Dynamic Behavior of Human Eye

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Abstract

This paper presents novel details on the dynamic behavior of human eyes (see Fig. 1). A high speed camera is used to capture the movement of the eye surface, which is excited by an air jet. For a group of subjects the dynamic response ends shortly after the excitation is over. For another group of subjects this first phase ends with a distinct offset in the displacement, which takes a significantly longer time to vanish. The two distinct phases are the result of dynamic response of the cornea and the total eye, respectively. Understanding this eye dynamic is an important step towards the increase in reliability of diagnostic tools for glaucoma.

Introduction

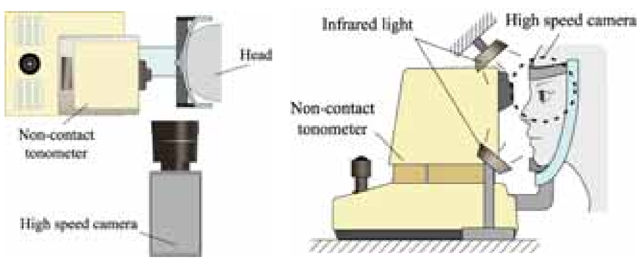
If a human has an elevated eye pressure, chances are that his (or her) optical nerve will be damaged. Such damaging leads to a gradual, irreversible loss of eye sight, known as glaucoma. In order to be able to prevent this, either by lowering the pressure by medication or an operation, the elevated eye pressure has to be diagnosed early on. Thus there is a demand in medicine for a reliable method to measure the eye pressure. The invasive method of directly measuring the internal eye pressure by inserting a microneedle into the eye ball is ruled out in a normal examination. Therefore indirect, less accurate, methods are used. The usual way to judge the inner eye pressure is to apply an external pressure to the eye and monitor the deformation it causes. The pressure is applied either in direct contact with the eye or in a noncontact way. In employing a direct contact method, e.g. in Goldman applanation tonometry[1], a probe is pushed onto the eye until the eye flattens in a disc with a radius of 3.06[mm] and the used force is recorded. If the pressure value exceeds 21[mmHg], the eye pressure of a patient is said to be high, otherwise normal. In the non-contact method, the surface of the eye is pushed by an air jet. The deformed area on the cornea is predefined by the shape of the air jet. The deformation of the eye is monitored by illuminating the eye by infrared light and using an optical sensor to measure the integrated reflected light intensity. Both measurement methods, however, do not take differences in the stiffness of the cornea of different subjects into account. If the actual cornea is stiffer than average corneas, it is harder to deform, the external pressure is higher and so the inner eye pressure is overestimated. Likewise, for compliant corneas the inner eye pressure is underestimated. In the second case, the measured pressure value may be well below 21[mmHg], while the actual inner eye pressure is above that medical treatment. A way to avoid this case is to estimate the corneal stiffness by measuring dynamic parameters during the eye deformation.

Fig. 1 Eye deformation due to an air jet.

A prerequisite for estimating the dynamic parameters of a human eye is to record the force and displacement with respect to time. In order to obtain this data, we utilize a high speed camera and an air jet system. In a second step the dynamic has to be understood and the dynamic parameters have to be extracted. As can be seen from the movies taken by the high speed camera, two main effects govern the displacement: The first, dominant, effect is the bending of the cornea similar to a membrane. The second effect is the displacement of the whole front of the eye. Thus, the measurement provides us not only with information on properties of the cornea, but also with information about the dynamic behavior of other parts of the human eye.

Experimental System

Fig. 2 shows the experimental system, which is composed of an air jet supply system for imparting a force to a human eye, a high speed camera for detecting the current shape of the human eye, and an infrared light source for providing sufficient illumination. As for the air jet supply system, we utilize the eye pressure measurement system (TOPCON CORPORATION) and for the high speed camera, we utilize the PHANTOM V7.1. The camera can capture the eye motions with a frame rate of 5[kHz]. Since the fast part of the eye deformation happens within 10msec, the camera frame rate of 5[kHz] is sufficient to obtain the appropriate number of frames for evaluating the dynamics. We are interested to see the dynamic motion captured by the high speed camera during the air jet operation. From the



(a) Top view (b) Side view

Fig. 2 Experimental system

captured the surface profile, we may identify certain movement patterns and the displacement of the tip of the cornea.

