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„Modelling of corneal tissue at refractive interventions“

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INTRODUCTION

The optical system of the human being is an ensemble of complex biological components, where the final aim of a *good vision* is given by an optimal co-operation of the special eye components. On the top level the system consists of cornea at the front, the anterior chamber, a lens system, the vitreous and the retina with „fovea centralis“ before processing in the brain (fig 1).

The refractive behavior of the human eye is based primarily on the cornea with about 43 dpt. There are different aspects of modelling of the corneal behavior when any changes in tissue geometry like surgical acts.

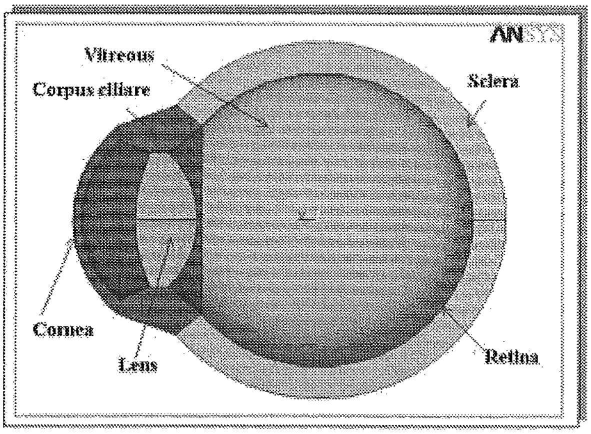

Figure 1: The „Gullstrand Eye“ model

SURGICAL TECHNIQUES AND CONDITIONS

With refractive corneal surgery, the different physiological and pathological cases of myopia and hyperopia and other forms of corneal damage can be corrected. As state of the art there are different surgical techniques like photorefractive keratectomy (PRK), in situ keratomileusis (LASIK) and different incision techniques.

In all cases we have a partially distortion of the human tissue and a deformation of the anterior curvature of the cornea. This fact leads to a different optical refractive behavior, whereby the final aim is to control and to predict the surgical parameters to generate a sharp image of the real objects at the retina position.

FEM MODELS IN THE BIOMECHANICS

In a first approach the human cornea is represented by a 3-D spherical shape of the Gullstrand eye with the limbus as regional boundary condition with zero displacement in all degrees of freedom. The 3-D spherical section is limited by areas of different radii with origin on the optical axis. This approach regards the different thickness of the cornea in the centre (about 0.55 mm) and near the limbus (about 0.75 mm). Because of patient related geometrical data, which results later from morphometric measurements, the solid modelling must be parameterised. So, a full automated generation of cornea solid geometry is performed, given by user specified global geometric parameters like thickness, diameter and radius of the inner and outer corneal curvature.

The second step for generating a FE-model is to develop useful net topology, adapted at the solid model [Scherer2001].

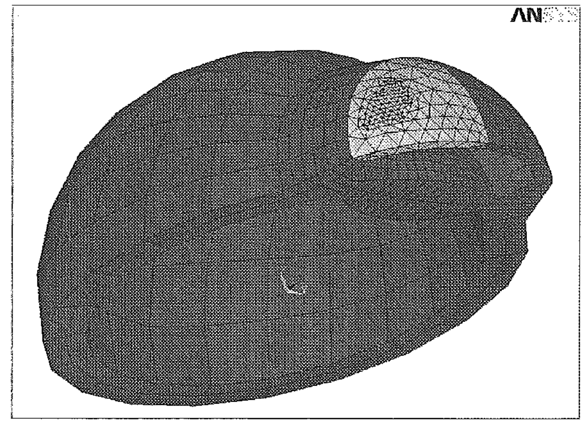

Figure 3: Mapped and free mesh for the eye solid

The real material parameters are very important for further simulations of the corneal tissue. So, a material dependent refinement of the cornea is useful and necessary. From biological point of view, there are different biological layers with different geometrical thickness parameters. Furthermore each layer consists of different material behaviour like E-modulus, Poisson ration and so on [Jue1986]. Additional to the one layer model, consisting of a unique material solid, a parameterised model of layer related composition seems necessary. Additionally to the given geometrical and material parameters, the number n of layers is specified. So, the different biological tissue composites can be regarded in a very fine manner (epithelium, Bowman lamella, stroma, Descement membrane and endothelium. But also within the stroma the keratocyte densities can be regarded as material with own characteristics.

