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Modern approaches to calculating parameters for laser vision correction

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Abstract: This article examines existing technologies for calculating the parameters of laser vision correction. Achieving optimal results requires considering corneal characteristics, including its shape, thickness, and specific refractive abnormalities. The objective of this study is to analyze the methods used to determine laser correction parameters.

Techniques such as optical coherence tomography, confocal microscopy, and multilayer corneal structure analysis provide a comprehensive assessment of its condition, allowing for the consideration of refractive disorders such as myopia, hyperopia, and astigmatism in determining laser exposure parameters.

The study demonstrates that technologies utilizing mathematical modeling enhance the accuracy of treatment outcome predictions. Three-dimensional corneal geometry analysis contributes to the predictability of surgical outcomes and minimizes the risk of complications. These methods pave the way for more effective vision correction techniques, positively impacting patients' quality of life.

The presented material will be valuable to ophthalmologists and developers of laser surgery equipment. The findings confirm the necessity of implementing methods based on individualized laser exposure calculations, as these technologies enable advancements in vision surgery and contribute to improving the quality of medical services.

Keywords: Laser vision correction, corneal topography, laser ablation, ocular biometry, optical coherence tomography, mathematical modeling, treatment individualization, ophthalmology.

Introduction: Laser vision correction plays a significant role among methods for eliminating refractive errors. The effectiveness of these procedures is determined by the precision of laser exposure parameter calculations, which require consideration of factors such as corneal shape, thickness, and the anatomical features of the eyeball.

A personalized approach necessitates a meticulous calculation of exposure parameters with a focus on the anatomical characteristics of each patient. This helps reduce the likelihood of complications and improve the quality of functional outcomes. The use of topographic analysis methods, biometric measurements, and modeling enables the prediction of surgical results by adapting parameters to individual characteristics. Despite advancements in the field, the need remains for the development of new methods to enhance procedural accuracy.

Laser vision correction represents a medical field where modern diagnostic techniques are being developed, and advanced surgical technologies are being implemented. Scientific studies in this area can be categorized into several groups: methods for myopia correction, techniques for astigmatism treatment, approaches for intraocular lens parameter calculation, and strategies for treating corneal diseases using innovative tools.

Research focused on the treatment of myopia and astigmatism emphasizes a personalized approach to therapy. In a study by Zainutdinov N. N., Kamilov H. M., and Kasimova M. S. [1], the use of phakic intraocular lenses for correcting high myopia is examined. The study highlights the necessity of selecting individualized parameters that account for each patient's condition.

Another study, conducted by Bikbov M. M. et al. [2], investigates methods for addressing residual astigmatism following cataract surgery. The research focuses on surgical techniques and the selection of optical parameters that minimize the risk of undesirable outcomes.

In a publication by Belikova E. I. et al. [3], the features of laser myopia correction in patients whose professional activities involve continuous visual strain are explored. The study underscores the importance of considering accommodative characteristics during surgical planning to prevent adverse effects.

Studies on intraocular lens parameter calculations propose advanced approaches to minimizing errors. Research by Holladay J. T. et al. [5] examines statistical data processing techniques that reduce the likelihood of errors in lens selection.

Wendelstein J. et al. [6] examine the effectiveness of methods used for selecting lens parameters in individuals with a short axial length of the eye. The study highlights techniques that consider the anatomical features of the visual system to improve outcomes.

Scientific publications demonstrate the implementation of new technologies for diagnosis and treatment. The review by Shang H., Liu C., and Wang R. [4] presents the potential application of computer vision to achieve precise corneal surface measurements. This technology enhances procedural accuracy and facilitates treatment planning.

Another study by D'Oria F. et al. [7] explores combined approaches for treating corneal pathologies. The publication provides a detailed description of methodologies that integrate corneal cross-linking with the implantation of corneal segments, improving their effectiveness.

Source [8], published on the official website of Russian Ophthalmology, presents calculations related to laser vision correction. The obtained data were used to describe the practical aspects of the procedure.

The reviewed studies identify several unresolved challenges. These include the need to establish standards for a personalized approach, improve methods for calculating lens parameters, and refine algorithms for the practical application of innovative technologies. Despite significant progress, further research is required to integrate new methodologies into clinical practice.

