front plate fibers together for structural support. Since the rear plate fibers run parallel to each other and in the deeper portions of the corneal stroma bridge fiber is less, this part of the cornea is more stable and more susceptible to mechanical stress.

It should be noted that the technology of surface effects – laser epithelial keratomileusis (LASIK), photorefractive keratectomy (PRK) [25] and epi-LASIK (the technique is basically an automatic LASIK without alcohol) slightly weaken the biomechanical properties of the cornea [25]. However, one drawback of these operations is the risk of subepithelial fibroplasia (SEF) of the cornea, accompanied by violation of its transparency in the ablation zone and regression of refractive effect. As a result of these interventions shell Bowman is destroyed (BO), taking part in the re-epithelialization of the cornea, but it is not able to regenerate. BO attached stromal collagen fibrils, which become part of the front stromal plates [26]. Also during PRK, LASIK and epi-LASIK the destruction of the basement membrane (BM) takes place, which is located anterior to Bowman's membrane. Lack of BM leads to ingrowth of epithelial cells in the anterior stroma and causes the formation of late epi-stromal fleur [27]. LASIK has distinct advantages over surface ablation due to the rapid recovery of visual function, less regression refractive effect, the absence of postoperative haze (SEF), minimal risk of infection and the absence of pain and discomfort in the postoperative period [8, 10, 28, 2, 11] Shown, for example, that the results of LASIK are significantly more predictable in comparison with PRK. Thus, after LASIK, 8 out of 10 eyes can obtain emmetropia or refraction in the range of ±2 diopters, and after PRK – only 3 out of 10 eyes [15]. An important feature of LASIK is that the epithelium, Bowman's layer, a significant portion of the nerve plexus and corneal nerves are preserved in the corneal hinge. Furthermore, the flap comprises Schwann cells that contribute to the process of restoring the nerves of the cornea. Regeneration comes from the edge to the center of the ablation zone [29].

While there are different types of procedures LASIK, such as standard, wavefront LASIK, IntraLase – Lasik they all stem from the invention of microkeratome and constantly evolving.

Currently one of the most promising technologies of optimized correction is aspheric personalized ablation, combining the advantages of both technologies excimer laser correction: the first is the implementation of individualized ablation that leads to the elimination of the initial higher-order aberrations of the eye. The second advantage is the preservation of the aspheric shape of the cornea, which is the prevention of postoperative induced spherical aberrations [30, 31, 32, 33, 34]. According to several authors, performance aspheric ablation in eyes with high myopia does not lead to the expected reduction of induction of spherical aberration and therefore the usefulness of it is not obvious. According to other authors perform once of customized corneal ablation is justified only if there is an initial high eye's HOA. Also, studies have determined that there is no dependence of values of higher-order aberrations on the degree of myopia; optimized ablation of the cornea does not lead to any significant increase in visual acuity compared with standard correction; when correcting high myopia according to standard and after LASIK optimized aspheric identical high value. It is also known, that customized aspheric ablation leads to greater consumption of corneal tissue during ablation compared to standard and tissue-preserving techniques. Performing of individualized aspherical ablation (technology Wavefront) is advisable in patients with mild to moderate myopia at the value of the fourth order spherical aberration more-0, 05 microns irrespective of the initial level of higher order aberrations of the eye [35], as well as mild to moderate myopia power, combined with astigmatism. The IntraLase – Lasik technology also appeared in recent years, based on the formation of the corneal flap for infrared light beam (femto-second- is a quadrillion part of a second), just separating the tissue through a process called photo gap, when laser pulses separated tissue at the molecular level without heat transfer effects on the surrounding tissue [12]. At the core of photo gap lies induced laser optical decay, which ends when strictly focused ultra-short laser pulse duration (600-800 femtosek) produces plasma. Plasma expands with supersonic speed, gradually replacing the shock waves of the surrounding tissue. After cooling of the plasma chamber is formed bladder, at the same time evaporates small piece of tissue (less than 1 micron), and the remaining bubble evacuated via endothelial pump or lifting the flap. Numerous studies have demonstrated an inflammatory response in the interface caused by the absorption of high-energy laser and a gas diffusion [36, 37, 38]. Increased hyper-reflexivity cornea revealed more than 25% of the formation of the flap. This leads to increased pain and delay vision recovery [Jean-Marc Ancel MD, Ocular Surgery News Europe Edition, September 2010]. Possibly lower energy exposure levels and improvement of femtosecond lasers will lead to a less pronounced inflammatory infiltration along the incision [39]. In addition, existing today femtosecond lasers do not allow to accurately predict the thickness of the flaps. Initial data on the use of femtosecond laser (Intra-Lase FS) in clinical practice have been collected in the U.S.A. in May 2000, showed no postoperative complications [13, 40]. Later, however, there were reports of the appearance of sporadic cases of sudden increase sensitivity in patients 4-6 weeks after IntraLase – Lasik. This syndrome was named - transient light sensitivity syndrome (TLSS). Such patients do not change visual acuity, no symptoms of inflammation in the cornea biomicroscopy. All patients have a good response to steroid topical therapy. Etiology of this syndrome is unknown, but studies showed the presence of activated keratocytes in the interface. Researchers believe that this inflammatory response may be associated with the spread of shock waves and the influence of high energy keratocytes and nerve endings in the formation of a flap with femtosecond laser [41].

