The introduction of the excimer laser for refractive surgery has opened up the possibility to change the corneal curvature to compensate for refractive errors of the eye. In the case of small spot hyperopic laser in situ keratomileusis (H–LASIK), excimer laser systems produce a steepness of the cornea by ablating mainly at the periphery of the cornea.

Hyperopic laser in situ keratomileusis (H-LASIK) treatments induce aberrations. Other studies attempted to determine the changes in corneal asphericity after H-LASIK, and found a extreme corneal prolateness, indicating large amounts of induced negative spherical aberrations. This is predominantly caused by the loss of efficiency at the periphery and the biomechanics of the cornea, and has been described previously by other authors.

Later studies on hyperopic treatments with excimer lasers also suggested an increase in negative spherical aberration. By comparison of the intended and achieved topographical changes after H-LASIK surgery, de Ortueta et al. obtained information as to whether the corneal power was changed as calculated, thus providing help in optimizing the ablation profiles (either in terms of nomogram adjustments or more sophisticated optimization algorithms like multifocal algorithms). Additionally, actual under- or overcorrection can be differentiated from under- or overcorrection due to wrong intended correction in this way.

A study by O’Brart et al. analyzing hyperopic LASEK using a Munnerlyn based classical profile and a
7 mm optical zone with a total treated zone of 9 mm demonstrated that the induced aberrations were lower than with the Munnerlyn profile in LASIK.

A recent study by de Ortueta et al.\textsuperscript{14}, using aspheric aberration neutral profiles showed that induced aberrations are less than in previous publications.

\section*{METHODS}

The first 80 eyes (40 patients) with preoperative manifest hyperopia or hyperopic astigmatism treated using the ESIRIS “aberration neutral” (Aberration-Free\textsuperscript{TM}) aspheric ablation profiles were retrospectively analysed.

All ablations were non-customised based on “aberration neutral” profiles and calculated using the ORK-CAM software module. Aspheric aberration neutral (Aberration-Free\textsuperscript{TM}) profiles are not based on the Munnerlyn proposed profiles\textsuperscript{15}, and go beyond that by adding some aspheric characteristics to balance the induced of spherical aberration\textsuperscript{16,17} (prolateness optimization\textsuperscript{18,19}).

The aberration neutral (Aberration-Free\textsuperscript{TM}) profile is aspherical-based\textsuperscript{20}, including a multidynamic aspherical transition zone, aberration and focus shift compensation due to tissue removal, pseudo-matrix based spot positioning, enhanced compensation for the loss of efficiency\textsuperscript{7}, and intelligent thermal effect control; all based on theoretical equations validated with ablation models and clinical evaluations.

A 6.7 mm central fully corrected ablation zone was used in all eyes with a variable transition size automatically provided by the laser related to the planned refractive correction (6.9 mm to 9.2 mm). The ablation was performed using the ESIRIS excimer laser (SCHWIND eye-tech-solutions, Kleinostheim, Germany) which is a flying-spot laser using real ablatice spot shape (volume) locally considered through a self-constructing algorithm. In addition, there are a randomized flying-spot ablation pattern and controls for the local repetition rates to minimize the thermal load of the treatment\textsuperscript{21}. Therefore, the ablated surface in the aspheric aberration neutral (Aberration-Free\textsuperscript{TM}) profiles should be very smooth, so that there will be some benefits in high order aberrations.

Ablations were centred on the corneal vertex (CV) using the pupillary offset, i.e., the distance between the pupil centre and the normal CV measured by videokeratoscopy (Keratron Scout topographer, Optikon 2000 s.p.a., Rome, Italy). The measurement was performed under photopic conditions of 1,500 lux, similar to the conditions under the operating microscope. This method was suggested and described by de Ortueta and Arba Mosquera\textsuperscript{22} and comparatively tested by Arbelaez et al.\textsuperscript{23} The excimer laser allows for modification of the ablation centration from the pupillary centre with an offset by entering either X and Y Cartesian values or R and \( \theta \) polar values in a regular treatment. The measurement of the pupillary offset was translated into the treatment planning as polar coordinates to be manually entered in the excimer laser computer.

