Recent advances in wavefront-guided LASIK

Edward Manche and Joshua Roe

Purpose of review
Laser vision correction remains an active area of research, and there have been many recent advances in the field. The purpose of this review is to provide an update on the recent advances for one of the most common methods of laser vision correction, wavefront-guided laser in-situ keratomileusis (LASIK).

Recent findings
Recent technological advancements in wavefront aberrometry are largely responsible for the improved visual outcomes that have been recently reported. In addition, improvements in femtosecond and excimer laser technology, used in flap creation and corneal ablation, have been shown to provide superior results when compared to microkeratomes and earlier lasers. Wavefront-guided LASIK appears to have advantages over some other keratorefractive modalities in terms of visual acuity, predictability, astigmatism correction, and subjective visual symptoms. Nonetheless, there may be some limitations in highly aberrated corneas, and also in biomechanical stability relative to other available platforms.

Summary
Improvements in wavefront aberrometry, and also femtosecond and excimer lasers, have continued to improve our ability to correct refractive errors. Wavefront-guided LASIK remains a well tolerated and effective keratorefractive procedure, with a trend toward superiority. Nonetheless, further studies comparing this modality to others are needed to define the role each can serve.

Keywords
aberrometer, excimer, femtosecond, LASIK, wavefront-guided

INTRODUCTION

Keratorefractive surgery is one of the most predictable and reliable surgeries with among the highest patient satisfaction rates [1]. Continued advances in laser technology, hardware, and software, both excimer and femtosecond, have further refined the refractive surgeon's ability to perform safe and effective treatments. One popular method is wavefront-guided (WFG) laser in-situ keratomileusis (LASIK). The purpose of this review is to provide an update on the recent advances in WFG LASIK.

IMPROVEMENTS OVER CONVENTIONAL EXCIMER TREATMENTS

The goal of modern excimer laser platforms is to correct refractive error and minimize or mitigate some of the visual changes seen after conventional LASIK. Conventional LASIK is known to induce higher-order aberrations (HOAs) as the cornea changes from a more prolate shape to an oblate shape [2–5]. These aberrations have been associated with unwelcome visual symptoms like glare, haloes, and starbursts [4,6–8]. Wavefront-optimized (WFO) ablations and WFG ablations are two common methods for improving outcomes of excimer-based refractive surgery over conventional ablations, but they differ in their approach [9].

The WFO ablations achieve superior results over conventional ablations [10] by minimizing the induction of HOAs. This is accomplished by generating an ablation profile based on population averages of aberrometry data, with a goal of decreasing the degree of change from prolate to oblate, thereby inducing fewer HOAs. WFG ablations have also been shown to be superior to conventional ablations [11,12]. WFG profiles are based on preoperative measurements of each patient's HOAs. This allows the WFG ablation profile to account for and treat, with a goal of reducing, the pre-existing HOAs, and also minimize inducing new HOAs [2,13]. Both of

The Byers Eye Institute, Stanford University School of Medicine, Palo Alto, California, USA

Correspondence to Edward Manche, MD, The Byers Eye Institute, Stanford University School of Medicine, Palo Alto, California, USA, 2452 Watson Court, Palo Alto, CA 94303, USA.
Tel: +1 650 723 6995; e-mail: edward.manche@stanford.edu

Curr Opin Ophthalmol 2018, 29:286–291
DOI:10.1097/ICU.0000000000000488

KEY POINTS

- Wavefront-guided LASIK has continued to improve, most recently due to the addition of a high-resolution aberrometer.
- The WFG LASIK performed with the high-resolution aberrometer out performs other keratorefractive modalities for astigmatism correction.
- Subjective quality of vision studies will likely have an increasingly important role in evaluating future laser technologies.

these methods are well tolerated, predictable, and effective for correcting refractive error.

Topography-guided lasers are another recently approved technology in the United States. This method does not rely on wavefront data, but rather corneal topography. An elevation profile of the corneal surface is calculated, and the desired or ideal corneal surface is determined. The difference between the calculated surface and the ideal surface is used to generate the ablation profile. Topography-guided ablations have been shown to be superior in highly aberrated corneas when wavefront data cannot be easily acquired [14–17]. Topography-guided ablations in normal corneas showed superior outcomes for some visual results [18▪▪], but more studies and long-term follow-up are needed to determine the best clinical role for this platform.

