

【文献综述】

卢玥浩 夏丽坤

1.2 散光大小

针对于散光度数的大小方面,总体趋势是散光量越大,SMILE 矫正的不稳定性也就越大,且主要是以欠矫为主。Ivarsen 等^[9]在早期的研究中发现,以 2.50 D 为分界,通过 SMILE 矫正低度

与高度散光分别造成了 13% 和 16% 的欠矫。Pedersen 等^[11]也在研究中发现,随访 SMILE 矫正近视散光术后 1 a 仍有 11% 的欠矫存在。Alió del Barrio 等^[8]在对 2010 至 2017 年 SMILE 矫正近视散光研究的 Meta 分析中,也推荐 SMILE 矫正近视散光时附加 10% 的补矫。

关于欠矫的原因方面并没有给出合适的理论,目前只有 Sideroudi 等^[21]发现在高度散光患者 SMILE 术后 3 a 角膜后表面散光值有所下降,并考虑与高度散光的欠矫有关,但这却与 Gyldenkerne 等^[22]的研究结果相悖,可能是因为随访时间较短,仍需要更多的研究证实。

1.3 眼内散光 眼内散光(ocular residual astigmatism, ORA)是人眼屈光异常的重要组成部分^[23]。传统观念认为 ORA 是角膜前表面以外的散光成分,但目前研究表明,ORA 其实是一个多种参数的集合体,包括角膜前表面高阶像差、角膜后表面散光、晶状体前后表面散光、生物屈光折射率的不稳定性、晶状体偏中心,甚至包括视网膜倾斜程度和大脑皮质认知能力等^[24],而这种构成复杂的参数通过验光只能在球柱镜水平表达出来,并且通过 SMILE 手术也只是在角膜前表面水平进行球、柱镜水平矫正,故可能造成一定的误差。ORA 在 LASIK 等其他角膜屈光手术的研究中被证明其对手术矫正的精确性及术后视觉质量,包括术后视力、术后残余散光、甚至对比敏感度和高阶像差均有着不同程度的影响^[25-28]。

同样作为板层角膜屈光手术的 SMILE 在矫正近视散光时也可能受到 ORA 的影响,但关于这方面的研究结果非常有限。在 Qian 等^[29]的研究中,发现较高的 ORA 会带来更高的术后散光,且术后 1~6 个月,各时间段高 ORA 组的成功指数均大于低 ORA 组,考虑 SMILE 在矫正高 ORA 近视散光时的效能降低。在 Chan 等^[30]的研究中通过不同的分组方式也得出了类似的结论。

1.4 散光的顺规、逆规性 由于睑裂位置及压力的作用,角膜水平子午线方向的屈光力较为平坦,且全眼散光的主要来源是角膜,故多数人表现为顺规性散光。Ivarsen 等^[31]发现,除了每 1.00 D 预矫正会造成 -0.15 D 大小误差外,逆规性散光者始终生成 0.32 D 大小误差,并建议在高度近视散光的矫正中考虑该影响因素。Pérez-Izquierdo 等^[32]将顺规、逆规、斜轴散光再按不同大小分类后,发现只有当散光 ≥ 1.50 D 后,顺规性散光的大小误差明显低于逆规性和斜轴散光,也说明了矫正高度近视散光时需考虑散光的顺规、逆规性。

1.5 眼别 由于手术并不是双眼同时进行,其先后顺序对患者情绪及配合程度的影响,以及术者对于左右眼手术的不同熟练度,或侧切口的位置等,均有可能对左右眼的散光矫正精确性造成影响。Yildiz 等^[33]研究发现,同时接受 SMILE 矫正近视散光的双

眼,虽然都取得了理想的术后视觉质量,但左眼会取得较高的矫正指数。故在 SMILE 矫正散光的研究中,推荐使用同一侧眼数据进行分析,可能会进一步提高可信度。

2 误差控制

近视散光矫正的误差主要来源是预矫正散光的度数大小及无法精确定位的眼球旋转造成的,故误差控制需要在这 2 个因素上进一步讨论。

2.1 散光度数的补偿 由散光度数造成的欠矫量可以得知,在预矫正散光大小的基础上添加 10% 的补矫是较为科学的。但不同的研究结果所报告的大小误差均不一样,甚至在个别研究中出现了低度散光过矫倾向^[34],这可能与每台设备的细微差别、不同治疗中心 nomograms 的设定及不同术者的经验有关。故在精确的术前检查及优秀的手术设计的前提下,个性化 nomograms 的设定、对设备矫正效能的摸索和长时间手术经验的积累也对精确的近视散光矫正起至关重要的作用。