No exact data on the possibility of reoperation after femtosecond laser (lift the corneal flap may be difficult due to less frequent flap surface, less smooth cut surface, the presence of peel tissue bridges makes lifting of flap more complicated and traumatic). The introduction of femtosecond lasers in clinical ophthalmological practice opened great prospects for the formation of ultra-thin, uniform, and most importantly, predictable thickness corneal flap, providing maximum safety and accuracy of refractive surgery. Currently, however, refractive surgeons are not ready to completely replace the mechanical microkeratome to femtosecond laser. Comparative analysis of clinical and functional parameters revealed no statistically significant differences between visual acuity and the residual component of refraction to patients in groups femtoLASIK and LASIK. Data, obtained using the analytical biomechanical properties of the eye, show equivalent negative impact of both methods on the biomechanical properties of the cornea. Femtosecond laser creates a thin, uniform corneal flap, in accordance with the specified parameters [42, 43]. Visual inspection of the vacuum and the individual selection of the parameters of a corneal flap with a femtosecond laser application significantly reduces but does not eliminate the risk of intraoperative complications [44]. Numerous studies have shown similar efficacy of femtosecond laser and mechanical keratome in the conduct of refractive laser correction [45, 38, 46]. Refractive results revealed no obvious advantages of IntraLASIK in comparison with LASIK, to 6-12 months after surgery, a statistically significant difference was not determined [47]. Should be noted that a new generation of mechanical microkeratome, such as Moria One Use Plus, XP (Tehnolaz) and ML7 (MED-LOGICS) can get even thinner flaps (90-80 microns) using a blade CLB (-30 microns), whereas, the thickness of the flap, produced using IntraLase (AbbottMedicalOptics), – at least 110 microns. Using mechanical microkeratome is possible to form a smooth cut surface. Cavitation bubbles (remaining after the formation of the flap with femtosecond laser) in 10-20% of cases make it impossible to iris pattern recognition, which is necessary for the laser tracking system for the movement of the eye during surgery.

Application of modern excimer laser systems allows using standard methodology LASIK to correct refractive errors in most cases with maximum preservation of corneal tissue (residual stroma, which is necessary for the conservation of the biomechanical stability of the cornea and the prevention of iatrogenic ectasia, and save reserve for possible reintervention). However, there are certain categories of patients for whom to conduct standard technologies is not possible due to insufficient thickness of the cornea. For correcting refractive errors in these patients developed aspheric ablation technique to allow a thrifty cornea ablation. The essence of this method is that in the program for the calculation of operations on spherical ablation parameters of the operation optic zone are set, the radius at which the sphericity is retained in the central zone of the cornea (from 4.0 to 6.0 mm) and the size to which occurs the linear decrease in the refractive effect (0 to 1.0). It should be noted that it smaller size and the radius to which there is a decrease of sphericity, the smaller is the thickness of the removed layer of cornea, and the greater number of diopters can be corrected. This technology combines perfectly with the procedure of forming ultrafine corneal flap, resulting in significantly reduced risk of postoperative ectasia. In general, this technique allows extending the indications for surgery in high myopia combined with thin corneas, to achieve the highest possible functional outcome and quality of vision.

