

# Corneal biomechanical changes after myopic and hyperopic laser vision correction



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## HIGHLIGHTS

Laser refractive surgery procedures reduce the corneal biomechanical stiffness in a different way. Understanding of these biomechanical changes might improve the safety and efficacy of laser vision correction treatment planning.

## ABSTRACT

Laser vision correction became a popular method of refractive error treatment. The laser vision correction techniques influence the corneal biomechanical properties including corneal hysteresis and corneal resistance factor. The ocular response analyzer and Corvis ST devices are used in clinical practice to measure the corneal biomechanics. Reasonable laser treatment planning, taking into account the impact on corneal biomechanics, may potentially improve the safety of the refractive procedures. Thicker caps in refractive lenticule extraction and thinner flaps in flap-related procedures promote better corneal biomechanics preservation. The myopic refractive treatment appears to have a greater effect on corneal biomechanics weakening than hyperopic correction.

**Key words:** corneal biomechanics, corneal hysteresis, corneal resistance factor, laser vision correction, myopia, hyperopia, SMILE, LASIK, PRK

## INTRODUCTION

The corneal biomechanical properties define the corneal bio-elasticity, viscosity, stiffness and corneal response to applied force. The role of these parameters in laser vision correction is currently under research of numerous clinical and experimental trials. It is believed that the preoperative corneal biomechanics may influence the risk of postoperative complications such as corneal ectasia [1]. The change in biomechanical parameters after laser vision correction depends on many factors, including type and size of refractive error, type of refractive surgery procedure, flap thickness, cap thickness, residual stromal thickness. Understanding corneal biomechanics may facilitate the treatment planning, and potentially improve the safety and efficacy of the laser vision correction procedures. The ocular response analyzer (ORA) or Corvis ST provide the specific parameters of corneal biomechanics, including corneal hysteresis (CH), corneal resistance factor (CRF), first applanation time (A1T), highest concavity point (HC), stiffness parameter at the 1<sup>st</sup> applanation (SP-A1).

## CORNEAL BIOMECHANICS AFTER MYOPIC LASER VISION CORRECTION

The corneal refractive surgery procedures for myopia correction include photorefractive keratectomy (PRK), laser-assisted sub-epithelial keratectomy laser (LASEK), laser in situ keratomileusis (LASIK), femtosecond LASIK (FS-LASIK), and refractive lenticule extraction (SMILE). According to the current studies, the myopic laser vision correction results in the weakening of the corneal biomechanical strength measured by ORA and Corvis ST [1–10]. The current clinical trials and meta-analyses are mostly consistent in terms of higher postoperative reduction of CH and CRF parameters after LASIK/FS-LASIK than after SMILE and PRK in patients treated for myopia and/or myopic astigmatism [5, 11–16]. Nevertheless, there are controversies in terms of Corvis ST – derived biomechanical parameters post SMILE vs. FS-LASIK [1, 5, 16]. Some studies proved significantly stronger Corvis ST biomechanical parameters after SMILE than LASIK/FS-LASIK [5, 16]. In contrast, the meta-analysis by Guo et al. revealed no significant differences in Corvis ST corneal measurements between those two procedures [1]. The authors suggested that the interpretation of postoperative biomechanics may be biased by the magnitude of refractive error corrected, percentage of tissue altered, central corneal thickness, intraocular pressure, and age of the patients [2]. The independent reports on the results of corneal biomechanics after surface treatments (PRK/LASEK) compared to LASIK/FS-LASIK are mostly similar [5, 13, 17–20]. The postoperative values of CH and CRF are higher in patients following PRK/

LASEK than after LASIK/FS-LASIK [5, 13, 17–20]. In turn, the results of CH, CRF or Corvis ST biomechanical parameters, after PRK/LASIK versus SMILE, do not differ significantly [1, 21]. This outcome suggests a similar maintenance of corneal biomechanical strength, following PRK/LASIK and SMILE in comparable degree of myopia correction.