WAVEFRONT ABERROMETRY UPDATE

In the past, many excimer lasers have relied on wavefront aberrometry data to create custom laser ablation profiles. There are four common techniques of acquiring the wavefront aberrations of an eye [19–22]. Of these, two are commonly used in commercially available aberrometers; Hartmann-Shack aberrometers and Tscherning aberrometers. Hartmann-Shack aberrometers include, but are not limited to, the following: Visx Wavescan (Johnson & Johnson Vision, Inc., Santa Ana, CA, USA); iDesign Advanced WaveScan (J & J Vision, Inc.); Alcon LADARWave (Alcon Laboratories, Inc., Fort Worth, TX, USA); B & L Zywave (Bausch & Lomb, Inc, Bridgewater, NJ, USA). Tscherning aberrometers have been used less frequently; examples include the WaveLight Allegro Analyzer, which was acquired by Alcon in 2007 and incorporated in the Alcon excimer laser suite. The iTrace (Tracey Technology) is one notable exception that employs a laser ray-tracing based aberrometer.

The various aberrometers use one of two possible mathematical techniques – Fourier or Zernicke expansion polynomials – to describe the aberrations in the optical system. Cade *et al.* [23] analyzed a variety of aberrometers and showed that, in general, there was good agreement among the different aberrometers for both lower-order aberrations and HOAs. However, there were some differences that suggested sensor design contributes to agreement in lower-order aberrations [23]. For example, agreement between aberrometers was more likely for astigmatism if both aberrometers were Hartmann-Shack based than if one was a Hartmann-Shack and the other a Tscherning based. They also showed that Fourier and Zernicke expansions might disagree in HOAs even if using the same type of aberrometer, whether Hartmann-Shack or Tscherning [23].

The various aberrometers also differ in the number of data points analyzed, with a range from 75 (B &L ZyWave) to 1250 (iDesign Advanced Wavescan). Numerous studies have shown that overall, there is relatively good correlation between aberrometers, but there can be significant differences [23–27]. Of note, the iDesign, which is the highest-resolution aberrometer, has not, as per our review of the available literature, been evaluated comparatively as the other aberrometers listed have. Early studies show safety, efficacy, and predictability of the iDesign to be at least as good as earlier aberrometers based on clinical outcomes [18▪▪,28,29▪]. Further studies are needed to fully evaluate the clinical significance of the higher-resolution aberrometer.

Although comparing outcomes achieved between WFG platforms is an indirect way of comparing the aberrometers, it is the most clinically relevant comparison. One confounding factor is that each aberrometer is paired with an excimer laser, and mixing and matching lasers and aberrometers to independently evaluate aberrometers and lasers is not currently possible. The Visx Star S4 Excimer Laser has two aberrometers that can be used to generate ablation profiles and may provide a unique opportunity to control for confounding variables. Jung *et al.*, [30] comparatively evaluated a small group – 90 eyes of 45 patients – with both the iDesign and WaveScan, and found significant differences in measurements of refraction and ocular aberrations. This group also compared a different set of patients for visual results, finding comparable predictability, but superior visual quality, postoperatively in the iDesign cohort. A prospective, contralateral eye comparison of the CustomVue WaveScan to the iDesign Advanced WaveScan, to the best of our knowledge, has not been published, but has the potential to show the true clinical significance of high-resolution aberrometers on visual outcomes in WFG ablations.

In addition, there is a relative paucity of studies comparing the visual outcomes of the various wavefront-guided platforms to each other. The majority

of the published literature comparing wavefront-guided treatments compares them to other excimer or femtosecond ablation platforms [e.g. conventional, WFO, small incision lenticule extraction (SMILE), topography-guided].

WAVEFRONT-GUIDED LASIK UPDATE

Much of the recently published literature regarding WFG LASIK focuses on a few key areas. First, the outcomes associated with the new-generation, high-resolution aberrometer (iDesign Advanced WaveScan) [18▪▪,29▪]. Second, subjective quality of vision outcomes after WFG LASIK treatments [31▪▪,32▪,33,34,35▪], especially when comparing different platforms. Third, comparing WFG LASIK to the other refractive modalities, such as SMILE or topography-guided ablations, for objective visual outcomes [18▪▪,36▪,37▪▪,38▪,39▪▪,40▪,41▪,42▪▪].

