Corneal Biomechanics following Laser Refractive Surgery in Eyes

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The role of corneal biomechanics in laser vision correction (LVC) is being raised in the assessment of postoperative corneal ectasia risk. Research reveal the highest corneal biomechanics reduction after laser in situ keratomileusis (LASIK) followed by small incision lenticule extraction (SMILE) and surface procedures, such as photorefractive keratectomy (PRK) or laser-assisted sub-epithelial keratectomy (LASEK). In SMILE procedure treatment planning, the use of thicker caps preserves the corneal biomechanics. Similarly, reduction of flap thickness in LASIK surgery maintains the corneal biomechanical strength.

laser vision correction PRK LASEK LASIK SMILE

1. Introduction

Corneal laser refractive surgery, also called laser vision correction (LVC), is a group of procedures for the correction of refractive errors, such as myopia, hyperopia, astigmatism, or presbyopia. In most cases, refractive surgery gives the possibility of complete independence from glasses or contact lenses, which significantly improves the overall patient's quality of life. Commonly used techniques of refractive surgery are surface techniques, such as photorefractive keratectomy (PRK) or laser-assisted sub-epithelial keratectomy (LASEK) as well as stromal techniques including laser in situ keratomileusis (LASIK) and small incision lenticule extraction (SMILE). Corneal ectasia is a very rare but serious complication of refractive procedures the prevalence of which arises in 0.04–0.6% of cases [1][2]. In order to minimize the risk of its occurrence, currently the most important role is assigned to the correct qualification of the patient for laser vision correction. The preoperative analysis of the corneal structure includes pachymetry, topography, keratometry, aberrometry, and finally, corneal biomechanics, the role of which is currently being raised [3]. Understanding corneal biomechanical properties is crucial in the preoperative screening of refractive surgery candidates, to minimize the risk of postoperative corneal ectasia. Currently, there are two commercially available devices that are used in clinical practice to assess corneal biomechanical parameters; the Ocular Response Analyzer (ORA) and Corvis ST.

2. Corneal Biomechanics after PRK/LASEK versus FS- LASIK or SMILE

The results of recent studies comparing corneal biomechanics after surface procedures (PRK with or without MMC, trans-PRK, LASEK) versus FS- LASIK are mostly consistent. The authors conclude that surface procedures weaken the biomechanics of the cornea less than or at least equal to LASIK or FS-LASIK [4][5][6][7][8][9][10]. There are, however, controversies over corneal biomechanics after surface procedures in comparison with SMILE [9]. The meta-analysis by Guo revealed that ORA parameters CH and CRF were insignificantly higher after PRK or LASEK than after SMILE [3]. However, in most studies that were taken into consideration, the amount of tissue removed was greater in the SMILE procedure than in PRK/LASEK, as the SMILE was performed to treat higher myopia than surface procedures [3]. As the authors concluded, to obtain more reliable results in the comparison of corneal biomechanics after surface procedures and SMILE, future studies should take into account the degree of myopia as an important inclusion criterion in research groups [3]. An attempt at the unification of study groups in terms of the degree of refractive error was made by Yu et al., who compared the CH and CRF per unit of corneal tissue removal after SMILE and LASEK, concluding that corneal biomechanics were stronger after SMILE than after LASEK in the early postoperative period [11]. Nevertheless, during long-term observation, the difference became insignificant [11]. The comparison of corneal biomechanics between SMILE and LASEK eyes with Corvis ST was performed by Shen et al., who found no differences between study groups [12].

3. Corneal Biomechanics after SMILE versus FS-LASIK or FLEX

In the vast majority of studies included, the postoperative biomechanical outcomes were better following SMILE than after LASIK or FS-LASIK [4][13][14][15]. Similarly, in the meta-analysis by Guo et al., CH and CRF provided by ORA were significantly higher after SMILE than after FS-LASIK or microkeratome-LASIK. Moreover, the difference increased when measured at 12 months postoperatively in favor of SMILE [3]. This is also consistent with the outcomes of a meta-analysis by Yan et al., of 5 studies in which the CH and CRF values were higher after SMILE than FS-LASIK [16]. Wang et al., assessed changes in posterior corneal elevation and corneal biomechanical parameters after SMILE and FS-LASIK for high myopia correction [17]. Their study revealed that SMILE maintained posterior corneal surface stability better than FS-LASIK at 12 months after surgery [17]. Corneal biomechanical parameters were similar after the two procedures, although FS-LASIK led to a greater reduction of postoperative CRF. The authors concluded that SMILE could be more advantageous biomechanically, particularly in high myopia correction [17]. In the review study by Raevdal et al., including six non-randomized and three randomized control trials, the authors found a significant reduction of corneal viscoelastic properties measured by ORA following all types of refractive procedures (SMILE, FLEX, FS-LASIK) [18]. The authors of the six non-randomized studies reported greater postoperative reduction of corneal biomechanics in the FS-LASIK group than in the SMILE group when measured by ORA [18]. In contrast, in the three randomized control trials included in their meta-analysis [18], no significant difference was found in terms of CH or CRF lowering between SMILE and flap- related procedures (FLEX or FS-LASIK) [19][20][21][22]. This was also consistent with the studies by Vestargaard et al. [19] and Agca et al. [20], which revealed no biomechanical differences between SMILE and FS-LASIK or FLEX procedures. [19][20]. Similar data were provided in the meta-analysis by Guo et al., in which corneal biomechanics did not differ after SMILE or FLEX procedures when measured either by ORA or Corvis ST [3]. In several studies included and also mentioned by Raevdal et al. [18], the corneal parameters were assessed by Corvis ST and revealed a significant weakening of corneal biomechanics after refractive procedures [4][7][15][23][24][25][26][27]. There, are, however controversies in terms of Corvis ST biomechanics post SMILE and FS-LASIK. Studies by Xin et al. [4] and He et al. [15] demonstrated significantly better corneal biomechanics preservation following SMILE than after LASIK or FS-LASIK, when assessed by Corvis ST [4][15]. On the other hand, in the majority of studies included in the meta-analysis by Guo et al. [3], the postoperative biomechanical parameters measured with Corvis ST did not differ between SMILE and FS-LASIK eyes [3]. Only in the study by Osman were there significant differences in the biomechanical parameters provided by Corvis ST (A1time, A2 time, A2 length, HC time, HC radius, and HC peak distance) between the SMILE group and microkeratome-LASIK group [28]. The authors concluded that the reason for this dissimilarity of results could be the use of microkeratome for flap creation [28]. Damgaard et al. [29] observed that the corneal biomechanical parameters provided by Corvis ST and ORA were stronger, or at least equal, after SMILE rather than LASIK. However, the authors stated that although the precise values of corneal biomechanical properties are provided by ORA and Corvis ST, the interpretation of biomechanical results is mostly biased by IOP, CCT, the magnitude of corrected refractive error, and age [29]. Kanellopoulos et al., demonstrated that the SMILE procedure performed in low myopic eyes resulted in greater tensile strength reduction than with the LASIK procedure, while in higher myopia, the reduction of corneal strength was similar in both SMILE and LASIK eyes [30]. Wei et al., assessed the change in biomechanical properties per unit of reduction in corneal volume, concluding that the change was lower following SMILE than FS-LASIK [31]. Therefore, future paired-eye studies and the unification of study groups are needed to confirm the biomechanical findings after SMILE versus FS-LASIK [29].

