# A comprehensive study of corneal tissue responses to customized surgical treatments

Chapter 9

# Summary

This dissertation is a collection of focused research on corneal tissue responses to customized surgical treatments. It is structured into tissue healing and biomechanical assessment within the domain of laser vision correction (LVC) surgery, predicting postoperative corneal stiffness after LVC and customized collagen cross-linking (CXL) planning for ectasia treatment.

**Chapter 1** starts with background information associated with the problem statements and discusses the structure of this dissertation. **Chapter 2** introduces an analytical biomechanical model (ABM) for Corvis-ST waveform analysis for LVC screening. The ABM derived mean and constant corneal stiffness were used in the separation of the suspect (fellow eye of a keratoconus eye) and the keratoconus eyes from the normal eyes. It was designed to model the cornea as a pure spring, which decision was further validated in **chapter 3**. The chapter investigated two ABM models: first a standard linear-viscous solid model (SLM) similar to chapter 2, then a 2-compartment Kelvin-Voigt model (KVM) in which both the cornea and extra-corneal tissue were modelled as viscoelastic materials. Corneal stiffness parameters derived from both models were almost perfectly similar and corneal viscosity calculated from the KVM model was practically zero for normal eyes. A similar trend was observed in the suspect eye and keratoconic cornea, despite disease-associated localized weakness having a profound effect on both elastic and viscous properties of the diseased cornea. Hence, **chapter 3** concluded that the air-puff applanation technique appeared inadequate to assess the viscous properties with the analytical models in its current configuration. **Chapter 4** investigated longitudinal tissue healing after LVC surgery from biophysical, structural and biomechanical response perspectives. Optical coherence tomography (OCT) speckle distribution biophysical marker changes after surgery to preoperative distribution in both laser-assisted in situ keratomileusis (LASIK) and small incision lenticule extraction (SMILE) showed two completely different recovery processes. The study found a better transient healing process after SMILE than LASIK overall. Bowman's roughness index (BRI) the structural marker showed differential crimping effects between LASIK and SMILE, due to differences in the number of severed fibres between a flap and a cap procedure. Analysis of mean corneal force vs. corneal deformation curves at higher forces correlated well with the BRI.

Based on the corneal tissue responses observed in **chapters 2,3 and 4** a postoperative corneal stiffness prediction finite element method (FEM) simulation models for LASIK, SMILE and photorefractive keratectomy (PRK) were introduced in **chapter 5**. The surgery specific models had a short-term and long-term prediction model assuming transient changes in play, and more stable effects of surgery, respectively. Excellent agreement observed between predicted versus the in-vivo postoperative stiffness indicated that our novel predictive simulation may be representative of the in-vivo state of the cornea after surgery. This was the first time such a predictive simulation had been showcased. However, the surgery specific predictive simulation needed to be validated using a larger database. **Chapter 6** conducted this validation study of the AcuSimX™ platform built from the surgery specific prediction model using 529 eyes from multiple centres around the world comprising LASIK, SMILE and PRK, and an additional 10 eyes that developed ectasia after LVC. The study also introduced a unique preoperative parameters pattern that could assist in identifying potential ectasia eyes before surgery. Thus, a predictive simulation that yields a low corneal stiffness postoperatively combined with preoperative parameters pattern could safeguard both the patients and surgeons further.

A novel customized CXL planning based on an inverse FEM modelling based method to estimate the shape and size of the biomechanical altered zone in an ectatic eye was introduced in **chapter 7**. A 3-dimensional patient-specific model of the cornea was developed from Scheimpflug tomography. Here, initially, the material property of the healthy cornea was assumed, which was then spatially scaled to simulated biomechanical degeneration. The resultant biomechanical degeneration zone was used in the prospective planning of customized CXL procedures. Evaluation of customized CXL results based on the newly generated biomechanical degeneration map showed improved tomographic remodelling of the cornea, comparable to the Dresden protocol. With this predictive simulation approach, better results were achieved using a lower treatment dose.