Continued technological advancements in both the hardware and software have improved the refractive surgeon's ability to perform increasingly well tolerated and effective surgeries. Prior improvements including iris registration and tracking, and also updates of ablation profiles, have significantly improved outcomes [43–45]. The development of a high-resolution aberrometer (iDesign Advanced WaveScan) is one such advancement. An early study evaluating this high-resolution aberrometer showed significant improvements in astigmatism correction at 1-month postoperative, as measured by vector analysis, when compared to previously reported results and high patient satisfaction [46]. Prakash *et al.* [47] also showed in a prospective case series that visual outcomes when using the iDesign were at least as good as with other aberrometers, and superior to prior Visx WaveScan results – a trend seen in other papers [46,48]. In addition to visual outcomes, aberrometric outcomes were reported by Moussa *et al.* [29▪], who showed a significant reduction in the total root mean square (RMS) value and the level of spherical aberration at 2 months postop for the iDesign & Visx Star S4 syestem, suggesting that it not only limits induction of aberrations, but reduces it in some cases. Another recent study by Schallhorn *et al.* [28] showed outcomes of a large cohort of high myopes who underwent WFG LASIK (iDesign & Visx Star S4) and were evaluated retrospectively. They showed improved results over prior published reports for high myopes, although their outcomes trended towards slight under-correction.

Historically, there have been some reports regarding postoperative visual symptoms with LASIK, largely based on anecdotal evidence. As LASIK remains an elective, self-pay procedure, patient satisfaction is paramount, and until recently, little had been done to directly evaluate subjective visual outcomes, a marker for satisfaction. Consequently, there has been a recent trend to assess patient reported outcomes and subjective visual symptoms for the various laser platforms. In a recent landmark study by Eydelman *et al.* [49▪▪], patients' self-reported symptoms were assessed prospectively, pre and postoperatively, in order to validate the PROWL (Patient Reported Outcomes With LASIK) questionnaire metrics. This study recommended that all patients undergoing LASIK should complete the validated PROWL questionnaire both pre and postoperatively to assess patients' symptoms and satisfaction. Patients were found to under-report negative symptoms and were more likely to report visual and ocular symptoms on a questionnaire rather than to their surgeon.

Other recent studies have specifically looked at subjective quality of vision (QoV) metrics. Kung and Manche [33] assessed QoV prospectively comparing contralateral eye WFG LASIK to WFO LASIK. They found no statistically significant difference between WFO and WFG LASK for individual symptoms, but more patients preferred the WFG LASIK; and, patients with RMS less than 0.3 had more 'excellent vision.' Two more recent publications by Yu and Manche prospectively compared the Visx CustomVue system using WaveScan aberrometry for wavefront-guided LASIK to the Allegretto Allegro aberrometry wavefront-guided system for LASIK. The first [50] showed the Allegretto WFG platform achieved greater predictability, reduced HOAs, and an improved patient-reported clarity, especially in patients with preoperative HOAs greater than 0.3 RMS. However, in the second [34], when comparing other subjective measures of visual quality, with the exception of daytime clarity, there was no difference at 1 year. In addition, patients had no preference for one platform over the other.

In our presented, but unpublished, data comparing WFG (Visx iDesign/Star S4) to WFO (Allegretto WaveLight Wave Eye-Q) we found the two platforms performed equally in terms of QoV symptoms at 6 months postoperative, with the exception of increased haze and glare symptoms in the Visx/iDesign cohort. However, our objective 6-month postoperative data showed significantly superior outcomes with the Visx/iDesign system for mean uncorrected distance visual acuity (UDVA), mean spherical equivalent, increase in corrected distance visual acuity (CDVA), 5 and 25% low-contrast CDVA. Our data will be formally published once the 12-month postoperative follow-up period is complete.

One question that remains unanswered in many regards is what laser platform is best for a given clinical situation. Many studies have aimed to

answer this question. One recent review article by Piñero and Teus [42▪▪] expertly reviews the published literature comparing WFG LASIK and SMILE prior to 2016, and summarizes much of known outcomes, advantages, and limitations of these two platforms. More recently, Kobashi *et al.* [36▪] retrospectively analyzed 2-year outcomes of 60 eyes, 30 WFG LASIK (B & L Zywave) and 30 SMILE (Visumax), and found SMILE offered more predictable refractive results. It should be, however, noted that this study did not compare the high-resolution aberrometer (iDesign), but the lowest-resolution aberrometer (Zywave). In light of the results from other studies, as reviewed Piñero and Teus [42▪▪], generalizing the results for WFG LASIK and SMILE based on a small retrospective study, may not fully describe the complexities of comparing the two lasers. In addition, the outcomes from this study in the SMILE cohort were notably better than other published results [51,52] and may not accurately reflect the true predictability of SMILE.