The objective of this study is to analyze the methods used to determine laser vision correction parameters.

The practical significance lies in the fact that the implementation of the proposed approaches contributes to better patient preparation and the selection of treatment parameters based on anatomical characteristics. This enhances procedural accuracy, reduces the risk of complications, and improves treatment outcomes.

The scientific novelty of the study lies in the development of a methodology for calculating laser vision correction parameters. The proposed approach expands the scope of laser correction applications and increases its effectiveness for patients with non-standard vision parameters, such as thin corneas or complex aberrations.

The working hypothesis states that the effectiveness and safety of laser vision correction can be improved through a combined approach that considers both the optical characteristics of the eye and the biomechanical properties of the cornea in dynamic conditions.

The methodology is based on a comparative analysis of domestic and international scientific publications.

RESULTS

Excimer laser-based vision correction remains a crucial aspect of ophthalmology. Advancements in techniques focus on optimizing laser exposure and developing new computational algorithms necessary to achieve stable outcomes. The correction of refractive errors, such as myopia, hyperopia, and astigmatism, requires consideration of multiple factors, including the anatomical characteristics of the eye, pupil reactions, and corneal properties.

Laser vision correction relies on a vast amount of data obtained through high-precision diagnostic equipment. Modern approaches prioritize procedure personalization. Mathematical models based on wavefront analysis and optical concepts play a significant role in these calculations [1, 5, 7]. Figure 1 below presents the approaches used for calculating laser vision correction parameters.

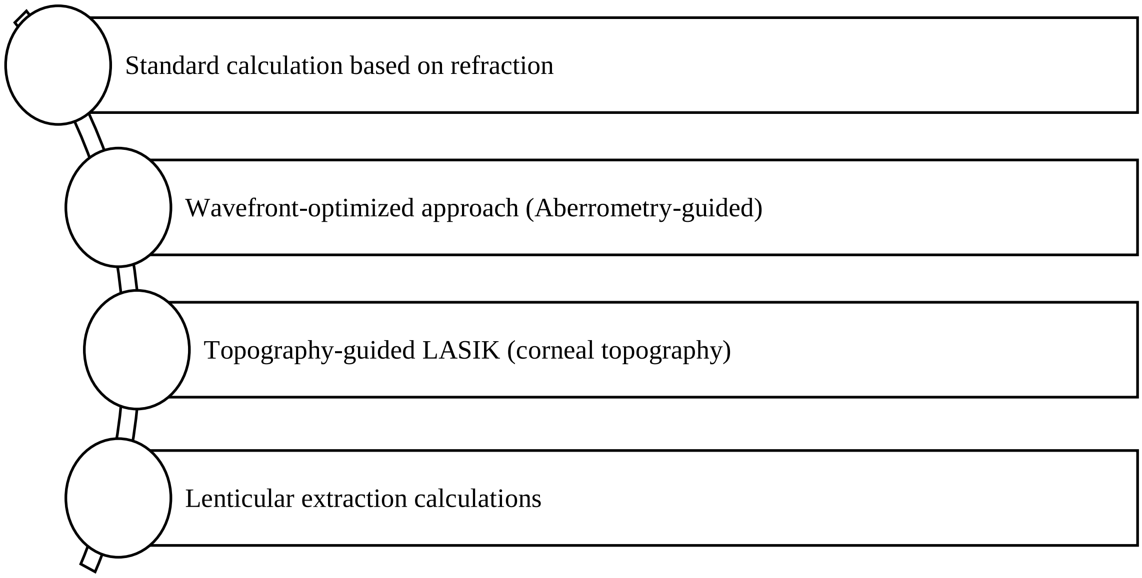

Fig.1. Approaches to calculating the parameters of laser vision correction [1, 5, 7].

Application of Wavefront Technology. This method allows for the analysis of light propagation through the optical media of the eye, identifying defects that require individualized correction. The use of this technology enables the elimination of refractive abnormalities and enhances visual quality after surgery.

Special attention is given to optical defects associated with various components of the ocular system. Accounting for these factors improves the accuracy of results.