2.2 轴位误差的补偿 Ganesh 等^[35]提出并报道了人工轴位补偿的方法及效果,即在负压吸引后,通过轻轻旋转锥形角膜接触镜,将 $0^\circ \sim 180^\circ$ 角膜缘标记与显微镜水平标记重合校正,发现高度近视散光患者术后角度误差和成功指数较低度近视散光更低,认为该方法对高度近视散光的矫正有较好的校正作用。

Jun 等^[36]在手术中使用三重标记中心定位技术,即在术前通过共轴视角角膜反射,在水平子午线和下方角膜做 3 处标记,在手术对接过程中,在三点坐标的帮助下,对偏中心和眼球旋转进行修正。术后 6 个月的角度误差绝对值(1.76 ± 1.75)和成功指数(0.13 ± 0.08)与波前像差引导的 PRK 无明显差异,证明该方法对近视散光的矫正有较好的轴位修正作用。Kang 等^[37]在 SMILE 手术中使用同样的方法修正偏中心,还得了更好的中心定位及更小的术后高阶像差效果。

Chen 等^[38]对比通过和不通过人工轴位补偿的 SMILE 矫正近视散光,发现虽然两者术后等效球镜相似,但补偿组术后视力(1.07 ± 0.11)高于未补偿组(0.92 ± 0.19),矢量分析补偿组大小误差和角度误差也明显小于未补偿组。同时在对 SMILE 矫正近视散光中轴位补偿的患者行 6 个月随访后,证实了这种方法的可预测性、有效性和安全性^[39]。

而在 Xu 等^[40]的研究中却显示,虽然通过人工轴位补偿可以达到一定程度的手术修正效果,但其对视觉质量的影响非常有限,故认为人工轴位补偿并不是 SMILE 手术矫正近视散光时必需的步骤。

3 散光的分析方法

3.1 测量 电脑验光仪和综合验光仪是测量全眼

散光最常用也是最基本的测量工具,其对患者整体屈光状态的获取分析在手术设计和术后随访中具有重要的意义。

由于 SMILE 手术是角膜板层屈光手术,通过改变角膜曲率来改变人眼的屈光状态,角膜地形图能够精确捕捉到角膜形态、曲率的变化,故角膜地形图在 SMILE 手术中拥有非常重要的临床意义及科研价值。不论是基于 Placido 环设计的经典角膜地形图设备(如 ATLAS),或是非基于 Placido 盘反射影像设定的新型设备(如 Orbscan),甚至现在最新型的基于 Scheimpflug 成像原理的 Pentacam 角膜地形图,其至少可以分析角膜前表面的曲率状态,用于术前圆锥角膜和术后角膜膨隆的筛查与诊断^[41]。而在散光研究中,其可以测量角膜前、后表面的曲率,进行眼球散光各项成分(如 ORA)的分析。目前研究最热门的 Pentacam 角膜地形图是 SMILE 角膜屈光研究最理想的设备,在 Qian 等^[42]的研究中,也证明由该设备测量出的全角膜屈光力(total corneal refractive power, TCRP)是最精确的手术前后散光测量值。

3.2 分析 散光应该被视为有大小和方向的矢量进行分析,矢量分析方法源于斜交柱镜(jackson cross-cylinders, JCC)理论,即任何以球、柱镜形式表示的验光结果均能分解为等效球镜与两个交叉柱镜的结合形式。Alpins^[43]首先提出了散光矢量分析的理念,通过测定并计算散光矫正的大小和轴位来分析散光矫正的效果,这种方法被用在了角膜激光屈光手术治疗散光疗效的评定中^[44],并被大量研究散光的学者沿用至今。虽然该方法可以准确地显示手术前后的散光大小、方向及变化关系,但其根本上是数学模型的计算结果,并且受到患者恢复过程、术者手术技术等客观因素影响,所以不能代表实际测量结果,其分析结果只能作为手术设计及预后预测的参考值,真正的疗效和误差分析仍然基于客观设备的分析检查。

4 总结

SMILE 作为最先进的角膜屈光手术之一,其在近视散光矫正上的安全性、有效性和可预测性是得到充分认可的,相较于传统 LASIK 及 PRK 手术,其创伤小、耗时少、恢复快、并发症少成为了不可取代的优势,为屈光不正的矫正提供了更优选的方案。但其在近视散光的矫正中仍存在误差,缺少客观的眼球运动追踪设备是最重要的原因之一。现有的人工角度修正或度数补偿方法在一定程度上提高了矫正的精确性,但这类方法并未被官方认可,也需要更大样本的研究。故更加精确的眼球定位方法的研究及 SMILE 术中眼球追踪定位系统的开发,是提高 SMILE 矫正近视散光精确性和有效性的重要方向。

参考文献

[1] RAEVDAL P, GRAUSLUND J, VESTERGAARD A H. Compari-

son of corneal biomechanical changes after refractive surgery by noncontact tonometry: small-incision lenticule extraction versus flap-based refractive surgery - a systematic review [J]. *Acta Ophthalmol*, 2018, 97 (2): 127-136.