Khalifa *et al.* [37▪▪,39▪▪], in two other recent studies, continued the general trend of superior results with WFG LASIK when compared to SMILE and WFO LASIK. They showed that astigmastism management, analyzed by vector analysis, is more predictable when using the Visx/iDesign high-resolution aberrometer than either SMILE or WFO LASIK. Possibly, the lack of control of cyclotorsion is a main factor in astigmatic under-correction with small-incision lenticule extraction and the superior results with WFG LASIK [37▪▪]. They also propose that less induction of HOAs and more predictabile cylinder correction seen in WFG LASIK may, in addition to the higher-resolution aberrometer, be attributable to other factors such as axial and torsional registration, improved centration due to centroid shift, and more energy delivery to the mid-periphery of the cornea [39▪▪].

Toda *et al.* [40▪] prospectively compared WFG LASIK (iDesign & Visx Star S4) to topography-guided LASIK (OPD-Scan & EC-5000 CXII, Nidek) and found that although visual function was excellent with both platforms, some subjective symptoms related to QoV were significantly milder in the WFG LASIK group. Another study comparing 1-year postoperative vector analysis of astigmatism change of WFG LASIK (iDesign & Visx Star S4) to SMILE (Visumax) showed significantly better results in the WFG group; both the magnitude and angle of error were significantly greater in the SMILE group [37▪▪].

Moshirfar *et al.* [18▪▪] analyzed and compared the US Food and Drug Administration (FDA)-reported visual outcomes for three newly approved laser platforms: the Visx iDesign, a WFG platform; the Alcon Contoura, a topography-guided platform; and the Nidek CATz, another topography-guided platform. The Alcon Contoura had a significantly higher percentage of eyes with UDVA better than 20/20. However, as noted by the same group [18▪▪], the data submitted for US FDA approval of the Visx iDesign consistently had greater preoperative sphere, cylinder, and spherical equivalent when compared to the other platforms analyzed; specifically, the Contoura had significantly lower sphere, cylinder, and spherical equivalent. Nonetheless, when treatment groups were stratified by spherical equivalent, the higher myopic treatment groups had significantly better results with the Alcon Contoura in line with prior studies [53] showing topography-guided ablations may outperform alternatives in highly aberrated corneas. The Visx showed that largest improvement in mesopic contrast sensitivity and the Contoura showed the largest improvement in photopic contrast sensitivity.

CONCLUSION

Modern keratorefractive surgery has continued to improve with the advent of improved technologies and new platforms. WFG LASIK remains an excellent, well tolerated, and predictable surgery that has excellent patient satisfaction. With the development of a high-resolution aberrometer, we anticipate continued improvement in outcomes, and also further clarification of the role each platform has in the refractive surgeon's armamentarium.

Acknowledgements

None.

Financial support and sponsorship

This study was not supported by the Department of Anesthesiology, London Hospital.

Conflicts of interest

Edward E. Manche, MD: Consultant, Avellino Laboratories, Avedro, Carl Zeiss Meditec, J & J Vision, Shire; Sponsored research: Allergan, Alcon, Avedro, Avellino Laboratories, Carl Zeiss Meditec, J & J Vision; Equity: Krypton Vision, RxSight, Seros Medical; Patents: Seros Medical. Joshua Roe, MD: None.

REFERENCES AND RECOMMENDED READING

Papers of particular interest, published within the annual period of review, have been highlighted as:

- ▪ of special interest
- ▪▪ of outstanding interest

1. Bamashmus MA, Hubaish K, Alawad M, Alakhlee H. Functional outcome and patient satisfaction after laser in stiu keratomileusis for correction of myopia and myopic astigmatism. Middle East Afr J Ophthalmol 2015; 22:108–114.

