Customised Laser Refractive Treatments for Better Patient Outcomes

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LASIK is the most common refractive operation.[1] Globally over 3.5 million refractive surgery procedures are performed each year with 85 per cent of those in the US being performed using LASIK.[1] It has been shown to have a better long-term satisfaction rate and safety profile than contact lenses[2] and continues to be highly investigated within the literature. We have come to expect repeatable and excellent results with a known, high degree of safety.

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LASIK seemed like a gigantic leap in innovation compared to photorefractive keratectomy (PRK) and this was further advanced by the use of femtosecond laser flap makers offering "blade-free" LASIK compared to LASIK performed with the use of keratomes.

While there have been many advances in LASIK, those that have significantly influenced quality of vision have been advances in the ablation pattern on the conventional ablation. These patterns are:

- Wavefront guided (WFG)
- Wavefront optimised (WFO)
- Q adjusted
- Topographic guided (TG)

What would be most desirable, though, would be to routinely give patients better vision than they have ever had in terms of improved best-corrected visual acuity (BCVA). This might be achieved by eliminating pre-existing higher order aberrations (HOA) through customisation. It might be that topographic guided ablations are the answer.

Topography-guided (TG) excimer laser ablation uses topography data to customise the ablation profile. Customisation seeks to not only correct refractive error, but to improve the optics of the eye and the quality of vision. Wavefront-guided (WFG) customised LASIK promised 'super vision' but never fully delivered. TG seems to have more potential.

PROBLEMS WITH CONVENTIONAL CORNEAL REFRACTIVE SURGERY

Conventional Ablations

PRK enjoyed enormous popularity over the years, but problems emerged. Many patients had significantly reduced night vision with halos. In Germany, where a night vision simulation is used in drivers' license testing, some who had had PRK were denied the right to drive at night.[3] Other studies of conventional ablation found an increase in night vision disturbances including glare disability and image degradation.[4] Contrast sensitivity was found to be worse than spectacle wear[5] and others showed a permanent reduction of contrast in low light.[6-8]

The problems can be attributed to an increase in spherical aberration (SA) and other higher order aberrations (HOA) induced by the ablation.[6,7] HOA are associated with poor night vision with glare and halos[4,9] and were increased in proportion to the attempted correction.[10]

The error of conventional ablation profiles should have been blindingly obvious, but it took some years to understand. The more peripheral the excimer laser ablation, the greater the angle of incidence of the beam. The energy density of the incident beam in the periphery of the optic zone was therefore lower, being spread over a greater area. Some of the energy was reflected. It was called the 'cosine rule' and algorithms were adjusted to put more energy in the periphery to compensate.

Caption here

The salvation of LASIK came in the form of Wavefront Optimised and Wavefront Guided ablations.

ABLATION PATTERN DEVELOPMENTS

Wavefront Guided Ablations

A Wavefront guided (WFG) ablation treatment is based on whole eye aberrometry and is a true customised treatment. The aim is to treat spherical aberration, coma, trefoil and other HOA detected on aberrometry to reduce them.

Results were significantly improved. For instance the Wavelight platform, in one of the early studies, had no statistically significant increase on HOA.[11] The turning point for LASIK was when vision was routinely improved rather than routinely diminished in some way. In an American Academy of Ophthalmology (AAO) meta-analysis of WFG treatments, WFG ablations were found to induce less HOA, with fewer halos, less glare and better night vision.[11]

There are several difficulties with WFG treatments though. They require an expensive aberrometer to measure the wavefront, upon which the ablation pattern is determined. Often an adequate acquisition is not possible and the whole process takes considerable staff time and cost.

Wavefront Optimised Ablations

Wavefront optimised (WFO) ablations were developed for these reasons. They were simpler and less expensive to perform. They simply added a fixed laser compensation in the periphery. They were not customised treatments. They paid no attention to pre-existing HOA. Multiple studies have showed they were inferior to WFG treatments.[12-16] Unfortunately, despite the evidence in the literature on efficacy, WFG treatments are being performed in lesser numbers with many surgeons favouring the less time consuming and affordable alternatives.[1]

Q Adjusted Treatments

Q values are used to describe the shape of a surface. A perfectly spherical surface would have a Q value of 0.0. A prolate surface, like the human cornea, has a negative Q value. Corneal spherical aberration and Q value are not the same thing however: as spherical aberration describes how a wavefront deviates after passing through a refracting surface, the cornea Q value will impact spherical aberration. Following traditional corneal refractive surgery a patient's corneal Q value will have been altered, which helps to understand why spherical aberration is induced.

