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COMMENTARY

Recent Advances in Refractive Surgery: An Overview

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Abstract: Refractive surgery has experienced substantial advancements over the past few years, driven by innovative techniques and continuous technological progress aimed at enhancing visual outcomes and patient satisfaction. Refractive errors such as myopia, hyperopia, and astigmatism affect a significant portion of the global population, impacting quality of life and productivity. Recent advancements have been fueled by a deeper understanding of ocular biomechanics and visual optics, leading to more precise and effective treatments. Traditional methods such as LASIK and PRK have been refined, and new procedures like SMILE (Small Incision Lenticule Extraction) have been introduced, expanding the range of treatable refractive errors and improving safety and predictability. Customized treatments, such as wavefront-guided LASIK and topography-guided PRK, allow for individualized plans tailored to each patient's unique corneal characteristics, enhancing visual acuity and reducing higher-order aberrations. The use of femtosecond lasers in procedures like Femto-LASIK and femtosecond laser-assisted cataract surgery (FLACS) offers unparalleled precision, reducing surgical risks and improving outcomes. Implantable Collamer Lenses (ICLs) and corneal crosslinking (CXL) have emerged as effective options for specific patient groups. Advanced diagnostic tools like optical coherence tomography (OCT) and Scheimpflug imaging have improved surgical planning and complication management. As research and technology continue to evolve, these advancements promise even greater improvements in refractive surgery, addressing the visual needs of the global population.
Keywords: refractive surgery, LASIK, PRK, SMILE, wavefront-guided LASIK

Refractive surgery has seen substantial advancements over the past few years, driven by innovative techniques and continuous technological advancements aimed at enhancing visual outcomes and patient satisfaction.[1] The importance of refractive surgery cannot be overstated, as refractive errors—such as myopia, hyperopia, and astigmatism—affect a significant portion of the global population, impacting quality of life and productivity. Recent advancements in refractive surgery have been fueled by a more profound and improved understanding of ocular biomechanics and visual optics, leading to more precise and effective treatments.[2] Traditional methods, such as LASIK and PRK, have been refined, and new procedures, such as SMILE (Small Incision Lenticule Extraction), have been introduced. These innovations have expanded the range of treatable refractive errors and improved the safety and predictability of outcomes.[3]

One significant development in refractive surgery is the advent of customized treatments. Technologies like wavefront-guided LASIK and topography-guided PRK allow for individualized treatment plans tailored to each patient's unique corneal and refractive characteristics.[4] These personalized approaches have been shown to enhance visual acuity, reduce higher-order aberrations, and improve overall patient satisfaction compared to conventional methods. Another breakthrough is the use of femtosecond lasers, which offer unparalleled precision and control during surgical procedures. Femtosecond laser-assisted cataract surgery (FLACS) has revolutionized cataract surgery by enabling precise capsulotomy, lens fragmentation, and corneal incisions. This technology reduces surgical risks, enhances visual outcomes, and shortens recovery times, making it a valuable tool in modern ophthalmic surgery.[5] In the realm of refractive surgery, Femto LASIK (Femtosecond LASIK) represents a significant leap forward. Unlike traditional LASIK, which uses a microkeratome blade to create the corneal flap, Femto LASIK employs a femtosecond laser, allowing for more precise

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and safer flap creation. This method enhances the accuracy of the flap's dimensions and thickness, improving visual outcomes and reducing complications.[6]