2. Schallhorn SC, Farjo AA, Huang D, *et al.,* American Academy of Ophthalmology. Wavefront-guided LASIK for the correction of primary myopia and astigmatism a report by the American Academy of Ophthalmology. Ophthalmology 2008; 115:1249–1261.
3. Chalita MR, Chavala S, Xu M, Krueger RR. Wavefront analysis in post-LASIK eyes and its correlation with visual symptoms, refraction, and topography. Ophthalmology 2004; 111:447–453.
4. Yamane N, Miyata K, Samejima T, *et al.* Ocular higher-order aberrations and contrast sensitivity after conventional laser in situ keratomileusis. Invest Ophthalmol Vis Sci 2004; 45:3986–3990.
5. Mutyala S, McDonald MB, Scheinblum KA, *et al.* Contrast sensitivity evaluation after laser in situ keratomileusis. Ophthalmology 2000; 107:1864–1867.
6. Buzzonetti L, Iarossi G, Valente P, *et al.* Comparison of wavefront aberration changes in the anterior corneal surface after laser-assisted subepithelial keratectomy and laser in situ keratomileusis: preliminary study. J Cataract Refract Surg 2004; 30:1929–1933.
7. Chalita MR, Xu M, Krueger RR. Correlation of aberrations with visual symptoms using wavefront analysis in eyes after laser in situ keratomileusis. J Refract Surg 2003; 19:S682–S686.
8. Moreno-Barriuso E, Lloves JM, Marcos S, *et al.* Ocular aberrations before and after myopic corneal refractive surgery: LASIK-induced changes measured with laser ray tracing. Invest Ophthalmol Vis Sci 2001; 42:1396–1403.
9. Kohnen T. Classification of excimer laser profiles. J Cataract Refract Surg 2006; 32:543–544.
10. Perez-Straziota CE, Randleman JB, Stulting RD. Objective and subjective preoperative refraction techniques for wavefront-optimized and wavefront-guided laser in situ keratomileusis. J Cataract Refract Surg 2009; 35:256–259.
11. He L, Liu A, Manche EE. Wavefront-guided versus wavefront-optimized laser in situ keratomileusis for patients with myopia: a prospective randomized contralateral eye study. Am J Ophthalmol 2014; 157:1170–1178.
12. Cummings AB, Kelly GE. Optical ray tracing-guided myopic laser in situ keratomileusis: 1-year clinical outcomes. Clin Ophthalmol 2013; 7:1181–1191.
13. Kim A, Chuck RS. Wavefront-guided customized corneal ablation. Curr Opin Ophthalmol 2008; 19:314–320.
14. Mysore N, Krueger R. Advances in refractive surgery: May 2013 to June 2014. Asia Pac J Ophthalmol (Phila) 2015; 4:112–120.
15. Holland S, Lin DT, Tan JC. Topography-guided laser refractive surgery. Curr Opin Ophthalmol 2013; 24:302–309.
16. Lin DT, Holland S, Tan JC, Moloney G. Clinical results of topography-based customized ablations in highly aberrated eyes and keratoconus/ectasia with cross-linking. J Refract Surg 2012; 28(11 Suppl):S841–S848.
17. Chen X, Stojanovic A, Zhou W, *et al.* Transepithelial, topography-guided ablation in the treatment of visual disturbances in LASIK flap or interface complications. J Refract Surg 2012; 28:120–126.
18. ■■ Moshirfar M, Shah TJ, Skanchy DF, *et al.* Comparison and analysis of FDA reported visual outcomes of the three latest platforms for LASIK: wavefront guided Visx iDesign, topography guided WaveLight Allegro Contoura, and topography guided Nidek EC-5000 CATz. Clin Ophthalmol 2017; 4:135–147.

This retrospective study analyzed and compared the US FDA clinical data from the three most recently approved LASIK platforms and showed the Alcon Contoura had the best UDVA and the Visx iDesign had the most improvement in mesopic contrast sensitivity.