An improvement on WFO is the Q adjusted treatment. A surgeon-variable peripheral compensation is made, aiming for a pre-determined corneal Q value. These are like WFO treatments in that there is peripheral compensation to reduce SA induction of conventional treatment, but the amount of compensation can be varied. When compared to WFO treatments, Q-adjusted treatments provide better corneal optics in corrections up to -5.0D.[17]

Topographic Guided Treatments

Topographic guided (TG) treatments represent another strategy to produce optimum corneal shape. Instead of using aberrometry as in WFG, the corneal topography is used to calculate the ablation pattern. The Placido image data is converted to height data. The system software builds a targeted shape and arranges laser pulses to create this shape.

TG treatments were once only used for treatment of irregular, pathological corneas. Early reports detailed successful corneal regularisation and improved vision following corneal trauma, keratoplasty, central islands and other laser ablation problems, such as decentred zones and small optic zones.[18,19] Since then other applications of TG treatments have been reported including using these in conjunction with corneal collagen cross-linking for the treatment of keratoconus.[20]

CONTOURA VISION, ALCON WAVELIGHT TOPOGRAPHIC-GUIDED LASIK

While TG LASIK for irregular cornea continues to be of strong interest, reports of using these customised treatments in virgin eyes can also be found within the literature that demonstrate satisfactory outcomes overall. Some suggest superiority compared to the more commonly used ablation patterns.[21-24]

As a requirement for FDA registration of the Alcon Wavelight platform for performing TG treatments, results of surgery on normal ametropic eyes had to be presented first. An important study resulted and was reported by Stulting in the 2016 FDA pre-market approval document and in the *Journal of Cataract and Refractive Surgery*. The results were outstanding,[25,26] perhaps even unexpectedly so. Alcon recognised they had something new and worthwhile and trademarked TG treatment of virgin eyes: 'Contoura Vision'. I have been using this modality in virgin eyes undergoing refractive surgery for just over 12 months now.

The feature is available on the earlier models of the Alcon Wavelight lasers: the 200 HZ Allegretto and the 400 Hz Eye Q. The newer EX 500 laser is employed in our clinic. This laser features short treatment time with its 500 Hz repetition rate. The shots are controlled by a 1050 Hz multidimensional tracker with a latency of 2ms. Fast small spot size scanning lasers are required for customised treatments. It is teamed with the FS 200 femtosecond laser for flap creation.

> "advances... that have significantly influenced quality of vision have been advances in the ablation pattern on the conventional ablation"

The platform can import topographic data into the laser treatment-planning mode from the Placido-disk topographer (Topolyzer Vario, WaveLight), topometry data from a Scheimpflug-based device (Oculyzer II-WaveLight) as well aberrometric data (Allegro, Wavelight). A closed Ethernet network (Wavenet) connects all devices. Together the system is known as the Alcon Wavelight Refractive Suite.

The important laser input data comes from the Topolyzer Vario, which employs 44 edges and 22,000 data points. In addition to data on corneal curvature, it detects the pupil and the corneal apex. It also takes an infrared image of the iris that is available to the EX500 excimer laser for exact registration of the input data to the exact spot on the cornea to be treated. This registration is not only in x and y-axes, but cyclotorsional error is automatically accounted for.

Several topography measurements are made and checked for similarity. Aberrant images are discarded and a mean map is used to calculate the ablation pattern. The Topolyzer data is transferred to the EX 500 through the Refractive Suite Ethernet network. The surgeon chooses the refraction to be treated and the aimed Q value.

The choice of refraction to treat is key. The topography, of course contains no information about the sphere, but it calculates the keratometric cylinder. The choice between whether to treat the subjective refractive astigmatism (RA) or the topographic astigmatism (TA) here goes to the heart of

the controversy about the reasons subjective refraction and keratometric cylinder differ. The answer is probably that treatment of the keratometric cylinder is better. This is further discussed below. The treatment proceeds in the same way as a non-customised WFO correction. Insignificantly extra corneal ablation depth is required.