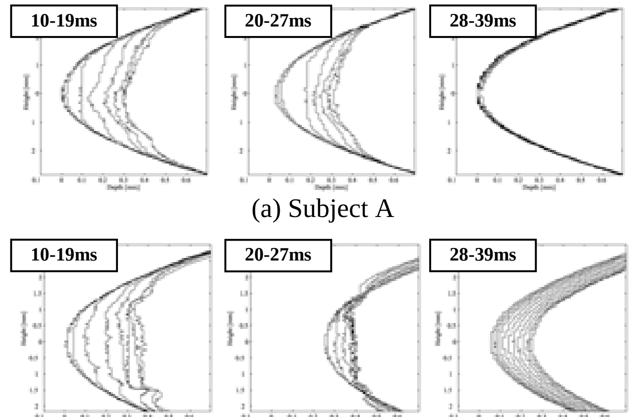
Experimental Results

The images captured by the high speed camera were processed offline in order to extract the movement of the edge of the eye in profile. Comparing the results for 72 subjects, two different groups of subjects were found. For each group, we picked a subject, whose eyes exhibit the typical dynamic behavior clearly. Fig. 3 shows some superimposed snapshots of the edge of the eye for subject A and subject B, respectively. The snapshots only show the middle part of the cornea. The time interval between two snapshots is 1ms. For subject A, the tip of the cornea starts to bend inward 10[ms] after the trigger signal and reaches its maximum displacement 10[ms] later. Afterwards the tip moves back to its original position, which takes also 10ms. The outer part of the depicted part of the cornea, however, does not move much. The eye of subject B shows a different behavior: In a first phase, in which the tip of the cornea is bent inward, is similar to that of subject A. In addition, the edge of the cornea starts to move backwards by a small amount. When the first phase is over after about 10[ms], the cornea tries to obtain its original shape. This movement is superimposed by a continued backward movement of the whole surface of the cornea. Thus only the very tip of the cornea moves forward, while the outer visible part moves backward. After 28[ms] the cornea has retained its original shape, while the whole surface of the cornea is displaced. It takes an additional 12[ms] for the eye to reach its original position.

The eye may exhibit a combination of the two distinct types of movement: the bending movement of the cornea and displacement of the cornea as a whole. This is also evident by analyzing the movement of the tip alone. Fig. 4 shows the movement of the eye tip of subject A and subject B, respectively. From these time series it is also evident that the eye movement in the case of subject A is dominated by one movement type, the bending movement of the cornea, while the eye movement of subject B shows two components with different time constants.

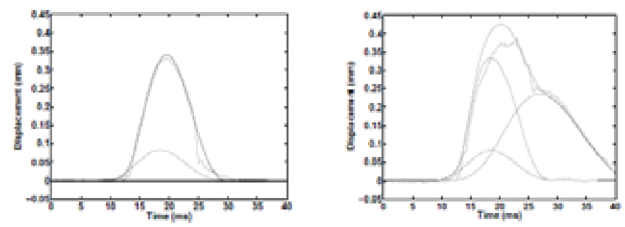
Conclusion

We showed that it is possible to visually capture and resolve the dynamic response of a human eye being excited by a conventional non-contact tonometer. For stiffness measurement, there are number of medical applications[2][3]. While here have been some works on dynamic models for human eye[4][5][6][7], this is the first work based on the direct measurement of the eye



(b) Subject B

Fig. 3 Snapshots of the cornea surface.



(a) Subject A (b) Subject B

Fig. 4 Displacement of subject A and B.

deformation.

Currently, work is underway to model the coupling of the bending movement of the cornea and the movement of the cornea as a whole by a finite element model in order to increase the understanding of the dynamic behavior of human eyes.

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Dynamic Properties of Human Eyes