19. Molebny VV, Panagopoulou SI, Molebny SV, *et al.* Principles of ray tracing aberrometry. J Refract Surg 2000; 16:S572–S575.
20. Burns SA. The spatially resolved refractometer. J Refract Surg 2000; 16:S566–S569.
21. Platt BC, Shack R. History and principles of Shack-Hartmann wavefront sensing. J Refract Surg 2001; 17:S573–S577.
22. Mrochen M, Kaemmerer M, Mierdel P, *et al.* Principles of Tscherning aberrometry. J Refract Surg 2000; 16:S570–S571.
23. Cade F, Cruzat A, Paschalis EI, *et al.* Analysis of four aberrometers for evaluating lower and higher order aberrations. PLoS One 2013; 8:e54990.
24. Rozema JJ, Van Dyck DE, Tassignon MJ. Clinical comparison of 6 aberrometers. Part 1: technical specifications. J Cataract Refract Surg 2005; 31:1114–1127.
25. Burakgazi AZ, Tinio B, Bababyan A, *et al.* Higher order aberrations in normal eyes measured with three different aberrometers. J Refract Surg 2006; 22:898–903.
26. Visser N, Berendschot TT, Verbakel F, *et al.* Evaluation of the comparability and repeatability of four wavefront aberrometers. Invest Ophthalmol Vis Sci 2011; 52:1302–1311.
27. Rozema JJ, Van Dyck DE, Tassignon MJ. Clinical comparison of 6 aberrometers. Part 2: statistical comparison in a test group. J Cataract Refract Surg 2006; 32:33–44.
28. Schallhorn SC, Venter JA, Hannan SJ, Hettinger KA. Outcomes of wavefront-guided laser in situ keratomileusis using a new-generation Hartmann-Shack aberrometer in patients with high myopia. J Cataract Refract Surg 2015; 41:1810–1819.
29. ■ Moussa S, Dexl AK, Krall EM, *et al.* Visual, aberrometric, photic phenomena, and patient satisfaction after myopic wavefront-guided LASIK using a high-resolution aberrometer. Clin Ophthalmol 2016; 12:2489–2496.

This prospective case series showed that a high-resolution aberrometer was predictable, effective, and had high patient satisfaction.

30. Jung JW, Chung BH, Han SH, *et al.* Comparison of measurements and clinical outcomes after wavefront-guided LASEK between iDesign and WaveScan. J Refract Surg 2015; 31:398–405.
31. ■■ Chen LY, Manche EE. Comparison of femtosecond and excimer laser platforms available for corneal refractive surgery. Curr Opin Ophthalmol 2016; 27:316–322.

This review of the available femtosecond and excimer platforms summarizes the advancements in technology that have continued to improve visual outcomes in keratorefractive surgery.

32. ■ Sáles CS, Manche EE. Comparison of self-reported quality of vision outcomes after myopic LASIK with two femtosecond lasers: a prospective, eye-to-eye study. Clin Ophthalmol 2016; 1:1691–1699.

This prospective, randomized contralateral eye study comparing patient self-reported visual symptoms found no difference between the the iFS 60 kHz and the iFS 150 kHz systems.

33. Kung JS, Manche EE. Quality of vision after wavefront-guided or wavefront-optimized LASIK: a prospective randomized contralateral eye study. J Refract Surg 2016; 32:230–236.
34. Yu CQ, Manche EE. Subjective quality of vision after myopic LASIK: prospective 1-year comparison of two wavefront-guided excimer lasers. J Refract Surg 2016; 32:224–229.
35. ■ Lee MD, Manche EE. Quality of vision after wavefront-guided laser in situ keratomileusis or photorefractive keratectomy: Contralateral eye evaluation. J Cataract Refract Surg 2017; 43:54–59.

This prospective, randomized, contralateral eye case series showed subjective quality of vision was better at 1 month postoperatively in LASIK eyes than PRK eyes, and this difference was greatest in eyes with higher preoperative HOAs, but at subsequent visits there was no difference in subjective QoV.

36. ■ Kobashi H, Kamiya K, Igarashi A, *et al.* Two-years results of small-incision lenticule extraction and wavefront-guided laser in situ keratomileusis for Myopia. Acta Ophthalmol 2018; 96:e119–e126.

This retrospective case-control series compared 60 eyes, 30 SMILE to 30 WFG LASIK, and showed SMILE had more predictability and refractive stability than WFG LASIK.

37. ■■ Khalifa MA, Ghoneim AM, Shaheen MS, Piñero DP. Vector analysis of astigmatic changes after small-incision lenticule extraction and wavefront-guided laser in situ keratomileusis. J Cataract Refract Surg 2017; 43:819–824.

This prospective case series showed WFG LASIK was more effective than SMILE at correcting astigmatism.

38. ■ Chen X, Wang Y, Zhang J, *et al.* Comparison of ocular higher-order aberrations after SMILE and Wavefront-guided Femtosecond LASIK for myopia. BMC Ophthalmol 2017; 17:42.