Optical zone – a zone of corneal ablation in which is predicted a complete correction of ametropia. The difference between the pupil diameter and the diameter of the optic zone leads to the type of halo effects disorders, reduction of the contrast sensitivity [48, 49, 50]. The impact of a wide pupil and a small optical zone on the retinal image has been proved theoretically and in practice by many authors [48, 51, 52, 53, 54, 55]. It was made possible to increase the optical zone of 6 mm in cases of medium and high degrees of myopia, with the introduction into practice a flying spot laser, and modern lasers around the optical zones form a transition zone connecting the ablated and not ablated zone of cornea. Fractional clearance (FC) was calculated by the formula (1.1):

$$FC = \frac{\text{programmed optical zone diameter (mm)}}{\text{(Scotopic) pupil diameter (mm)}} \quad (1.1)$$

If FC is less than 1, the optical zone of the pupil diameter is less and vice versa. Many studies show that not the pupil diameter, but the relation between the planned diameter of the optical zone and the diameter of the pupil in scotopic conditions must be taken into consideration before refractive laser correction. Creating a wide enough ablation zone permits to avoid the disorders of halo effects type. However, it should be noted that the formation of a wider optical zones need more ablate corneal tissue. Accordingly to save corneal tissue must be combined the formation of a wider optical zones with forming a thin flap.

It should be noted that using LASIK can be achieved best corrected visual acuity 1.0. However, there are cases of overcorrection, which cannot be fully considered as a complication, since myopia combined with thin corneas initially such a result is considered more advantageous for a long term (due to the possible effects of late regression of the refractive effect). It is known that the refractive effect after LASIK procedure is sufficiently predicting [21]. At the same time in literature there is evidence that prolonged wearing of contact lens plays an important role in changing keratotopography, thickness and refraction of the cornea, and reduces predictability of the refractive error rate increases [56, 57].

One of the important advantage of photorefractive operations is to improve the visual quality and capacity [58, 59, 60]. It was proved that after photorefractive operations there is no significant change in the state of neuro-receptor visual analyzer but frequency-contrast sensitivity significantly increases in the high and medium spatial frequencies [43]. Disorder of contrast sensitivity in the range of frequencies takes place in case of amblyopia of different genesis [61], therefore increasing the frequency-contrast characteristics and improving vision after refractive surgery and conservative treatment is very important for recovery of patients with refractive errors, complicated by amblyopia [62, 63, 64]. In the literature there are reports that show that after LASIK with a thin flap, takes place an improvement of test results in contrast sensitivity [65]. Other authors cite these studies comparing the results of interventions with a thin flap LASIK and PRK, which showed no difference in postoperative contrast sensitivity. Researchers noted a tendency to increase the total higher-order aberrations in both groups, and there was no significant difference between the groups, similar trends were observed in the sphere and coma [66].

Corneal refractive interventions change the size and quality of the retinal image. The size of the retinal image in contact lens is bigger than in spectacles. Refractive operation leads to the formation of the retinal image, close in quality to the results of contact lens. Retinal image size with spectacles correction, compared with increases of refractive correction by 14 3% of its definition (retinal image) of 10.6%. Retinal illuminance increased at an average of corneal correction of 4.5%. Increasing the size and clarity of the retinal image can be regarded as factors positively influencing the visual acuity in myopes [67].

The stability of refractive result largely depends on the stability of myopia before the correction, depends on the accommodative capacity of eyes, as well as the biomechanical properties of the cornea. After refractive laser correction (ablation) is formed optical zone in the center of the cornea and the peripheral zones of the cornea remain intact. Consequently, in the central (macular) hyperopic defocus formed – by flattening the cornea and in the mid-periphery – myopic defocus due to refraction through the peripheral intact zone of the cornea. Theoretically, the absence of progression of myopia after laser refractive operations is consistent with the hypothesis put forward 40 years ago by Hoogerheide et al. and remain relevant in our time [29, 68, 69]. This theory highlights the role of myopic defocusing formed on the retina and leads to emmetropization of the eye. Another fact which explains the stability of the refractive effect is that after laser refractive correction of myopia, accommodation mechanism starts to work intensively due to increased load on the ciliary muscle. As a result, the three months after surgery reserve of relative accommodation doubled. These data suggest that the enhancement of accommodation helps prevent myopia progression by removing the most important link of the pathogenesis of myopia, weakness of accommodation. Formed by refractive intervention emmetropia increases efficiency of ciliary muscle, normalizes relations between accommodation and convergence. Data on the causes of regression of refractive effect are in described literature and include: an atypical healing, properties of accommodation, change in the biomechanical properties of the cornea [70].

Conclusion

Summarizing the analytical review of modern methods of correction of myopia and astigmatism it should be noted that the technique with a thin flap LASIK preserves natural balance of anatomical structures of the cornea, significantly reduces postoperative recovery period, reduces the incidence of complications, in some cases, provides an opportunity to reoperation in case of regression of refractive effect, thereby opening up new opportunities for the correction of myopia and astigmatism.

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