4. Cap or Flap Thickness and Corneal Biomechanics

The influence of cap thickness on corneal biomechanics remains unclear. Many surgeons believe that increasing the thickness of the cap maintains stronger biomechanics of the cornea [12]. Recently, Wu et al., conducted a prospective contralateral eye study comparing the corneal biomechanics and curvature after SMILE in eyes with thinner (110 µm) and thicker (140 µm) caps [24]. In eyes with a 110 µm cap, the second applanation time (SP-A2), deformation amplitude (DA), and integrated radius were significantly lower than in eyes with a 140 µm cap [24]. Similarly, El-Massary et al., reported less corneal biomechanics weakening with a 160 µm cap than with a 100 µm cap based on the results of CH and CRF measured with ORA [32]. The above findings are consistent with the concept described by Reinstein et al. [33] and Randleman et al. [34], that corneal biomechanics and tensile strength are higher in anterior than posterior stroma, which suggests greater corneal biomechanics in thicker caps [24][25][32][33][34][35]. Although the corneal biomechanics are better preserved in thicker caps, in high myopic patients, the increase in cap thickness results in deeper lenticule creation and a thinner posterior residual stromal bed (RSB), which can finally weaken the corneal biomechanics [25]. In research by Jun et al., the corneal biomechanics were weaker in the 140 µm cap group compared to the 120 µm cap group, which was confirmed by the greater differences in the corneal shape deformation, deformation amplitude ratio, and integrated inverse radius in the 140 µm cap group [25]. However, the authors noted that the lenticule thickness was significantly greater and the RSB was significantly thinner in the 140 µm cap group in comparison to the 120 µm cap group, which might have strongly influenced the biomechanical outcomes [25]. The authors of the study postulated that the role of cap thickness in preserving corneal biomechanics should be verified in further studies. In addition, other parameters, such as the thickness of the lenticule, percentage of tissue removed, anterior and posterior residual stromal bed, the arc length of the posterior cap, and size of the side incision should be taken into account in this consideration [25].

According to Reinstein et al., for maximum protection of the corneal biomechanics, it is recommended to prepare thin corneal flaps using the LASIK or FemtoLASIK methods and a thicker cap using SMILE [36]. The significant reduction of corneal biomechanical parameters, such as CH and/or CRF was also reported by other authors who compared patients after 110 µm flap LASIK versus epi-LASIK, 130 µm flap LASIK versus PRK and finally 160 µm/180 µm flap LASIK versus LASEK [6][37][38]. In all the above-mentioned studies, the CH and/or CFR were higher after surface procedures rather than after LASIK. Medeiros et al., compared the corneal biomechanical parameters reduction after thick-flaps LASIK and thin-flaps LASIK, concluding that thick LASIK flaps compromised the corneal biomechanics much more than thinner flaps [39]. The study by Goussous et al., compared the preoperative and 3-months postoperative values of CH and CRF in patients who underwent either epi-LASIK with MMC, thin-flap (90 µm) LASIK, or thick-flap (130 µm) LASIK [40]. The greater reduction of CH and CRF was observed after both 90 µm and 130 µm flap LASIK than after epi-LASIK. CH was significantly lower in thick-flap LASIK than in epi-LASIK eyes, while the CH difference between thin-flap LASIK and epi-LASIK eyes was not statistically significant [40]. The CRF reduction in both LASIK groups compared to the epi-LASIK group was not statistically significant but the decrease in CRF value was greater in the thick-flap LASIK group than in the thin-flap LASIK group [40]. There were, however, some limitations of the study, including greater ablation depth in the 90 µm flap LASIK patients, greater preoperative CCT and CH in the 130 µm flap LASIK patients, and use of M-2 microkeratome which overcut the flaps on average 10–15 µm (no flap thickness control was performed postoperatively) [40]. To summarize, most recent clinical studies support the statement that the biomechanical strength of the cornea decreases with LASIK-flap thickness increase [6][37][38][40][41]. However, future studies are needed to obtain more reliable outcomes [40].

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