This retrospective case series showed overall induction of HOAs was similar for SMILE and WFG LASIK, but SMILE had more induced vertical coma, likely the result of imperfect centration.

39. ■■ Khalifa MA, Alsahn MF, Shaheen MS, Pinero DP. Comparative analysis of the efficacy of astigmatic correction after wavefront-guided and wavefront-optimized LASIK in low and moderate myopic eyes. Int J Ophthalmol 2017; 10:285–292.

This prospective case series compared astigmatism correction of WFO and high-resolution WFG LASIK for treatment of low and moderate myopia found WFG LASIK more effective in correcting astigmatism and superior control of HOAs.

40. ■ Toda I, Ide T, Fukumoto T, Tsubota K. Visual outcomes after LASIK using topography-guided vs wavefront-guided customized ablation systems. J Refract Surg 2016; 32:727–732.

This prospective, randomized study showed the new high-resolution aberrometer for WFG LASIK may offer superior subjective QoV and better contrast sensitivity than topography-guided LASIK.

41. ■ Ye MJ, Liu CY, Liao RF, *et al.* SMILE and wavefront-guided LASIK outcompete other refractive surgeries in ameliorating the induction of high-order aberrations in anterior corneal surface. J Ophthalmol 2016; 2016:8702162.

This prospective case series showed WFG LASIK and SMILE were better at minimizing induced HOAs than conventional LASIK with microkeratome or conventional LASIK with femtosecond flap creation.

42. ■■ Piñero DP, Teus MA. Clinical outcomes of small-incision lenticule extraction and femtosecond laser-assisted wavefront-guided laser in situ keratomileusis. J Cataract Refract Surg 2016; 42:1078–1093.

This review article summarizes the available literature comparing WFG LASIK to SMILE through 2015.

43. Zhang J, Zhou YH, Li R, Tian L. Visual performance after conventional LASIK and wavefront-guided LASIK with iris-registration: results at 1 year. Int J Ophthalmol 2013; 6:498–504.
44. Wu J, Zhong X, Yang B, *et al.* Combined wavefront-guided laser in situ keratomileusis and aspheric ablation profile with iris registration to correct myopia. J Cataract Refract Surg 2013; 39:1059–1065.
45. Narváez J, Brucks M, Zimmerman G, *et al.* Intraoperative cyclorotation and pupil centroid shift during LASIK and PRK. J Refract Surg 2012; 28:353–357.
46. Schallhorn S, Brown M, Venter J, *et al.* Early clinical outcomes of wavefront-guided myopic LASIK treatments using a new-generation Hartmann-Shack aberrometer. J Refract Surg 2014; 30:14–21.

47. Prakash G, Srivastava D, Suhail M. Femtosecond laser-assisted wavefront-guided LASIK using a newer generation aberrometer: 1-year results. J Refract Surg 2015; 31:600–606.
48. Smadja D, De Castro T, Tellouck L, *et al.* Wavefront analysis after wavefront-guided myopic LASIK using a new generation aberrometer. J Refract Surg 2014; 30:610–615.
49. Eydelman M, Hilmantel G, Tarver ME, *et al.* Symptoms and satisfaction of ■■ patients in the Patient-Reported Outcomes With Laser In Situ Keratomileusis (PROWL) studies. J Am Med Assoc Ophthalmol 2017; 135:13–22.
This prospective observational cohort study reported the frequency of patient reported visual symptoms, dry eye symptoms and patient satisfaction with both LASIK and their postoperative vision.
50. Yu CQ, Manche EE. Comparison of 2 wavefront-guided excimer lasers for myopic laser in situ keratomileusis: one-year results. J Cataract Refract Surg 2014; 40:412–422.
51. Pedersen IB, Ivarsen A, Hjortdal J. Three-year results of small incision lenticule extraction for high myopia: refractive outcomes and aberrations. J Refract Surg 2015; 31:719–724.
52. Yıldırım Y, Alagöz C, Demir A, *et al.* Long-term results of small-incision lenticule extraction in high myopia. Turk J Ophthalmol 2016; 46:200–204.
53. Lin DT, Holland SR, Rocha KM, Krueger RR. Method for optimizing topography-guided ablation of highly aberrated eyes with the ALLEGRETTO WAVE excimer laser. J Refract Surg 2008; 24:S439–S445.