The first major study of Contoura was reported in the 2016 FDA pre-market approval document, part of which is reported by Stulting in the *Journal of Cataract and Refractive Surgery*.[25,26]

The study was a prospective multicentre trial involving 249 myopic eyes with spherical correction up to -9.00 D and cylindrical correction up to 6.00 D. Topographic acquisition was with the Alcon Wavelight Topolyzer. The data, including the calculated ablation, was transferred to the Allegretto excimer laser. The subjective refraction was used and not the topographic astigmatism.

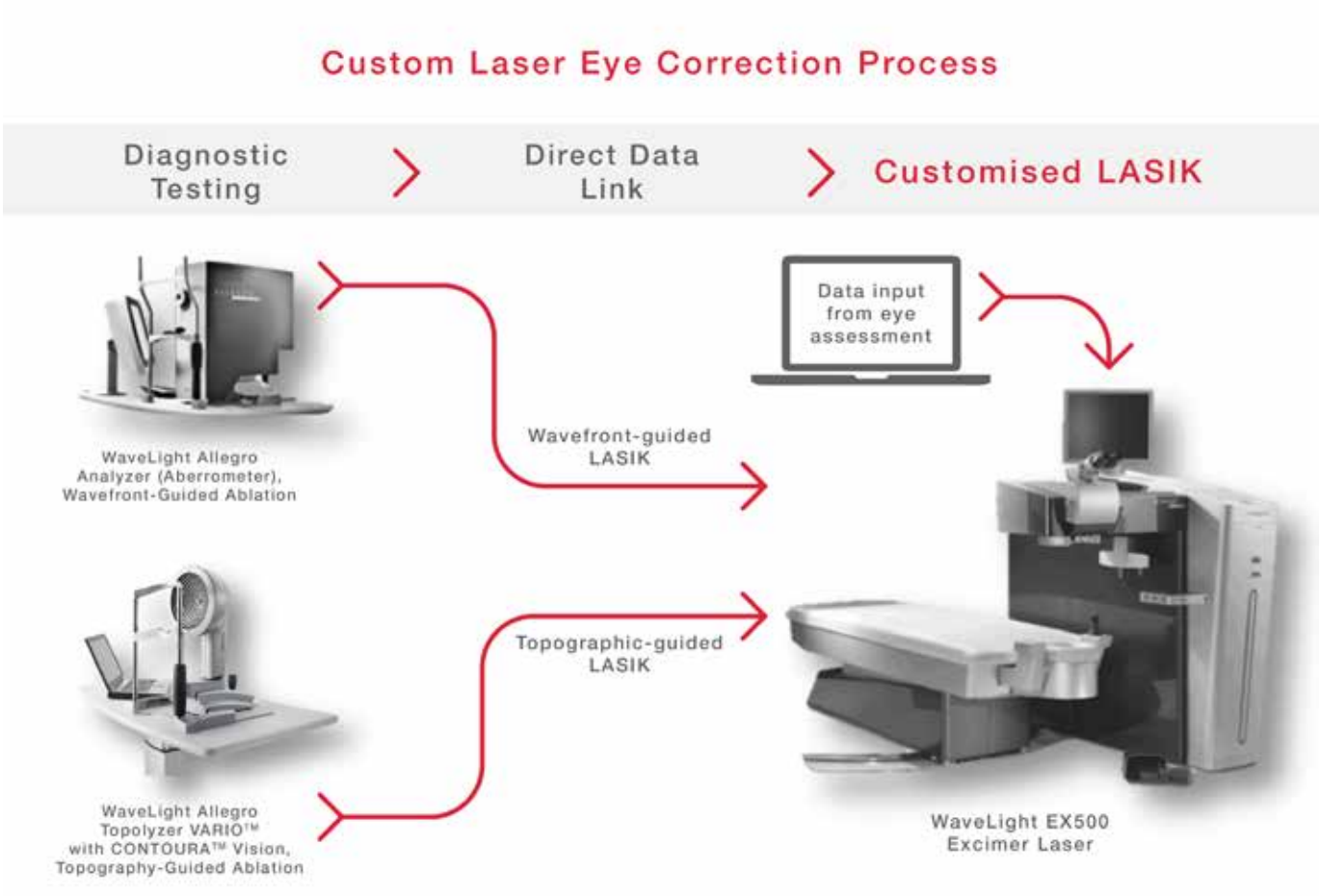
Key outcomes of the study were:

- Forty per cent of cases gained lines of best corrected visual acuity (BCVA);
- Mean contrast sensitivity values at every spatial frequency for mesopic, photopic, with and without glare, were greater post than best-corrected contrast sensitivity before surgery;
- On wavefront aberrometry at pupil size 5mm, SA was unchanged pre to post-op;
- On corneal wavefront analysis, total HOA increased median value by only 2.5 per cent,
- Patients, on average, experienced less light sensitivity, night driving difficulty, reading difficulty and glare than before surgery,
- Halo, starburst, dryness and foreign body sensation were, on average, unchanged by surgery.

The features often associated with LASIK: increased SA and other HOA, dry eye, light sensitivity, worsened night vision and lowered mesopic contrast sensitivity were, on average, either not worsened by the procedure or improved! These are exceptional outcomes, but further studies, and in particular, comparative studies are required.

The problem facing studies is that real improvements will necessarily be small because of the ceiling effect of studying surgery with such high efficacy. Large numbers are often required to adequately power comparative studies. Randomised fellow eye studies are very powerful, but expensive and difficult to perform. El Awady performed a fellow eye study on 84 patients undergoing LASIK. One eye was treated with TG LASIK and the other WFG LASIK. He found better UCVA with TG. HOA terms were increased with WFG and decreased with TG LASIK.[24] Shetty performed a randomised fellow-eye study of TG v. WFG treatments on the same laser, in 30 myopes with and without astigmatism. He found similar visual results but statistically lower post-op total RMS HOA and lower SA and change in corneal Q value.[27]

The most interesting study of all is from Kanellopoulos. It was a randomised fellow-eye study of 50 patients. One eye was treated with the Alcon Wavelight EX500 excimer laser employing TG mode or Contoura Vision using the clinical refraction. The other eye was treated in the same way but using a technique he calls 'topographic modified refraction (TMR)'.[28] It is the topographic astigmatism, with a small modification in sphere for greater or lesser cylinder and a factor for spherical change, that the irregular component of the ablation induces. All previous studies had used clinical refraction and it is no surprise that these eyes had similar outcomes to the FDA T-CAT Study (which also used treated refractive astigmatism). While the results which treated refractive astigmatism are impressive, what is more interesting is what happened with the eyes in which topographic cylinder, rather than subjective cylinder, was used. These eyes experienced a 67 per cent increase in one or more lines of BCVA, twice what the fellow eyes achieved.[28] HOA, as measured with the Allegro aberrometer, were very much lower in these eyes.[28] Contrast sensitivity was even more improved on pre-op than the fellow eye and most importantly, residual cylinder was less than in eyes where subjective



cylinder was used.[28] It is quite possible that results of other studies on Contoura Vision might also be similarly improved.

How do we explain these results? There are several approaches. Kanellopoulos theorises that the TMR bypasses active, compensatory lenticular astigmatism (LA) active in young individuals, which reduces the refractive astigmatism (RA) generally below the topographic astigmatism (TA).[28]

What are the reasons for the often-observed difference in TA and RA? Alpins found, in the absence of LA there was often a difference between RA and TA.[29] He attributed this to 'irregular astigmatism' (i.e. asymmetry of topographic hemi-meridians). He used this term before the parlance of wavefront error and HOA became popular.

Zhou et. al. recently examined corneas with high coma and low TA. They found vertical coma can subjectively refract as against-the-rule astigmatism and horizontal coma as with-the-rule astigmatism.[30] They suggest then, that in TG ablations, where coma is being taken into account and RA is used in planning, the coma itself would be treated as well as the astigmatic effect of that coma, resulting in a double treatment and perhaps a poorer result. It supports the use of topographic astigmatism, not refractive astigmatism in topographic treatments.

WHY MIGHT TG ABLATIONS BE BETTER THAN WFG?