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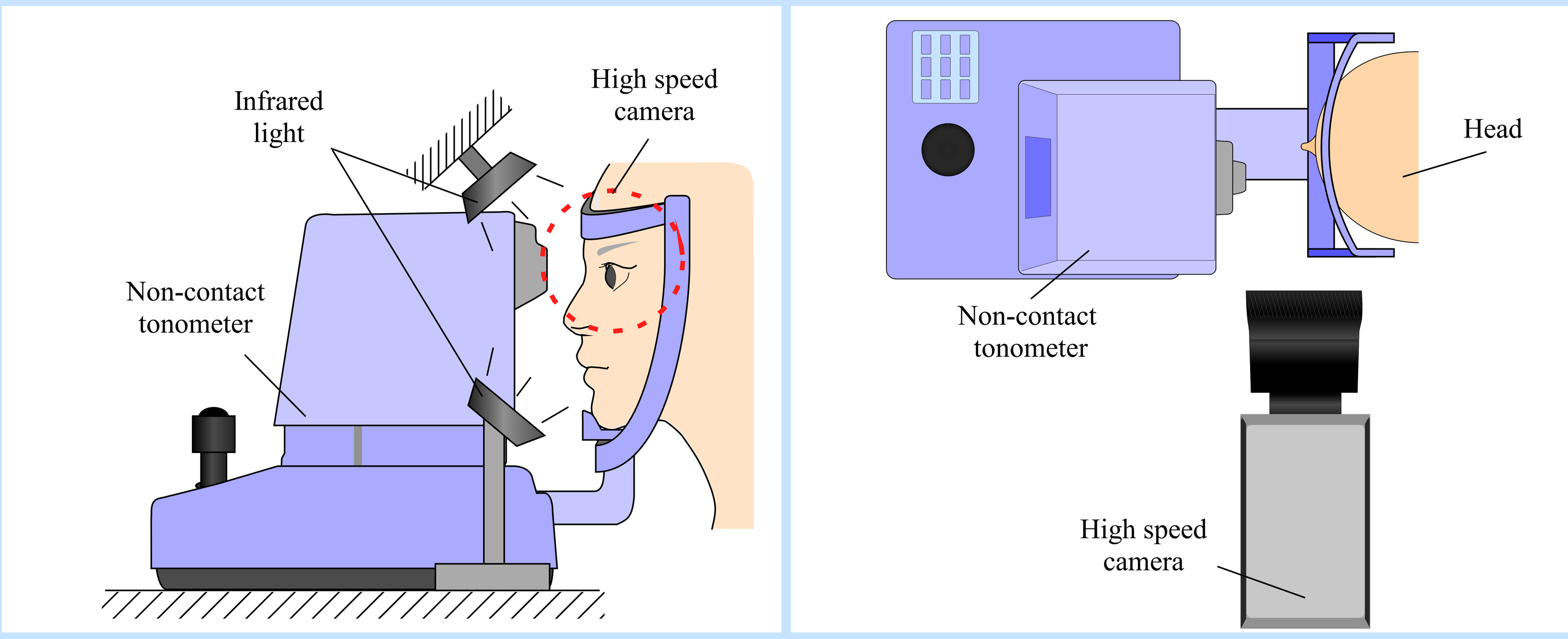
Abstract

Non-contact tonometers are a widely used tool for measuring the intra ocular pressure (IOP) in eye examinations. They excite the human eye by an air pulse and evaluate the force needed to cause a certain deformation of the eye. The dynamic motion of the eye caused by the air jet has not been studied in detail, yet.

A high speed camera is used to capture the motion of the eye surface. The eyes exhibit two types of motion: A bending motion of the cornea and a slower motion of the whole eye. The bending motion is similar for different subjects, while the motion of the whole eye differs significantly. A large amplitude of the motion of the whole eye is also visible in a distinguished offset in the displacement of the cornea's tip at the time the bending motion vanished. Parameter identification from a simple dynamic model support this interpretation.