Corneal Topographic Analysis. Corneal topographic analysis is a critical diagnostic tool used to evaluate the surface geometry of the cornea. By examining the corneal surface, clinicians can precisely identify laser impact zones and calculate procedural parameters for refractive surgeries, such as LASIK or PRK. This process involves the generation of detailed corneal maps, which provide a comprehensive visualization of the cornea's curvature, elevation, and thickness. These maps enable the incorporation of individual anatomical characteristics, ensuring a personalized approach to treatment planning. The ability to account for unique corneal features, such as irregularities, astigmatism, or ectatic conditions, enhances the accuracy and safety of laser-based interventions, ultimately optimizing visual outcomes.

Optical Coherence Tomography (OCT). This imaging technique is used to analyze ocular structures, including the cornea, retina, and optic nerve. The method is based on low-intensity infrared radiation and the interference of reflected signals. In laser vision correction, OCT enables the precise measurement of corneal parameters, characteristics, and unique features while also diagnosing pathologies such as keratoconus or corneal thinning. The obtained results are utilized in laser exposure calculations, ensuring a predictable outcome with a minimized risk of complications.

Confocal Microscopy. This technique is used to study the cellular structure of ocular tissues, allowing for the assessment of epithelial and stromal layers, cell distribution, and pathological changes. During the preparation for laser vision correction, this approach helps determine tissue condition and evaluate regenerative capacity following the procedure [2, 3, 4]. Table 1 below outlines the stages involved in calculating laser vision correction parameters.

Table 1. Stages of Calculating Laser Vision Correction Parameters [2, 3, 4].

Stage	Key Features	Indications	Method Advantages
1. Initial Consultation	Medical history collection, visual acuity assessment, identification of refractive errors, detection of contraindications.	Myopia, hyperopia, astigmatism, stable refraction (at least 1 year).	Personalized approach, risk minimization.
2. Instrumental Examination	Keratotopography, corneal thickness measurement (pachymetry), anterior-posterior axis assessment (AXL).	Suitable for patients with adequate corneal thickness and no corneal pathology.	High diagnostic accuracy reduces complication risks and enhances effectiveness.
3. Calculation of Procedure Parameters	Utilization of computer algorithms and diagnostic data to model laser exposure.	For patients with unique corneal structural features.	Personalized calculations, high precision, minimized errors.
4. Preoperative Preparation	Prescription of eye drops for corneal hydration, discontinuation of contact lens use 1-2 weeks before the procedure.	Recommended for all patients before surgery.	Optimizes corneal condition for optimal surgical outcomes.
5. Laser Vision Correction	Corneal tissue ablation under laser control (LASIK, SMILE, PRK methods).	Suitable for myopia up to -12D, hyperopia up to +6D, astigmatism up to ±6D.	Rapid and safe procedure with minimal tissue trauma.
6. Postoperative Monitoring	Regular check-ups to assess recovery, prescription of anti-inflammatory and hydrating eye drops.	Patients who have completed vision correction.	Ensures eye health, prevents complications, and maintains stability.

The success of vision correction is determined by the precision of calculations and the influence of external and internal factors on the eye's condition after surgery. Laser exposure induces changes in corneal tissue, including its geometric and structural properties. The prediction of these processes is achieved using hybrid models that account for all significant parameters.

To enhance calculation accuracy, data on corneal thickness, elasticity, and tissue response are utilized. This approach helps prevent complications.

Corneal thickness plays a crucial role in surgical planning. Modern technologies accurately measure this parameter, ensuring precise laser exposure and reducing the likelihood of adverse effects.

A personalized approach to laser vision correction is becoming a standard in ophthalmological practice. The use of data on the anatomical characteristics of the eyeball and the patient's genetic predispositions enables the development of individualized surgical plans.

Genetic factors influencing corneal condition are considered in outcome predictions. Integrating this data into computational algorithms improves the accuracy of results.

The postoperative period requires thorough monitoring of corneal condition. Modern systems allow real-time tracking of changes and adjustment of the recovery process [1, 3, 5, 7]. For instance, trackers integrated into laser systems detect even the slightest eye movements with high speed, automatically adjusting the laser beam position. This ensures precise corneal ablation, even if the patient cannot maintain a completely steady gaze. After the procedure, monitoring systems track the recovery process, analyzing dynamic changes in corneal parameters. Table 2 below describes the approaches used to calculate laser vision correction parameters.

