Chapter 8

CONCLUSIONS

This thesis contributes to both methodological advances in wavefront sensing (Laser Ray Tracing and Hartmann Shack techniques) and advance in the assessment of ocular aberration in ametropia, and the optical changes after corneal refractive surgery.

The main conclusions regarding the aberrometry technology implemented in this thesis are:

1.- High order aberrations (third and higher order terms) can be reliably measured in infrared, both with Laser Ray Tracing (LRT) and Hartmann Shack (HS) techniques. There are no statistically significant differences in high order aberrations measured with visible (543 nm) and near infrared (787 nm) light.

2.- Differences in defocus from aberrometry using green (532 nm) and near infrared (787 nm) are consistent with longitudinal chromatic aberration, with an average chromatic difference of focus of 0.78 ± 0.29 D.

3.- Despite large differences in the intensity distribution of retinal spot patterns (both with LRT and HS) as a function of the polarisation state of the illumination and recording channels, the estimated aberrations are independent of polarisation.

4.- The metrics refined to compare estimates of ocular aberrations using different sampling pattern configurations (RMS of the difference , RMS_diff, and percentage of differences between wave aberration maps, W%), the hierarchical cluster analysis and Student's t-test have proved adequate to assess the performance of different sampling patterns.

5.- The variability of the wave aberration is generally larger than the effects due to the sampling. In healthy human eyes the sampling pattern does not seem to play a major role on the accuracy of the aberrations estimated, as long as the number of samples is sufficient for the number of Zernike terms to estimate. The spatial distribution of the sampling can be more important than the number of samples. Moderate density sampling patterns based on the zeroes of Albrecht's cubature (49 samples) or hexagonal sampling (37 samples) performed relatively well.

The main conclusions on ocular aberrations of ametropic eyes and following LASIK correction are:

1.- Hyperopic and myopic eyes (23-40 years and 26-39 years; +0.5-+7.4 D and –0.8 - –7.6 D, respectively) differ both geometrically and optically. Hyperopic eyes are statistically significantly shorter than myopic eyes and have less prolate corneas. Hyperopic eyes also show larger corneal spherical aberration and less negative internal spherical aberration than myopic eyes.

2.- Hyperopic eyes show an earlier loss of the balance between corneal and internal spherical aberration, perhaps associated to an earlier onset of presbyopia.

3.- Standard LASIK for myopia and hyperopia produce a change of ocular (total) and corneal spherical aberration towards positive and negative values, respectively. This change in spherical aberration is correlated with the attempted correction.

4.- Slightly higher changes in the anterior cornea compared to the total ocular changes suggest a slight counteracting effect from the posterior cornea.

5.- The fact that changes are relatively higher after LASIK for hyperopia than after LASIK for myopia are suggested of a larger influence of geometrically-related laser efficiency losses and of biomechanical effects in hyperopic LASIK.

In brief, this thesis has contributed to the understanding and improvement of ocular wavefront sensors by indentifying optimal configuration parameters (wavelength, polarisation and sampling). This technology has been used to expand the knowledge and understanding of ametropic eyes, and to assess the optical changes induced by LASIK surgery for myopia and hyperopia. This research has implications in the identification of best candidates for surgery and interpretation of the surgical outcomes through the combination of total and corneal aberration measurements. These findings are important to understand the limitation of standard LASIK ablation algorithms, and the optimisation of the state-of-the-art wavefront customised procedures.

Trying to look into the future, it looks like aberrometry has arrived to stay. In the last years, aberrometry has earned a place in the clinical environment thanks to refractive surgery. However, it has also been proven valuable at identifying ocular conditions affecting the optics of the eye (keratocous, pellucid marginal corneal degeneration, dry eye, lenticonus, cataracts) and as an objective assessing tool for different correction methods (contact lenses, intraocular lenses, orthokeratology, apart from refractive surgery) (see review by Maeda, 2009). There is no reason to think that in the future aberrometry will be not applied to early identification of new ocular conditions, perhaps in combination with new imaging techniques which might also benefit of the correction of aberrations. Additionally, the power of aberrometry as an objective evaluation tool will surely be useful to assess *in vivo* new correction methods and to understand better the psychophysical and psychometric outcomes of these corrections when combined with the optics of the eye.

Additionally, aberrometry has helped to advance in the knowledge of the optical mechanisms of the eye, such as the balance between corneal and internal aberrations, or the change in aberrations with accommodation. There are still some questions to be clarified where aberrometry could contribute maybe in combination with biometric or imaging techniques. Specifically, some issues related to the crystalline lens are still unknown, given its inaccessibility *in vivo*, and the complications of reproducing the *in vivo* conditions *ex vivo*. These issues include the exact structure of the GRIN, the changes taking place in the lens, including GRIN distribution, during the process of accommodation or the structural changes taking place in the lens with age leading to presbyopia onset. For this last issue a comparison between different refractive groups around pre-presbyopia age range might help to identify early gradual changes on the aberration pattern that might give an insight in the optical changes involved.

Regarding methodology, there are still issues to tackle, such as which is the adequate sampling pattern for general population, or for screening of particular conditions. Although it seems quite clear that the sampling pattern should be adapted to the aberrations to measure, this implies to predict in advance what is to be found. A future study in a wider population would be desirable, as well as having a gold standard such an interferometric aberration pattern for comparison across patterns. Population subgroups with similar optimum sampling might be then determined and therefore the characteristics making a sampling pattern more suitable for specific eyes could be identified.

Finally, will ocular (and corneal, internal, etc) aberrations still be represented using Zernike polynomials?. Although for some particular applications Zernike polynomials might not be accurate enough, they have been doing the job quite well all these years, becoming a standard. Aberrometry has brought together such different disciplines as physicists and physicians. Many physicians have made an effort to update and complement their training in order to be able to understand and apply aberrometry in their practice. This effort included understanding the Zernike expansion. If a more adequate mathematical tool is found, it should be used for those specific cases where Zernike polynomials fail. However, before changing the standard, it is important to make sure that the new tool is really bringing a general benefit, and to make available a way to convert to and from Zernike into the new base.