Measurement System

Setup

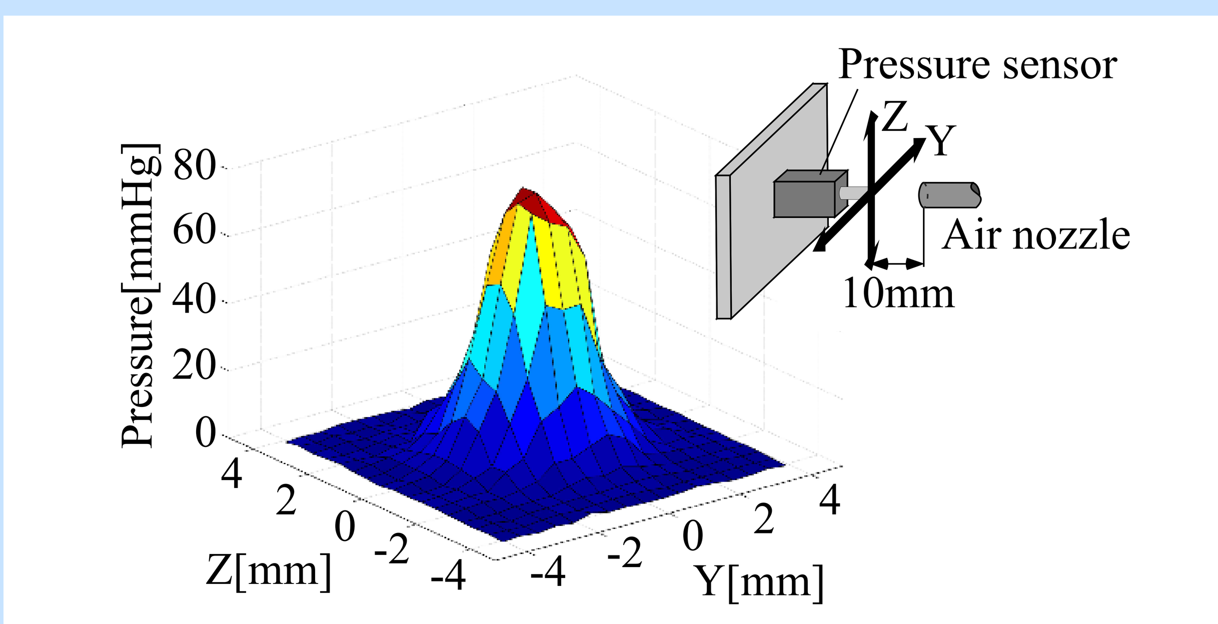


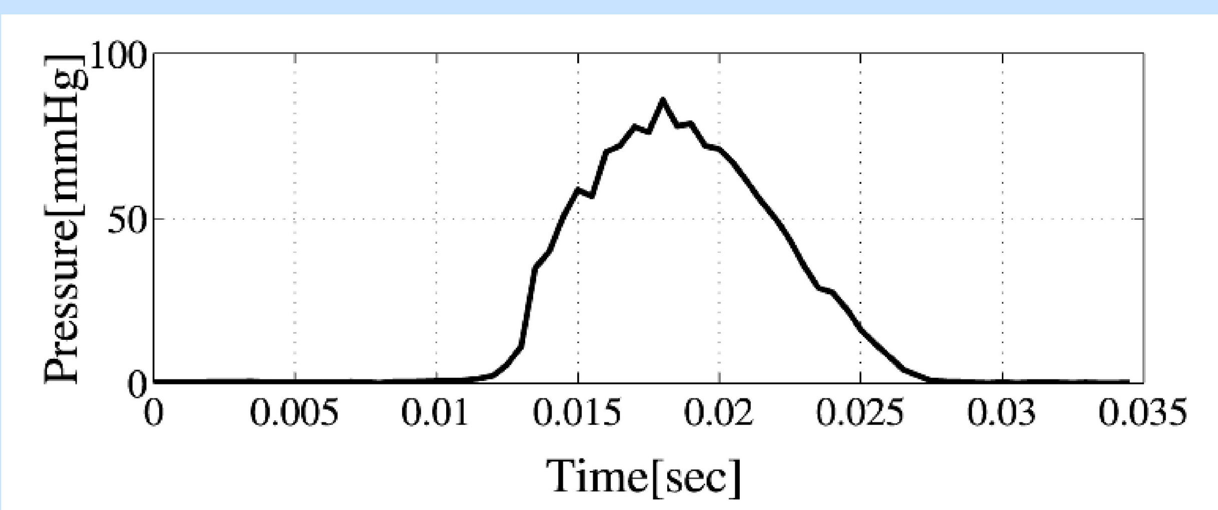
Side view Top view

Camera

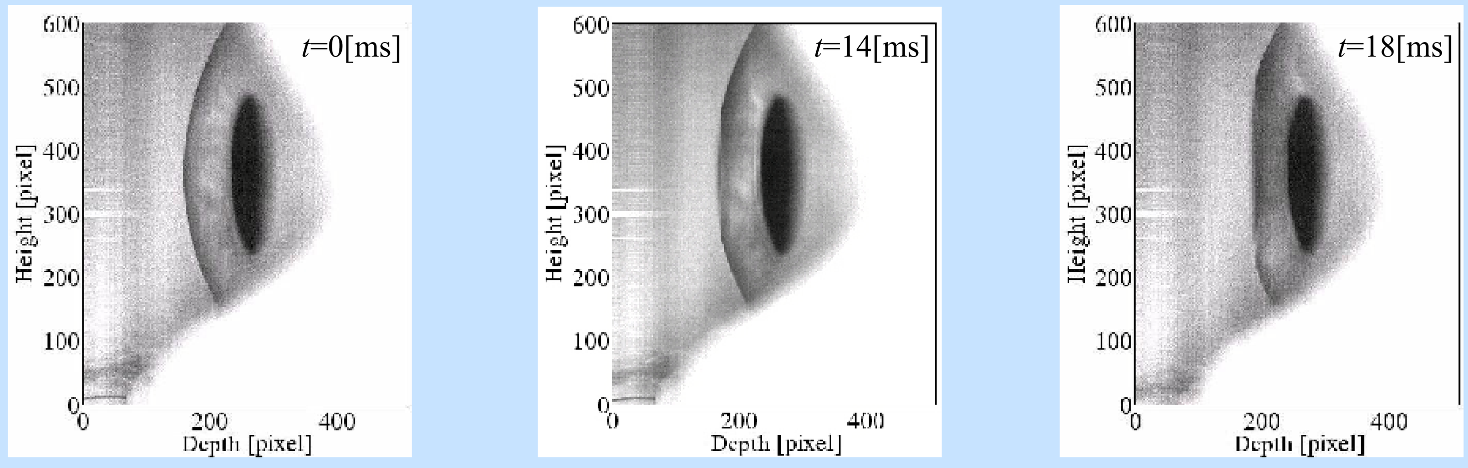
Frame rate	5000[fps]
Image size	600x512[pixel]
Resolution	14[µm/pixel]

