Abstract

Recent development of new technologies based on Fourier Profilometry and the improvement of established ones such as the Optical Coherence Tomography (OCT) are now providing new means to move further on anterior eye research allowing to face the new challenges due population ageing. In order to advance our understanding about the anterior eye's topography and structure, and to improve the therapeutic alternatives available to restore those visual capabilities that are affected by ageing, the work presented in this dissertation was divided into two parts. The first one approaches the micro-structural changes that occur in cornea whereas the second is focused on the characterisation of anterior eye surface features.

In the first part, a new approach to assess the properties of the corneal microstructure in vivo based on statistical modelling of speckle obtained from OCT is presented. A number of statistical models were proposed to fit the corneal speckle data obtained from OCT raw image. Short-term changes in corneal properties were studied inducing corneal swelling, whereas age-related changes were observed by analysing data of sixty-five subjects aged between twenty-four and seventy-three years. Generalised Gamma distribution has shown to be the best model, in terms of Akaike's Information Criterion, to fit the OCT corneal speckle. Its parameters have shown statistically significant differences (Kruskal–Wallis, $p < 0.001$) for short and age-related corneal changes. In addition, it was observed that age-related changes influence the corneal biomechanical behaviour when corneal swelling is induced. The role of corneal micro-structure on intraocular pressure (IOP) measurements was also studied. The information obtained from speckle statistics presented a significant correlation with the IOP measurements obtained from applanation tonometry. In general, this study showed that Generalised Gamma distribution can be utilised to modelling corneal speckle in OCT in vivo providing complementary quantified information where micro-structure of corneal tissues is of essence.

The second part of this work was dedicated to the analysis of the anterior eye surface. The main aim was to develop computational methods for estimating limbus position based on the measurements of three-dimensional (3D) corneoscleral topography and ascertain whether corneoscleral limbus routinely estimated from the frontal image corresponds to that derived from topographical information. Two new computational methods were proposed: one based on approximating the raw anterior height data by a series of Zernike polynomials and another that combines the 3D corneoscleral topography with the frontal grayscale image acquired with the digital camera in-built in the profilometer. The estimates of corneoscleral limbus radius were characterised with high precision. The group average (mean ± standard deviation) of the maximum difference between estimates derived from all considered methods was 0.27 ± 0.14 mm and reached up to 0.55 mm. The four estimating methods lead to statistically significant differences (non-parametric ANOVA test, $p < 0.05$). This study showed that precise topographical limbus demarcation is possible either from the frontal digital images of the eye or from the 3D topographical information of corneoscleral region. In addition to corneoscleral characterisation, a new methodology to measure the

scleral radius was developed. The estimated scleral radius (11.2 ± 0.3mm) of 23 emmetropic subjects aged 28.1 ± 6.6 years was shown to be highly precise with a coefficient of variation of 0.4%. This study showed that, the three-dimensional topography of anterior eye acquired with Eye Surface Profiler can, together with a given estimate of the axial length, be used to calculate the scleral radius with high precision.

Finally, the dissertation presents a method that simplifies calculation of the geometrical point spread function of 2D non-circularly symmetric systems. For this method, a two-dimensional ray tracing procedure for an arbitrary number of surfaces and arbitrary surfaces shapes has been developed where surfaces, rays, and refractive indices are all represented in functional forms approximated by Chebyshev polynomials.