Finally, all these optimizations theoretically diminish the induced wavefront aberration and improve the efficacy of the hyperopic correction.

The ESIRIS laser system works at a true repetition rate of 200 Hz and produces a beam size of 0.8 mm Full-Width-at-Half-Maximum (FWHM) with a paraGaussian ablative spot profile\textsuperscript{24,25}. High-speed eye-tracking (pupil and limbus tracker without cyclotorsional tracking\textsuperscript{26}) with a 1050-Hz acquisition rate is accomplished with a 5-ms latency time\textsuperscript{27}.

Inclusion criteria for review were preoperative hyperopia or hyperopic astigmatism targeted for emmetropia, BSCVA \( \geq 20/25 \) (logMAR \( " +0.1 \)), \(<0.75 \mu \text{m RMS-HO CW for } 6\text{-mm diameter, and successful completion of 6-month follow-up. All 40 patients (80 eyes) fulfilled the criteria for being taken in the retrospective analysis, and so no one was excluded.}

Six-months follow-up was available in 80 of these eyes (100%), and their preoperative data were as follows: mean manifest defocus refraction +1.63±1.68 D (range, +0.13 to +6.00 D); mean manifest astigmatism magnitude 1.32±1.22 D (range, 0.00 to 5.50 D). In all eyes, we measured corneal topography\textsuperscript{28} and derived corneal wavefront\textsuperscript{29} analyses (Keratron-Scout, OPTIKON2000, Rome, Italy), manifest refraction, and uncorrected and best spectacle-corrected Snellen visual acuity\textsuperscript{30} (UCVA and BSCVA respectively). Results are reported for the measurements performed preoperatively and at six months and one year after surgery.

Optical errors centred on the line-of-sight, representing the Wavefront Aberration, are described by Zernike polynomials\textsuperscript{31} and coefficients in OSA standard\textsuperscript{32}, and analysed for a standardised diameter of 6 mm for corneal wavefront.

\section*{SURGICAL TECHNIQUE}

For corneal and conjunctival anaesthesia, two drops of proparacaine HCl 0.5% (Aurocaine\textsuperscript{®}, Aurolab, Madurai, India) were instilled three times before shifting the patient to the Operation Theatre. All flaps were created using a Carriazo-Pendular microkeratome (SCHWIND eye-tech-solutions) with superior hinges for maximised safety, 110 \( \mu \text{m nominal flap thickness.}

Online pachymetry\textsuperscript{33} was performed before and after lifting flap (stromal bed thickness) with the integrated optical coherence pachymeter (Heidelberg Engineering, Heidelberg, Germany). After lifting the flap, ablation was performed preserving flap edges, hinge, and inner face of the flap disk from being ablated. Contact lens was applied at the end of surgery (Biomedics 55 evolution, Ocular Sciences, Cooper Vision, Hamble, UK) in eyes with ‘achieved’ flap thickness less than 110 microns.
POSTOPERATIVE TREATMENT

One eye drop Tobradex (Alcon Inc, USA) 3 times a day was used for 1 week along with Oasis soft plugs extended duration (6404 Glendora CA) and preservative free artificial tear drops during the first three months.

Efficacy

We analysed the number of eyes with postoperative UCVA in scale from 20/16 to 20/40.

Refractive outcome

We analysed the mean values of defocus and astigmatism, and the number of treatments with postoperative refraction within 0.25, 0.50, 1.00 and 2.00 D, as well as, the number of treatments with norm of postoperative U-vector within 0.25, 0.50, 1.00 and 2.00 D. We assessed the statistical significance of the postoperative status compared to the preoperative baseline using paired Student’s T-tests.

Safety

We analysed differences in BSCVA postoperative compared to the preoperative baseline for each eye. We assessed the statistical significance of the postoperative status compared to the preoperative baseline using paired Student’s T-tests.