SMILE (Small Incision Lenticule Extraction) is another cutting-edge procedure that has gained popularity. SMILE involves the creation of a small incision in the cornea and the extraction of a lenticule (a small piece of corneal tissue) using a femtosecond laser. This minimally invasive technique preserves corneal biomechanics better than traditional LASIK and is associated with less postoperative discomfort and faster recovery times.[7] SILK (Small Incision Lenticule Keratomileusis) Elita is a further refinement in the field, combining elements of both SMILE and LASIK. SILK Elita aims to provide the benefits of SMILE's minimally invasive approach while incorporating advanced customization techniques similar to wavefront-guided LASIK. This hybrid technique shows promise in offering highly precise corrections with minimal invasiveness, potentially improving patient outcomes even further.[8] While SMILE has gained popularity as an alternative to LASIK, its clinical and biomechanical superiority over LASIK, whether performed with a femtosecond laser or a mechanical microkeratome, remains under debate. Clinical recovery after SMILE is generally slower than LASIK, and the assumption that SMILE preserves corneal biomechanics better is not conclusively supported. This is largely because the residual stromal bed (RSB) in SMILE tends to be thinner than in LASIK, raising concerns about long-term corneal stability. Therefore, it would be an overstatement to claim that SMILE is categorically superior to LASIK in all cases. The choice between SMILE and LASIK should be based on individual patient factors, including corneal thickness, refractive error, and the patient's visual needs, rather than assuming one technique is universally better than the other.[9] One of the previous studies compared the incidence of dry eye disease (DED) and corneal sensitivity (CS) in myopic patients after Femto LASIK and SMILE and concluded that on while both FS-SMILE and FS-LASIK led to significant DED one month after surgery, the incidence and severity were lower in the FS-SMILE group. Additionally, corneal sensitivity was reduced more in FS-LASIK than FS-SMILE at one month postoperatively, though the difference was not statistically significant by six months. The study concluded that FS-LASIK has a more pronounced effect on both CS and DED compared to FS-SMILE, indicating a higher risk of DED following FS-LASIK.[10] Rattan et al compared the predictability and uniformity of corneal flap thickness between the Visumax femtosecond laser and the Moria sub-Bowman keratomileusis (SBK) microkeratome in LASIK procedures for correcting myopia and myopic astigmatism in 100 patients. Flap thickness was measured using anterior segment optical coherence tomography three months post-operatively. The results showed that the femtosecond laser group had an average central flap thickness (CFT) of 91.35 µm, with no significant difference between target and actual thickness. In contrast, the microkeratome group had a CFT of 102.18 µm, with significant differences in both target thickness and uniformity across the flap. The study concludes that femtosecond laser provides more predictable and uniform flap thickness compared to the SBK microkeratome.[11]

Implantable Collamer Lenses (ICLs) have also gained prominence as an effective alternative for patients unsuitable for corneal refractive surgery. ICLs are particularly beneficial for individuals with high refractive errors or thin corneas. Recent studies highlight the safety, efficacy, and long-term stability of ICLs, making them a viable option for achieving spectacle independence.[12] In the past three decades, ICLs have undergone significant advancements, particularly in lens design. One of the most crucial innovations has been the introduction of a central port, known as the KS-Aqua PORT, which allows aqueous fluid to circulate freely through the lens. This feature enables smaller vaults between the lens and the crystalline lens, effectively reducing the risk of cataract formation, a common complication associated with earlier ICL designs. These improvements have greatly enhanced the safety profile and efficacy of ICLs, making them a viable and popular option for refractive correction in patients with high myopia and other vision issues.[13]

Corneal crosslinking (CXL) has emerged as a crucial technique for managing keratoconus, particularly in the early stages of subclinical keratoconus and post-refractive surgery ectasia. By strengthening corneal collagen fibers, CXL halts the progression of these conditions and improves corneal stability. Combined with refractive procedures. This is particularly beneficial in cases where ectasia is suspected following laser corneal ablation, such as LASIK or PRK, where the cornea may become weakened. The procedure is relatively simple, involving the application of riboflavin (vitamin B2) drops followed by ultraviolet light exposure, which enhances corneal rigidity. Early intervention with CXL can preserve vision and prevent the need for more invasive procedures like corneal transplantation, making it a crucial tool in modern corneal therapy. CXL offers a comprehensive approach to treating complex cases, enhancing both visual acuity and structural integrity of the cornea.[14] Combining photorefractive keratectomy (PRK) with CXL offers a promising approach for managing keratoconus (KC). Topography-guided PRK aims to normalize the corneal surface by selectively ablating tissue based on detailed corneal maps, while non-topography-guided PRK follows a more standardized ablation pattern. Studies suggest that topography-guided PRK with CXL may result in better visual and topographic outcomes by reducing irregular astigmatism more effectively than non-topography-guided approaches. However, variations in study designs, patient selection, and follow-up durations contribute to the differences in reported outcomes. Further comparative studies are essential to establish the most effective strategy for stabilizing and improving vision in KC patients.[15] Combining CXL with ICL implantation has emerged as an effective strategy for a specific subset of KC patients. This approach stabilizes the cornea through CXL while correcting refractive errors with the ICL, thereby reducing the need for intrastromal corneal ring (ICR) implantation, which was previously the primary alternative to keratoplasty when corneal transplantation was not indicated. By addressing both biomechanical stability and refractive correction, this combined treatment offers a comprehensive solution, delaying or even eliminating the need for more invasive interventions like ICRs or keratoplasty.[16]