Table 2. Approaches to Calculating Laser Vision Correction Parameters [1, 3, 5, 7].

Method	Procedure Features	Advantages	Disadvantages	Future Trends
LASIK	Creation of a corneal flap using a mechanical microkeratome, followed by excimer laser reshaping of the cornea.	Fast recovery, minimal discomfort after surgery, stable results.	Risk of complications due to improper flap formation, not suitable for patients with thin corneas.	Development of automated AI-based algorithms for parameter calculation and improved procedural safety.
Femto-LASIK	A femtosecond laser is used to create the flap instead of a mechanical microkeratome, followed by excimer laser reshaping of the cornea.	Increased precision and safety, suitable for patients with thin corneas, shorter recovery time.	Higher cost compared to LASIK, potential.	Integration with diagnostic platforms for full procedure personalization.
Super-LASIK	Customized correction program based on individual corneal anatomy, corneal reshaping with an excimer laser.	Personalized approach, improved visual quality, ability to correct higher-order aberrations.	Requires longer diagnostic procedures, higher cost.	Development of more precise corneal scanning technologies and the implementation of neural networks for data analysis.
Photorefractive Keratectomy (PRK)	Removal of the superficial corneal epithelial layer without flap formation, followed by excimer laser reshaping of the cornea.	Suitable for patients with thin corneas where other methods are contraindicated.	Longer healing time, postoperative discomfort, risk of corneal haze.	Development of new corneal epithelial materials to accelerate regeneration after the procedure.

The process of determining the calculated value of laser correction in Femto-LASIK for patients with mild to moderate hyperopia to achieve the target refraction is examined.

One of the key conditions for achieving high clinical outcomes in Femto-LASIK for hyperopic patients is reaching a postoperative target refraction within the range of -1.0 to +1.0 D [8]. The optimal target refraction for hyperopic patients aged 25 to 30 years was defined as a postoperative clinical refraction value under pharmacological cycloplegia ranging from 0 to 0.5 D.

To achieve optimal target refraction in Femto-LASIK for patients with mild to moderate hyperopia, a formula for calculating the required laser correction must be developed, taking into account the clinical refraction values obtained under pharmacological cycloplegia before the procedure. To determine this calculation formula, a retrospective analysis of Femto-LASIK outcomes was conducted in Group 1, which included 233 patients with mild to moderate hyperopia (233 eyes). The mean spherical equivalent of refraction under pharmacological cycloplegia was 3.5±1.2 D (M±σ). Figure 2 presents the distribution of target refraction values after Femto-LASIK in patients of Subgroup 1 (116 eyes, absolute success) and Group 2 (99 eyes, relative success).

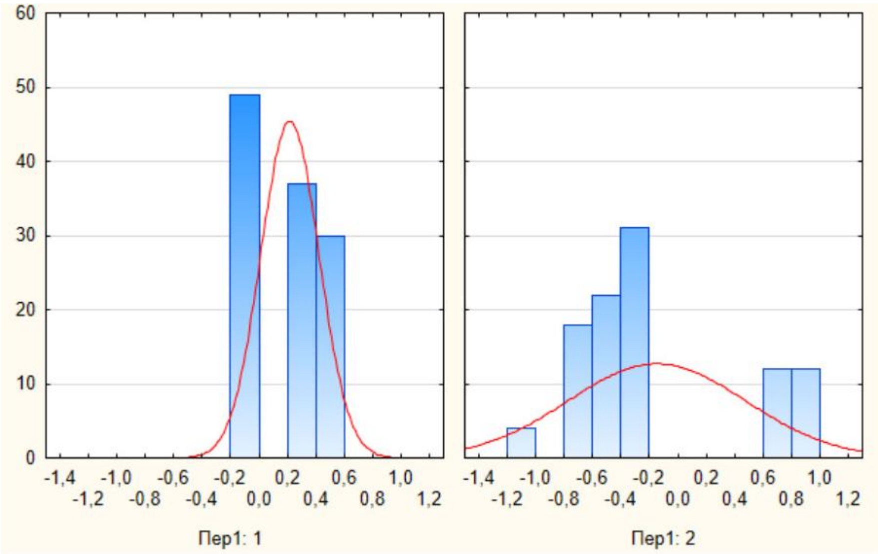

Fig.2. Distribution of target refraction values after Femto-LASIK surgery in patients of Subgroup 1 (116 eyes, absolute success) and in patients of Group 2 (99 eyes, relative success) [8].