## THE IMPACT OF CAP THICKNESS ON CORNEAL BIOMECHANICS

Many clinical reports revealed that the increased cap thickness induces less corneal biomechanics, weakening the creation of the thinner cap [22]. The comparison of 140  $\mu\text{m}$  and 110  $\mu\text{m}$  cap in the study of Wu et al. or 160  $\mu\text{m}$  and 100  $\mu\text{m}$  cap in the study of El-Massry et al., showed higher postoperative corneal biomechanical strength in favor of thicker caps [23, 24]. The results are consistent with the experimental study by Randleman, which proved the higher tensile strength in the anterior stroma than in the posterior stroma of the cadaver eyes [25]. The above outcomes suggest the main role of the anterior stroma in the overall corneal biomechanical strength [25]. On the other hand, in patients treated for high myopia, increased cap thickness may result in the excessive reduction of posterior residual stromal thickness (RST) leading to unintended weakening of the cornea [26]. Thus, in higher degree of myopic refractive error, especially in myopic astigmatism, the cap thickness should be planned carefully. To confirm the role of cap thickness in the biomechanical strength of the cornea, further clinical studies should be performed, with unification of study groups and treatment parameters [26].

## THE IMPACT OF FLAP THICKNESS ON CORNEAL BIOMECHANICS

In the experimental study on human cadaver eyes, Knox Cartwright et al. investigated the influence of vertical side cuts, horizontal delamination incision and complete FS-LASIK flap creation on corneal biomechanical strength [4]. Each type of the corneal incision was performed in two variants of FS-LASIK flap thickness – 90  $\mu\text{m}$  and 160  $\mu\text{m}$  [4]. Authors reported that the corneal strength was significantly lower in eyes with 160  $\mu\text{m}$  flap thickness in comparison with 90  $\mu\text{m}$  flaps [4]. In addition, the study revealed that vertical side cuts cause more decrease in corneal strength than horizontal incisions [4]. Similar results were also obtained by other authors in the numerous clinical in vivo studies, confirming that corneal biomechanical parameters such as CH and CRF decrease significantly with the increase of LASIK-flap thickness [13, 21, 27–29].

## CORNEAL BIOMECHANICS AFTER HYPEROPIC LASER VISION CORRECTION

The influence of hyperopic laser vision correction (LVC) on corneal biomechanics has been recently reported in a few studies. De Medeiros et al. assessed the CH and CRF values at 1-week post-FS-LASIK in myopic and hyperopic eyes. The study groups were similar in terms of preoperative corneal biomechanical parameters, flap thickness, magnitude of refractive error, volume of tissue removal, preoperative CH and CRF, and simulated keratometry values [30]. The study reported the greater decrease in CH and CRF in myopic rather than hyperopic ablation profiles [30]. The authors concluded that the spatial profile and volume of corneal ablation together with preoperative corneal biomechanical stiffness are important factors that influence corneal biomechanics after FS-LASIK [30]. Moreover, the paracentral hyperopic ablation profile in anatomically thicker peripheral cornea can explain statistically less common corneal ectasia following hyperopic FS-LASIK [30]. In the recent experimental ex vivo study on human fellow eye corneas, Spuru investigated the influence of hyperopic SMILE vs. FS-LASIK on corneal biomechanics [31]. To assess elastic and viscoelastic properties of donor corneas, authors applied two-dimensional biomechanical measurements: stress

strain-curve and stress relaxation-curve. The results of the study revealed no difference between hyperopic SMILE and FS-LASIK in terms of effective elastic modulus in stress-strain and stress-relaxation measurements [31]. The authors concluded that in contrast to myopia correction, SMILE and FS-LASIK in hyperopia correction have a similar effect on the corneal biomechanics in ex vivo studied fellow human corneas [31].

## CONCLUSIONS

In conclusion, the PRK/LASEK and SMILE in myopia correction, compromise the corneal biomechanics less than the LASIK/FS-LASIK. The thicker caps in SMILE and thinner flaps in LASIK/FS-LASIK are beneficial in maintaining the corneal biomechanical integrity. The hyperopic laser vision correction seems to have less effect on corneal biomechanics weakening than myopic correction. The future research over corneal biomechanics after laser vision correction should standardize the study groups in terms of refractive error degree and type, ablation profile, optical zone, preoperative corneal thickness, percentage of tissue removed, lenticule thickness, residual stromal bed left and patients' age.