The integration of advanced diagnostic tools, such as optical coherence tomography (OCT) and Scheimpflug imaging, has further improved the precision of refractive surgery. These imaging modalities provide detailed corneal maps and ocular structures, aiding in the accurate assessment and planning of surgical interventions. They also enable the early detection of potential complications, ensuring timely management and better outcomes.[17] Advanced diagnostic tools like epithelial maps and the Corvis ST have become essential in the early detection and management of corneal conditions, particularly when differentiating between early keratoconus and corneal warpage. Epithelial mapping provides detailed information about the epithelial layer's thickness across the cornea, which is crucial for identifying subtle changes indicative of early keratoconus. This distinction is vital for determining the appropriate treatment approach, as keratoconus requires different management than corneal warpage, which is often related to contact lens wear. The Corvis ST, on the other hand, offers valuable insights into the biomechanical properties of the cornea, assessing its ability to withstand laser ablation during refractive surgery. By measuring corneal deformation in response to an air puff, Corvis ST helps predict how the cornea will behave post-surgery, reducing the risk of ectasia. Together, these tools enhance diagnostic accuracy and guide safer, more effective treatment planning.[18] Another study compared the epithelial thickness profile in 120 patients of dry eyes, keratoconus suspects and healthy subjects planned for refractive surgery. The authors found that epithelium tends to be thicker inferiorly in dry eye patients and thinner in keratoconus suspects. The displacement of the thinnest location on the epithelial map could serve as an early indicator of keratoconus. However, further follow-up studies are needed to validate whether this displacement consistently aids in the early diagnosis of keratoconus.[19] Patient education and postoperative care have also seen significant improvements, contributing to higher satisfaction rates. Advances in digital health technologies, such as telemedicine and mobile health apps, facilitate continuous monitoring and communication between patients and healthcare providers. These tools empower patients to actively participate in their care, ensuring adherence to postoperative instructions and early identification of issues. The recent advancements in refractive surgery have transformed the field, offering more precise, effective, and safer treatment options for patients with refractive errors. These innovations have improved visual outcomes and enhanced the overall quality of life for individuals, reaffirming the critical role of refractive surgery in modern ophthalmology. As research and technology continue to evolve, the future of refractive surgery holds even greater promise for addressing the visual needs of the global population.[20]

Importance of Refractive Surgery

Refractive Surgery Addresses Several Critical Challenges

First and foremost is the visual impairment. As millions suffer from refractive errors that impair daily activities. Surgical interventions offer a permanent solution, reducing dependency on corrective lenses. Next is the quality of life. Improved visual acuity post-surgery can significantly enhance quality of life, providing patients with greater freedom and confidence. Refractive surgery also has an economic impact. Reducing the burden of visual impairment can lead to economic benefits by improving productivity and reducing healthcare costs. This collection emphasizes the importance of tailoring surgical approaches to individual needs, leveraging advancements in intraocular lens (IOL) technology, and refining surgical techniques for better outcomes.[2]

This editorial aims to summarize the significant findings and trends from the recent collection of papers on refractive surgery, providing a cohesive overview of the key contributions and their broader relevance to the field. In this special issue, the article titled "Customizing Clinical Outcomes with Implantation of Two Diffractive Trifocal IOLs of Identical Design" explores the outcomes of trifocal IOLs, emphasizing the customization of visual outcomes to cater to individual patient needs. The study highlights the importance of precise IOL selection to optimize visual acuity across different distances. This is important as, in the current scenario, personalized IOLs can significantly improve patient satisfaction and visual performance. Developing more advanced and customized IOLs could lead to even better visual outcomes and broader applications for various visual impairments.[21]

The next article, "Comparison of Refractive Prediction Error by Axial Length in Flanged Intrascleral Intraocular Lens Fixation", by Kabata et al, evaluates the accuracy of refractive predictions using the SRK/T formula. The study found that the formula performs well across different axial lengths, indicating its robustness in various clinical scenarios. This is vital as accurate predictions reduce postoperative surprises, enhancing the trust and satisfaction of patients. Hence, continuous refinement of predictive models can lead to near-perfect accuracy in refractive surgeries, minimizing the need for corrective procedures.[22]

The next systematic review on "Corneal Collagen Crosslinking for Ectasia After Refractive Surgery: A Systematic Review and Meta-Analysis" provides a comprehensive review of corneal crosslinking (CXL) as a treatment for ectasia post-refractive surgery. The meta-analysis supports CXL's efficacy in stabilizing corneal structure and improving visual acuity. The importance of this article is that CXL provides a solution to a significant complication post-refractive surgery, preserving vision in affected patients. Moreover, enhanced CXL techniques and combined therapies could offer more robust and longer-lasting solutions for ectasia and other corneal conditions.[23]