[2] DAMGAARD I B, REFFAT M, HJORTDAL J. Review of corneal biomechanical properties following LASIK and SMILE for myopia and myopic astigmatism [J]. *Open Ophthalmol J*, 2018, 12: 164-174.

[3] KOBASHI H, KAMIYA K, SHIMIZU K. Dry eye after small incision lenticule extraction and femtosecond Laser-Assisted LASIK: Meta-analysis [J]. *Cornea*, 2017, 36 (1): 85-91.

[4] TANERI S, KIEBLER S, ROST A, SCHULTZ T, DICK H B. Small-incision lenticule extraction for the correction of myopic astigmatism [J]. *J Cataract Refract Surg*, 2019, 45 (1): 62-71.

[5] LAU Y T, SHIH K C, TSE R H, CHAN T C, JHANJHI V. Comparison of visual, refractive and ocular surface outcomes between small incision lenticule extraction and laser-assisted in situ keratomileusis for myopia and myopic astigmatism [J]. *Ophthalmol Ther*, 2019, 8 (3): 373-386.

[6] WONG C W, CHAN C, TAN D, MEHTA J S. Incidence and management of suction loss in refractive lenticule extraction [J]. *J Cataract Refract Surg*, 2014, 40 (12): 2002-2010.

[7] WONG J X, WONG E P, HTOON H M, MEHTA J S. Intraoperative centration during small incision lenticule extraction (SMILE) [J]. *Medicine (Baltimore)*, 2017, 96 (16): e6076.

[8] ALIÓ DEL BARRIO J L, VARGAS V, AL-SHYMALI O, ALIÓ J L. Small incision lenticule extraction (SMILE) in the correction of myopic astigmatism: outcomes and limitations- an update [J]. *Eye Vis (Lond)*, 2017, 4: 26.

[9] IVARSEN A, HJORTDAL J. Correction of myopic astigmatism with small incision lenticule extraction [J]. *J Refract Surg*, 2014, 30 (4): 240-247.

[10] ZHANG J W, WANG Y, CHEN X. Comparison of moderate- to high-astigmatism corrections using wave front-guided laser in situ keratomileusis and small-incision lenticule extraction [J]. *Cornea*, 2016, 35 (4): 523-530.

[11] PEDERSEN I B, IVARSEN A, HJORTDAL J. Changes in astigmatism, densitometry, and aberrations after SMILE for low to high myopic astigmatism: A 12-month prospective study [J]. *J Refract Surg*, 2017, 33 (1): 11-17.

[12] MIRAFTAB M, HASHEMI H, ASGARI S. Two-year results of femtosecond assisted LASIK versus PRK for different severity of astigmatism [J]. *J Curr Ophthalmol*, 2017, 30 (1): 48-53.

[13] NIPARUGS M, TANANUVAT N, CHAIDAROON W, TANG-MONKONGVORAGUL C, AUSAYAKHUN S. Outcomes of LASIK for myopia or myopic astigmatism correction with the FS200 Femtosecond Laser and EX500 excimer Laser platform [J]. *Open Ophthalmol J*, 2018, 12: 63-71.

[14] STANCA H T, MUNTEANU M, JIANU D C, MOTOC A G M, JECAN C R, TÂBĂCARU B, et al. Femtosecond-LASIK outcomes using the VisuMax®-MEL® 80 platform for mixed astigmatism refractive surgery [J]. *Rom J Morphol Embryol*, 2018, 59 (1): 277-283.

[15] CHAN T C, NG A L, CHENG G P, WANG Z, YE C, WOO V C, et al. Vector analysis of astigmatic correction after small-incision lenticule extraction and femtosecond-assisted LASIK for low to moderate myopic astigmatism [J]. *Br J Ophthalmol*, 2016, 100 (4): 553-559.

[16] KANELLOPOULOS A J. Topography-guided LASIK versus small incision lenticule extraction (smile) for myopia and myopic astigmatism: a randomized, prospective, contralateral eye study [J]. *J Refract Surg*, 2017, 33 (5): 306-312.