SURGICAL DEPENDENT FEM MODELS

For correction of different damages or emmetropia like myopia or hyperopia different surgical acts are considered. The photorefractive keratectomy (PRK) is based on change of the curvature of the outer corneal surface, whereby myopia correction is performed by more flatness in the central area around the optical axis. Furthermore hyperopia correction is corrected by extension of the gradient in the same area. So, the focus of the object rays, coming from pattern outside the eye can be moved on the optical axis to the retinal position.

When deforming the cornea by hyperopia based correction, very strong strain of the mesh nodes is possible, especially at the transition from the "old" tissue to the ablation state (fig. 3).

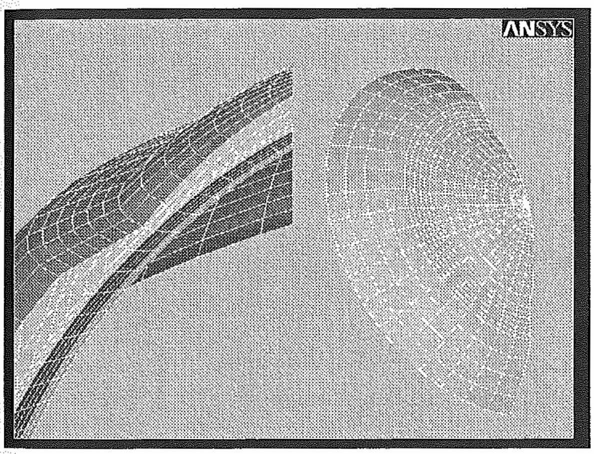

Figure 3: Mapped meshing after hyperopia correction

With LASIK method both myopia and hyperopia effects can be corrected in a special bandwidth of dioptries. The top layer of the cornea is modelled as a flap, and so the laser acts inside the stroma bed, which is an advantage for health generation no distortion of the Bowman lamella. The simulation itself is performed for the second layer.

SOLUTION PROCESSING

For FEM analysis we used in a first approach elastic material properties with parameterised inputs. Radial symmetric intraocular pressure (IOP) as surface load on the inner endothelium area of the cornea leads to a deformation of the inner layer nodes. By node connecting with other of the next layer and the specific layer dependent material properties the node stress strain is continued at the next layer and so on. The input of the optical simulation must be the outer deformation because of refractive indices for the different surfaces.

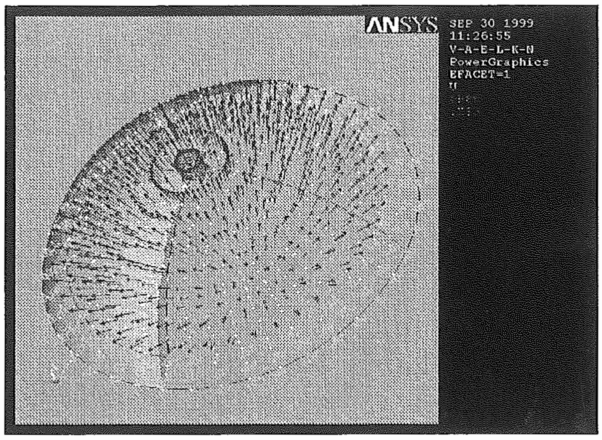

Figure 4: Intraocular pressure as surface load

CONCLUSION

The relationship between geometry, material and loaded human cornea data are important for the FEM simulations of the 3-D corneal tissue behaviour. In combination with optical simulations postoperative results concerning visus are expected. Basic results concern the qualitative behaviour of corneal tissue regarding different constraints. For elastic material properties any deformation simulations for different surgery types (PRK, LASIK) could be performed. The FEM simulations refer to a parameterised solid and net modelling and regards also an n layered biological tissue. The advantage of simulation and modelling the surgical acts are the possibility of reiteration, the parameterisation and the prediction without training at real patients. But results must be validated by clinical proofs.

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