Figure 3 illustrates the distribution diagram of values for achieving target refraction in Subgroup 1 (absolute success) and Subgroup 2 (relative success).

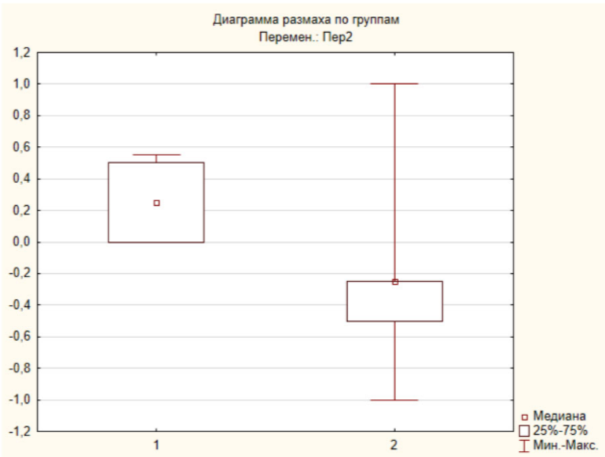

Fig.3. A diagram of the distribution of values for achieving target refraction in the subgroup with absolute success (1) and in Subgroup 2 (2) with relative success [8].

To determine the formula for achieving optimal target refraction, clinical and functional outcomes of Femto-LASIK in 116 patients of Subgroup 1 (116 eyes) were analyzed. These patients achieved the target refraction of 0 to 0.5 D within 1–3 months postoperatively. Based on this analysis, the following formula was developed:

$$Rf_{target} = Rf_{m.c.} - \Delta K$$

Where:

- Rf_{target} — achievement of the required level of target refraction;
- $Rf_{m.c.}$ — initial clinical refraction values under pharmacological cycloplegia before surgery;
- ΔK — keratometry change [8].

Thus, the specific features of calculating laser correction parameters using the Femto-LASIK technology for patients with mild to moderate hyperopia, aimed at achieving precise target refraction, have been examined. The developed formula accounts for keratometric changes and minimizes errors associated with accommodation, thereby enhancing procedural accuracy.

The proposed method for determining laser vision correction parameters is implemented through structured stages, each designed to address specific tasks. The diagnostic stage includes corneal assessment, analysis of optical tissue characteristics, and the detection of aberrations using wavefront analysis techniques. Special attention is given to cases involving anatomical corneal features that complicate the application of standard calculation approaches.

The final stage focuses on verification and adaptation of calculations. The methodology is based on modeling data and previous scientific studies, allowing for adaptation to various clinical cases, including adjustments for patients with unique anatomical features. The application of this method expands access to vision correction procedures for patients who were previously ineligible for such interventions.

Laser vision correction relies on a comprehensive approach that integrates mathematical modeling, diagnostic data analysis, and individual patient characteristics. Modern techniques ensure calculation precision, procedural safety, and predictable outcomes. This approach improves treatment quality.

CONCLUSION

This study examined existing algorithms that incorporate corneal topography, biometric diagnostics, and mathematical modeling. The findings demonstrate high efficiency in selecting laser exposure parameters, improving the accuracy of surgical outcome predictions.

Technologies such as optical coherence tomography and multilayer corneal surface analysis enhance the diagnostic process by considering all relevant aspects for ablation modeling. This approach reduces the likelihood of complications and facilitates vision restoration for various types of refractive disorders. Collecting data on corneal parameters, including shape and thickness, allows for precise treatment planning tailored to each patient's characteristics.

The conclusions focus on improving methods for calculating laser exposure parameters. The advancement of technologies contributes to the development of tools for accurate ablation parameter selection, thereby enhancing treatment quality and ensuring patient comfort.

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