[17] BOHAC M, KONCAREVIC M, DUKIC A, BISCEVIC A, CEROVIC V, MERLAK M, et al. Unwanted astigmatism and high-order aberrations one year after excimer and femtosecond corneal surgery [J]. *Optom Vis Sci*, 2018, 95 (11): 1064-1076.

[18] EL-MAYAH E, ANIS M, SALEM M, PINERO D, HOSNY M. Comparison between Q-adjusted lasik and small-incision lenticule extraction for correction of myopia and myopic astigmatism [J]. *Eye Contact Lens*, 2018, 44: S426-S432.

[19] HAN T, XU Y, HAN X, ZENG L, SHANG J, CHEN X, et al. Three-year outcomes of small incision lenticule extraction (SMILE) and femtosecond laser-assisted laser in situ keratomileusis (FS-LASIK) for myopia and myopic astigmatism

- [J]. *Br J Ophthalmol*, 2018, 103 (4): 565-568.
- [20] CHAN T C Y, WANG Y, NG A L K, ZHANG J, YU M C Y, JHANJ V, *et al*. Vector analysis of high (≥ 3 diopters) astigmatism correction using small-incision lenticule extraction and laser in situ keratomileusis [J]. *J Cataract Refract Surg*, 2018, 44 (7): 802-810.
- [21] SIDEROUDI H, LAZARIDIS A, MESSERSCHMIDT-ROTH A, LABIRIS G, KOZOBOLIS V, SEKUNDO W. Corneal irregular astigmatism and curvature changes after small incision lenticule extraction [J]. *Cornea*, 2018, 37 (7): 875-880.
- [22] GYLDENKERNE A, IVARSEN A, HJORTDAL J Ø. Comparison of corneal shape changes and aberrations induced by FS-LASIK and SMILE for myopia [J]. *J Refract Surg*, 2015, 31 (4): 223-229.
- [23] SCHUSTER A K, PFEIFFER N, SCHULZ A, HOEHN R, PONTTO K A, WILD P S, *et al*. Refractive, corneal, and ocular residual astigmatism; distribution in a German population and age dependency—the Gutenberg Health Study [J]. *Graefes Arch Clin Exp Ophthalmol*, 2018, 256 (2): 445-446.
- [24] GAUVIN M, WALLERSTEIN A. Astig MATIC: an automatic tool for standard astigmatism vector analysis [J]. *BMC Ophthalmol*, 2018, 18 (1): 255.
- [25] QIAN Y S, HUANG J, LIU R, CHU RY, XU Y, ZHOU X T, *et al*. Influence of internal optical astigmatism on the correction of myopic astigmatism by LASIK [J]. *J Refract Surg*, 2011, 27 (12): 863-868.
- [26] FRINGS A, KATZ T, STEINBERG J, DRUCHKIV V, RICHARD G, LINKE S J. Ocular residual astigmatism: Effects of demographic and ocular parameters in myopic laser in situ keratomileusis [J]. *J Cataract Refract Surg*, 2014, 40 (2): 232-238.
- [27] QIAN Y, HUANG J, CHU R, ZHOU X, OLSZEWSKI E. Influence of intraocular astigmatism on the correction of myopic astigmatism by laser-assisted subepithelial keratectomy [J]. *J Cataract Refract Surg*, 2014, 40 (4): 558-563.
- [28] ARCHER TJ, REINSTEIN DZ, PIÑERO D P, GOBBE M, CARP G I. Comparison of the predictability of refractive cylinder correction by laser in situ keratomileusis in eyes with low or high ocular residual astigmatism [J]. *J Cataract Refract Surg*, 2015, 41 (7): 1383-1392.
- [29] QIAN Y, HUANG J, CHU R, ZHAO J, LI M, ZHOU X, *et al*. Influence of intraocular astigmatism on the correction of myopic astigmatism by femtosecond laser small-incision lenticule extraction [J]. *J Cataract Refract Surg*, 2015, 41 (5): 1057-1064.
- [30] CHAN T C Y, WAN K H, ZHANG L, WANG Y. Impact of ocular residual astigmatism on predictability of myopic astigmatism correction after small-incision lenticule extraction [J]. *J Cataract Refract Surg*, 2019, 45 (4): 525-526.
- [31] IVARSEN A, GYLDENKERNE A, HJORTDAL J. Correction of astigmatism with small-incision lenticule extraction; Impact of against-the-rule and with-the-rule astigmatism [J]. *J Cataract Refract Surg*, 2018, 44 (9): 1066-1072.
- [32] PÉREZ-IZQUIERDO R, RODRÍGUEZ-VALLEJO M, MATAM-OROS A, MARTÍNEZ J, GARZÓN N, POYALES F, *et al*. Influence of preoperative astigmatism type and magnitude on the effectiveness of SMILE correction [J]. *J Refract Surg*, 2019, 35 (1): 40-47.