Another important study on "Comparison of Distance-Based Uncorrected Visual Acuity Based on the Optical Profile of Same Platform IOLs" by Suzuki and Nishiyama, compares visual outcomes of different IOL designs within the same platform. The study underscores the impact of optical design on uncorrected visual acuity (UCVA) across various distances. The take-home message is that understanding the impact of IOL design on visual outcomes helps in better preoperative planning and patient counseling. Additionally, the development of IOLs with superior optical profiles could lead to universally better visual outcomes, reducing the variability seen with different designs.[24]

The next article on, "Angle Kappa is Not Correlated with Patient-Reported Outcomes After Multifocal Lens Implantation" investigates the relationship between angle kappa and patient satisfaction. The findings suggest that angle kappa does not significantly affect patient-reported outcomes, which is crucial for preoperative planning. This study helps refine patient selection criteria and preoperative assessments. Further research could develop more comprehensive models for predicting patient satisfaction, incorporating various ocular and psychological factors.[25]

The article "Ray-Tracing Customization in Myopic and Myopic Astigmatism LASIK Treatments for Low and High Order Aberrations" underscores the importance of automated ray-tracing customization in enhancing visual outcomes. This study demonstrates that using precise, individualized calculations based on detailed eye measurements can significantly improve visual acuity, and high-order aberrations can be minimized. This approach substantially advances LASIK surgery in the current scenario, providing more accurate and effective treatments. The continued development and refinement of ray-tracing customization techniques could lead to even better surgical outcomes and potentially expand the range of treatable refractive errors.[26]

Another interesting article in this special issue on, "Update on Femtosecond Laser-Assisted Cataract Surgery: A Review" reviews the latest advancements in femtosecond laser-assisted cataract surgery (FLACS). The review highlights the precision and safety improvements that FLACS offers over traditional methods. FLACS represents a significant technological advancement, offering better outcomes and fewer complications. Continued improvements in laser technology could make FLACS the standard for all cataract surgeries, further enhancing safety and efficacy.[27] The study on the "Long-Term Refractive Outcomes and Visual Quality of Multifocal Intraocular Lenses Implantation" explores the durability and visual quality of multifocal IOLs over an extended period. The study confirms the long-term benefits of multifocal IOLs in providing spectacle independence and satisfactory visual outcomes. This demonstrates the lasting benefits of multifocal IOLs, encouraging their use. The future innovations could improve multifocal IOLs to provide even better visual quality and adaptability to different lighting conditions.[28] The article on "The Effects of Implantable Collamer Lens (ICL) Implantation in High Myopia Patients' Mental Health" by Lin et al examines the psychological benefits of ICL implantation. The study found significant improvements in anxiety and depression levels post-surgery, emphasizing the holistic benefits of refractive surgery. This acknowledges the mental health benefits of refractive surgery, which is crucial for holistic patient care. Greater emphasis on mental health outcomes could lead to more comprehensive patient care models in refractive surgery.[29]

Refractive surgery addresses significant challenges related to visual impairments such as myopia, hyperopia, and astigmatism. The evolution of surgical techniques and IOL designs has enhanced visual outcomes and improved overall patient quality of life. The research papers in this collection collectively highlight the ongoing innovations and their implications.[1] Advances in IOL technology allow for personalized treatment plans catering to individual visual needs and lifestyle preferences. Accuracy and Predictability by improved predictive models and surgical techniques have reduced refractive errors, leading to higher patient satisfaction. Innovations such as femtosecond lasers and corneal crosslinking have enhanced refractive surgeries' safety profile and efficacy. The psychological and quality-of-life improvements post-refractive surgery underscore the importance of considering mental health in patient care.[30]

Future Directions

The field of refractive surgery is poised for further advancements. Critical areas for future research and development include continued refinement of predictive algorithms to reduce refractive errors further and improve surgical outcomes. Development of next-generation IOLs that offer even greater customization and improved visual quality across all distances.

Exploration of new surgical techniques that minimize invasiveness while maximizing safety and efficacy, leveraging AI to enhance preoperative planning, intraoperative guidance, and postoperative care.

Conclusion

The recent advances in refractive surgery highlighted in this collection demonstrate significant progress in both technological innovation and patient care. As the field continues to evolve, these studies provide a solid foundation for future research and clinical practice, aiming to enhance visual outcomes and improve the overall quality of life for patients undergoing refractive surgery. Continuous collaboration between researchers, clinicians, and industry will be crucial in driving these advancements forward and ensuring that the benefits of refractive surgery are accessible to all who need them.

Author Contributions

Both the authors made a significant contribution to the work reported, whether that is in the conception, editorial design, execution, acquisition of data, analysis, and interpretation, or in all these areas; took part in drafting, revising, or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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