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## References

1. Guo H, Hosseini-Moghaddam SM, Hodge W. Corneal biomechanical properties after SMILE versus FLEX, LASIK, LASEK, or PRK: a systematic review and meta-analysis. *BMC Ophthalmol.* 2019; 19(1): 167. <http://doi.org/10.1186/s12886-019-1165-3>.
2. Damgaard IB, Reffat M, Hjortdal J. Review of Corneal Biomechanical Properties Following LASIK and SMILE for Myopia and Myopic Astigmatism. *Open Ophthalmol J.* 2018; 12: 164-74. <http://doi.org/10.2174/1874364101812010164>.
3. Shang J, Shen Y, Jhanji V et al. Comparison of Corneal Biomechanics in Post-SMILE, Post-LASEK, and Keratoconic Eyes. *Front Med (Lausanne).* 2021; 8: 695-97. <http://doi.org/10.3389/fmed.2021.695697>.
4. Knox Cartwright NE, Tyrer JR, Jaycock PD et al. Effects of variation in depth and side cut angulations in LASIK and thin-flap LASIK using a femtosecond laser: a biomechanical study. *J Refract Surg.* 2012; 28(6): 419-25. <http://doi.org/10.3928/1081597X-20120518-07>.
5. Xin Y, Lopes BT, Wang J et al. Biomechanical Effects of tPRK, FS-LASIK, and SMILE on the Cornea. *Front Bioeng Biotechnol.* 2022; 10: 834270. <http://doi.org/10.3389/fbioe.2022.834270>.
6. Huang G, Melki S. Small Incision Lenticule Extraction (SMILE): Myths and Realities. *Semin Ophthalmol.* 2021; 36(4): 140-8. <http://doi.org/10.1080/08820538.2021.1887897>.
7. Raevdal P, Grauslund J, Vestergaard AH. Comparison of corneal biomechanical changes after refractive surgery by noncontact tonometry: small-incision lenticule extraction versus flap-based refractive surgery – a systematic review. *Acta Ophthalmol.* 2019; 97(2): 127-36. <http://doi.org/10.1111/aos.13906>.

