Optimal cornea shape design problem for corneal refractive surgery

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Abstract

Corneal refractive surgery is a promising technique to correct irregularities of cornea shape accompanying various types of aberration in eye ball system, and correction of refractive power for nearsightedness and farsightedness are fundamental application of refractive surgery. However there have been reported some risks such as over-/under-corrections, abnormal sight symptom like halo or glare. Intraocular pressure is always acting in vivo on the posterior surface of cornea, and the secondary deformation is induced by laser ablation. Therefore the cornea shape should be considered by taking the deformation of cornea tissue. In this article, the optimal cornea shape is studied for the correction of higher order aberration, which was not corrected by eye glasses or contact lenses. This optimal shape design of deformed nonlinear elastic body is composed of two sub-problems.

The first is the optimal shape design for correction of higher order aberration. The current cornea shape is regarded as the initial shape in structural optimization and the optimal shape is determined for the anterior surface of cornea so that minimizes the aberration over the optical zone. The design variables are the position of anterior cornea surface within the designated operation zone. Here, the aberration at individual point on cornea surface is calculated by using the reduced eye model and the law of refraction, Snell's law. The solution is the shape in equilibrium to the intraocular pressure, and is regarded as the target shape of cornea for refractive surgery.

The second is the determination of ablation volume. The shape of current cornea in vivo is of the deformed state under the intraocular pressure. The target shape of cornea to be realized after refractive surgery is also the deformed one. The second problem is thus reduced to the determination of the stress-free cornea shapes corresponding to the current and target cornea respectively. The minimization problem is formulated for the integral of squared difference between the surfaces of current/target cornea shapes under the intraocular pressure. These problems determine the stress-free cornea shapes for the current and target cornea shapes respectively by means of the traction method, and the ablation volume is then identified as the difference between these stress-free shapes.

The effectiveness of the proposed optimal shape design approach was examined with a numerical case study of correction of spherical aberration, a kind of higher order aberration, and the sufficient reduction of non-uniform aberration was confirmed with the uniform and sufficiently small aberration within normal range over the optical zone.