- [33] YILDIZ B K, URDEM U, GOKSEL ULAS M, YILDIRIM Y, AGCA A, FAZIL K, *et al*. Correction of myopic astigmatism by small incision lenticule extraction; does laterality matter? [J]. *Lasers Med Sci*, 2019, 34 (2): 311-316.
- [34] QIAN Y, HUANG J, ZHOU X, WANG Y. Comparison of femtosecond laser small-incision lenticule extraction and laser-assisted subepithelial keratectomy to correct myopic astigmatism [J]. *J Cataract Refract Surg*, 2015, 41 (11): 2476-2486.
- [35] GANESH S, BRAR S, PAWAR A. Results of intraoperative manual cyclotorsion compensation for myopic astigmatism in patients undergoing small incision lenticule extraction (SMILE) [J]. *J Refract Surg*, 2017, 33 (8): 506-512.
- [36] JUN I, KANG D S Y, REINSTEIN D Z, ARBA-MOSQUERA S, ARCHER T J, SEO K Y, *et al*. Clinical outcomes of SMILE with a triple centration technique and corneal wavefront-guided transepithelial PRK in high astigmatism [J]. *J Refract Surg*, 2018, 34 (3): 156-163.
- [37] KANG D S Y, LEE H, REINSTEIN D Z, ROBERTS C J, ARBA-MOSQUERA S, ARCHER T J, *et al*. Comparison of the distribution of lenticule decentration following SMILE by subjective patient fixation or triple marking centration [J]. *J Refract Surg*, 2018, 34 (7): 446-452.
- [38] CHEN P, YE Y, YU N, ZHANG X, HE J, ZHENG H, *et al*. Comparison of small incision lenticule extraction surgery with and without cyclotorsion error correction for patients with astigmatism [J]. *Cornea*, 2019, 38 (6): 723-729.
- [39] CHEN P, YE Y, YU N, ZHANG X, ZHUANG J, YU K. Correction of astigmatism with smile with axis alignment; 6-month results from 622 eyes [J]. *J Refract Surg*, 2019, 35 (3): 138-145.
- [40] XU J, LIU F, LIU M, YANG X, WENG S, LIN L, *et al*. Effect of cyclotorsion compensation with a novel technique in small incision lenticule extraction surgery for the correction of myopic astigmatism [J]. *J Refract Surg*, 2019, 35 (5): 301-308.
- [41] SAVINI G, BARBONI P, CARBONELLI M, HOFFER K J. Agreement between Pentacam and videokeratography in corneal power assessment [J]. *J Refract Surg*, 2009, 25 (6): 534-538.
- [42] QIAN Y, LIU Y, ZHOU X, NAIDU R K. Comparison of corneal power and astigmatism between simulated keratometry, true net power, and total corneal refractive power before and after SMILE surgery [J]. *J Ophthalmol*, 2017, 2017: 9659481.
- [43] ALPINS N A. New method of targeting vectors to treat astigmatism [J]. *J Cataract Refract Surg*, 1997, 23 (1): 65-75.
- [44] REINSTEIN D Z, ARCHER T J, RANDLEMAN J B. JRS standard for reporting astigmatism outcomes of refractive surgery [J]. *J Refract Surg*, 2014, 30 (10): 654-659.

A review and update in myopic astigmatism correction by small incision lenticule extraction (SMILE)

LU Yuehao, XIA Likun

Ophthalmic Laser Operating Center, Shengjing Hospital of China Medical University, Shenyang 110000, Liaoning Province, China

Corresponding author: XIA Likun, E-mail: xialk@sj-hospital.org

[Abstract] Small incision lenticule extraction (SMILE) is a flap-free lamellar corneal refractive surgery. It is extensively accepted by surgeons and patients due to its safety, efficiency, predictability and comfort, which makes it one of the most desirable corneal refractive surgeries. However, this technology lacks automated centration and cyclotorsion control systems. Centration of optical zone and compensation of astigmatism axial rely on fixation of patients and experience of surgeons. Several concerns have been raised regarding to its capability to correct myopic astigmatism. This article will review the curative effect and influence factors, analysis and control of error, and measurement methods in astigmatism correction following SMILE.

[Key words] small incision lenticule extraction; myopic astigmatism; refractive surgery