Predictability

We plotted scattergrams for the achieved dcefocus and astigmatism corrections versus the attempted ones (both at the corneal plane, where the ablation procedure occurs). We analysed slope and intercept of the correlations. We assessed the statistical significance of the correlations using Student’s T-tests, the Coefficient of Determination ($r^2$) was used, and the significance of the correlations has been evaluated considering a metric distributed approximately as $t$ with $N-2$ degrees of freedom where $N$ is the size of the sample.

Statistical analysis

The level of statistical significance was taken as $p<.05$.

RESULTS

Adverse events

In the 80 eyes, only 2 eyes showed some kind of complications (2%). 1 eye showed flap dislocation (1%), 1 eye showed flap striae (1%). No eye showed: severe dry eye, diffuse lamellar keratitis, or infection. No single eye needed to undergo a 2nd procedure.

Efficacy

At one year, UCVA was 20/16 or better in 19% of the treatments (15 eyes), and 20/25 or better in 81% (65 eyes) (Figure 1).

Refractive Outcome

1-year postoperatively, mean residual defocus was $+0.04\pm0.42D$ (range, -1.00 to +0.75D) ($p<.0001$) and mean residual astigmatism $0.45\pm0.36D$ (range, 0.00 to 1.25D) ($p<.0001$). Ninety-five percent eyes (76) were within $\pm0.50D$ of attempted defocus correction (Figure 2) and ninety-five percent eyes (76) within 1.00D of the norm of the residual U-vector (Figure 3).

Safety

Regarding safety, 3% of eyes (2 eyes) gained two lines of best spectacle-corrected visual acuity (Figure 4) ($p<.01$).
Predictability

The achieved refractive change, defined as the vectorial difference in the astigmatism space of postoperative and preoperative refractions (incorporating defocus and astigmatism) at the corneal plane, was significantly correlated with the intended correction ($r^2=0.90$, $p<.0001$). Regression slope was 0.94, very close to the ideal correction.

The achieved changes in astigmatism was significantly correlated with the intended correction ($r^2=0.85$, $p<.0001$). The regression slope of 0.82 indicates slight undercorrections.

DISCUSSION

In this study, results were good and promising. We can conclude that CAM Aberration-Free Hyperopic treatments produce safe and predictable ablations on the Cornea. From post-op VA, we have got 81% eyes in UCVA 20/25 or better and more than 36% eyes improved their pre-op BSCVA, due to the minimum aberrations induction by the ORK-CAM aspherical profile. From the refractive power change (in terms of achieved correction), we can see that both the sphere and cylinder corrections are quite accurate, predictable and stable from the first month follow-up.

De Ortueta\textsuperscript{12} found after H-LASIK with the ESIRIS system a good predictability, with ninety-two percent of the eyes (61) having a postoperative refraction within ±0.50 D of the attempted correction. Moreover, as expected, the achieved refractive change was significantly correlated with intended refractive correction ($r^2=0.91$), and was very close to the ideal correction. These values are similar to the ones in this study for 1-year follow-up (95% within 0.50 D).

The conventionally accepted limits for H-LASIK (about 5 Diopters SEQ, spherical equivalent) are lower than the ones accepted for myopic LASIK (up to about 10 Diopters if the residual stromal bed is thicker than 250-300 µm). One of the causes is that the induction of aberrations per achieved diopter is higher in hyperopic treatments\textsuperscript{9}. The centration of refractive surgery remains also controversial. The offset between the corneal vertex and pupil centre is higher in hyperopic eyes, with a nasal fixation in most of the cases. This is also a problem to take into account\textsuperscript{34}. Hyperopic eyes are usually short in axial length, showing higher values for the angles alpha, kappa, and lambda. This also causes an offset between the corneal vertex and the pupil centre of higher magnitude than in myopic eyes, making it difficult to decide where to centre the refractive procedure.

New ablation patterns, which minimize the induction of aberrations, will allow us to perform H-LASIK more predictably and safely and may allow us in the future to treat higher hyperopia.

Reducing the corneal aberrations after H-LASIK will possibly allow us to treat higher hyperopia, however further studies are necessary to confirm this hypothesis.

REFERENCES

6. Dorronsoro C, Cano D, Merayo-Lloves J, Marcos S. Experiments on PMMA models to predict the impact of