The reasons for the excellent results are probably several:

- WFG seeks to treat the aberrations in the crystalline lens and the cornea on the cornea. The lenticular aberrations change with time and accommodation;
- TG only uses the cornea to guide it, where most of the astigmatism will lie;
- The zone of acquisition on the cornea in TG is generally greater than for WFG, which is limited by pupil size. WFG acquisition might not adequately represent shape disorders extending beyond the pupil;
- Perfect registration of the corneal topographic data, with the eye at the time of surgery, avoids the registration errors inherent in WFG treatments. Imperfect registration must affect the outcome;
- TG treatment is centred on the corneal apex, as is the topographic acquisition. This is the closest point to the corneal intercept of the visual axis of the schematic eye. This might confer optical advantage.

BIOMECHANICS

Along with visual outcomes, referring healthcare professionals may be concerned about the impact of corneal refractive surgery on one's corneal biomechanics and the subsequent risk of ectasia. An audit conducted by Moshirfar and colleagues, of 1,992 eyes followed up for four years, found the rate of ectasia was 0.25 per cent and this could have been reduced to 0.05 per cent with tighter pre-op review protocols and exclusion of subclinical keratoconus.[31] Despite the incidence being low, it is encouraging to know that collagen cross-linking has been shown to be successful at stopping the progression of ectasia.[32]

Small incision lenticule extraction (SMILE) initially promised to provide an answer to this potential side-effect of corneal refractive surgery. The literature to date has failed to provide any evidence to support this with multiple studies concluding that both SMILE and LASIK reduce corneal hysteresis (CH) and corneal resistance factor (CRF) with no statistical difference between the two procedures.[33-35]

> "The features often associated with LASIK... were, on average, either not worsened by the procedure or improved"

Wang et al published a case study of ectasia following SMILE in 2015. The authors concluded that "This report documents corneal ectasia as a complication of small incision lenticule extraction and highlights the importance of preoperative evaluation and the need for long-term follow-up". After only a few

years of SMILE, there are now seven eyes reported as developing corneal ectasia.[36-40] As a result, it is generally accepted amongst refractive surgeons that the exclusion criteria for both procedures with regard to subclinical keratoconus remains the same. As previously mentioned, evidence is emerging as to the safety of using collagen corneal cross-linking in conjunction with topographically guided LASIK in such patients.[20]

POSITIVES FOR QUALITY OF LIFE

While corneal refractive surgery remains a significant investment for patients compared to the stand-alone cost of glasses or contact lenses, it would be difficult to deny the potential positive impacts that such a procedure could have to improving quality of life.

People who will benefit include shift workers who need to be on call throughout the night, mothers tending to newborns and toddlers, travellers or people without convenient access to on-demand eye care, those with active life-styles including motorcycle riders and people wanting to play sport, particularly water-sports, as well as those who have contact lens non-compliance or simply anatomy that is not favourable for spectacles wear… people from all walks of life exist that could benefit from surgical vision correction. As healthcare professionals, we should be aiming to offer the best treatments available to these patients with the least risk of side-effects. Customisation of LASIK ablation patterns, in particular those performed using Contoura Vision, appear to be one of the most predictable ways of achieving this.[12-17,25,26]

CONCLUSION

Topographic-guided treatments from the Alcon Wavelight EX 500 have given some of the best results seen in laser corrective surgery.[25,26] It looks like results can be improved even further by the input of topographic astigmatism rather than refractive astigmatism.[28] This treatment has become the first choice for all LASIK in my clinic.

Other platforms have not shown equivalent results, but doubtless we will see them develop. Such corneal regularisation and improvement in optics is not an option for small incision lenticule extraction. They must rely on a non-customised pattern of shape change. It is difficult to see a road forward for SMILE to match TG LASIK results.

Most laser surgery performed today is WFO. I believe that we should be trying to do better for our patients, and use a customised treatment every time it is possible. There is now such renewed interest in TG ablations that I am sure we will be hearing much more. mi

Dr Rick Wolfe is one of Australia's most accomplished and experienced eye surgeons. He is internationally recognised and is regularly invited to speak and present his own statistics as well as conduct live surgery at world eye surgery conferences.

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