8. Agca A, Ozgurhan EB, Demirok A et al. Comparison of corneal hysteresis and corneal resistance factor after small incision lenticule extraction and femtosecond laser-assisted LASIK: a prospective fellow eye study. *Cont Lens Anterior Eye*. 2014; 37(2): 77-80. <http://doi.org/10.1016/j.clae.2013.05.003>.
9. Kanellopoulos AJ. Comparison of corneal biomechanics after myopic small-incision lenticule extraction compared to LASIK: an ex vivo study. *Clin Ophthalmol*. 2018; 12: 237-45. <http://doi.org/10.2147/OPHT.S153509>.
10. Ganesh S, Patel U, Brar S. Posterior corneal curvature changes following Refractive Small Incision Lenticule Extraction. *Clin Ophthalmol*. 2015; 9: 1359-64. <http://doi.org/10.2147/OPHT.S84354>.
11. Hashemi H, Asgari S, Mortazavi M et al. Evaluation of Corneal Biomechanics After Excimer Laser Corneal Refractive Surgery in High Myopic Patients Using Dynamic Scheimpflug Technology. *Eye Contact Lens*. 2017; 43(6): 371-7. <http://doi.org/10.1097/ICL.0000000000000280>.
12. Lee H, Roberts CJ, Kim TI et al. Changes in biomechanically corrected intraocular pressure and dynamic corneal response parameters before and after transepithelial photorefractive keratectomy and femtosecond laser-assisted laser in situ keratomileusis. *J Cataract Refract Surg*. 2017; 43(12): 1495-503. <http://doi.org/10.1016/j.jcrs.2017.08.019>.
13. Qazi M, Sanderson J, Mahmoud A et al. Postoperative changes in intraocular pressure and corneal biomechanical metrics: laser in situ keratomileusis versus laser-assisted subepithelial keratectomy. *J Cataract Refract Surg*. 2009; 35(10): 1774-88. <http://doi.org/10.1016/j.jcrs.2009.05.041>.
14. Wu D, Wang Y, Zhang L et al. Corneal biomechanical effects: Small-incision lenticule extraction versus femtosecond laser-assisted laser in situ keratomileusis. *J Cataract Refract Surg*. 2014; 40: 954-62.
15. Elmohamady MN, Abdelghaffar W, Daifalla A et al. Evaluation of femtosecond laser in flap and cap creation in corneal refractive surgery for myopia: A 3-year follow-up. *Clin Ophthalmol*. 2018; 12: 935-42.
16. He S, Luo Y, Ye Y et al. A comparative and prospective study of corneal biomechanics after SMILE and FS-LASIK performed on the contralateral eyes of high myopia patients. *Ann Transl Med*. 2022; 10: 730.
17. Hwang ES, Stagg BC, Swan R et al. Corneal biomechanical properties after laser-assisted in situ keratomileusis and photorefractive keratectomy. *Clin Ophthalmol*. 2017; 11: 1785-9.
18. Lee H, Roberts CJ, Kim TI et al. Changes in biomechanically corrected intraocular pressure and dynamic corneal response parameters before and after transepithelial photorefractive keratectomy and femtosecond laser-assisted laser in situ keratomileusis. *J Cataract Refract Surg*. 2017; 43: 1495-503.
19. Liu M, Shi W, Liu X et al. Postoperative corneal biomechanics and influencing factors during femtosecond-assisted laser in situ keratomileusis (FS-LASIK) and laser-assisted subepithelial keratomileusis (LASEK) for high myopia. *Lasers Med Sci*. 2021; 36: 1709-17.
20. Santiago MR, Wilson SE, Hallahan KM et al. Changes in custom biomechanical variables after femtosecond laser in situ keratomileusis and photorefractive keratectomy for myopia. *J Cataract Refract Surg*. 2014; 40: 918-28.
21. Kamiya K, Shimizu K, Ohmoto F. Comparison of the changes in corneal biomechanical properties after photorefractive keratectomy and laser in situ keratomileusis. *Cornea*. 2009; 28(7): 765-9. <http://doi.org/10.1097/ICO.0b013e3181967082>.
22. Shen Y, Chen Z, Knorz MC et al. Comparison of corneal deformation parameters after SMILE, LASEK, and femtosecond laser-assisted LASIK. *J Refract Surg*. 2014; 30: 310-18. <http://doi.org/10.3928/1081597X-20140422-01>.
23. Wu D, Liu C, Li B et al. Influence of Cap Thickness on Corneal Curvature and Corneal Biomechanics After SMILE: A Prospective, Contralateral Eye Study. *J Refract Surg*. 2020; 36(2): 82-8. <http://doi.org/10.3928/1081597X-20191216-01>.
24. El-Massry AA, Goweida MB, Shama AE et al. Contralateral eye comparison between femtosecond small incision intrastromal lenticule extraction at depths of 100 and 160  $\mu\text{m}$ . *Cornea*. 2015; 34(10): 1272-5. <http://doi.org/10.1097/ICO.0000000000000571>.
25. Randleman JB, Dawson DG, Grossniklaus HE et al. Depth-dependent cohesive tensile strength in human donor corneas: implications for refractive surgery. *J Refract Surg*. 2008; 24(1): S85-9.
26. Jun I, Kang DSY, Roberts CJ et al. Comparison of Clinical and Biomechanical Outcomes of Small Incision Lenticule Extraction With 120- and 140- $\mu\text{m}$  Cap Thickness. *Transl Vis Sci Technol*. 2021; 10(8): 15. <http://doi.org/10.1167/tvst.10.8.15>.
27. Zhang L, Wang Y, Yang X. Ablation depth and its effects on corneal biomechanical changes in laser in situ keratomileusis and epipolis laser in situ keratomileusis. *Int Ophthalmol*. 2014; 34(2): 157-64. <http://doi.org/10.1007/s10792-013-9798-3>.
28. Goussous IA, El-Agha MS, Awadein A et al. The effect of flap thickness on corneal biomechanics after myopic laser in situ keratomileusis using the M-2 microkeratome. *Clin Ophthalmol*. 2017; 11: 2065-71. <http://doi.org/10.2147/OPHT.S148216>.
29. Medeiros FW, Sinha-Roy A, Alves MR et al. Biomechanical corneal changes induced by different flap thickness created by femtosecond laser. *Clinics*. 2011; 66: 1067-71.
30. De Medeiros FW, Sinha-Roy A, Alves MR et al. Differences in the early biomechanical effects of hyperopic and myopic laser in situ keratomileusis. *J Cataract Refract Surg*. 2010; 36(6): 947-53. <http://doi.org/10.1016/j.jcrs.2009.12.032>.
31. Spuru B, Torres-Netto EA, Kling S et al. Hyperopic SMILE Versus FS-LASIK: A Biomechanical Comparison in Human Fellow Corneas. *J Refract Surg*. 2021; 37(12): 810-15. <http://doi.org/10.3928/1081597X-20210830-02>.

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