Pulse Characteristic

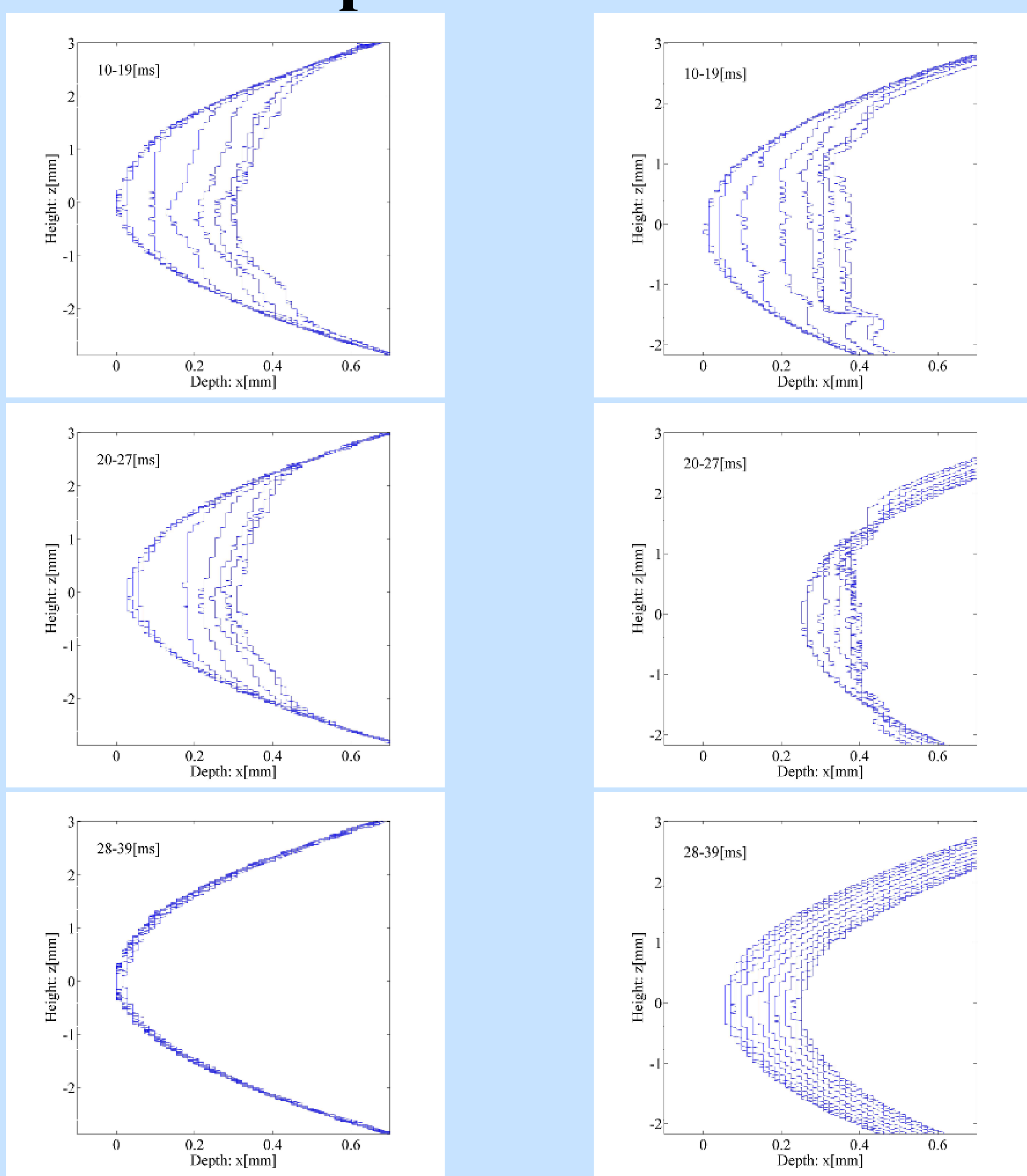




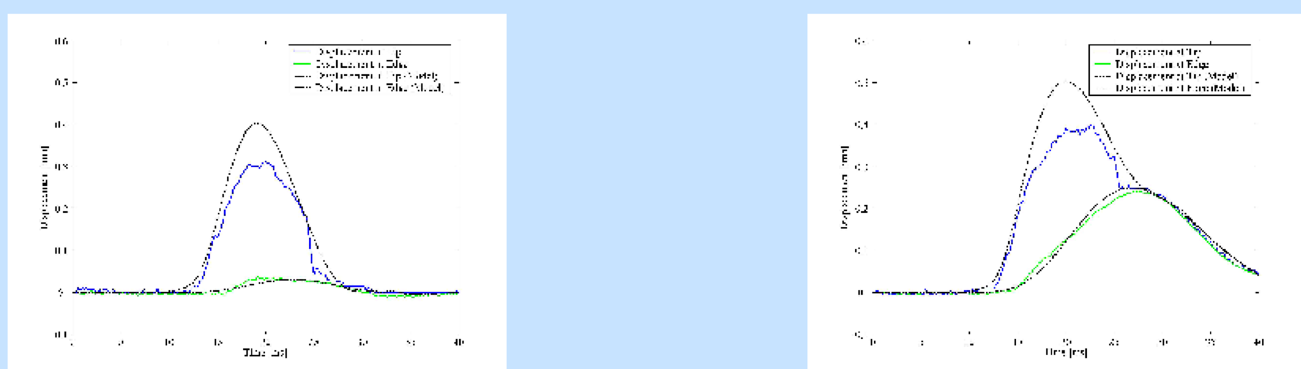
Dynamic Behavior



Snapshots of Cornea

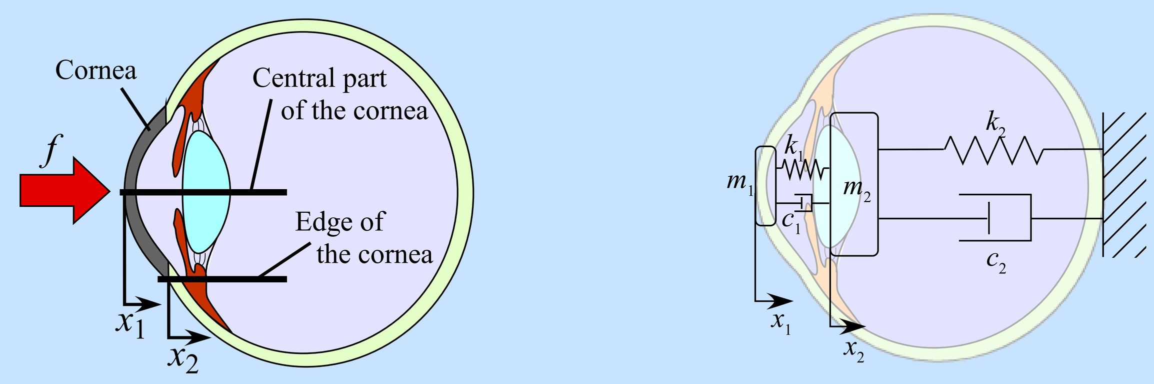


Motion of Tip and Edge



Subject 1 Subject 2

Model



$$m\ddot{x}(t)+c\dot{x}(t)+kx(t) = f(t)$$

	Subject 1		Subject 2	
	Layer 1	Layer 2	Layer 1	Layer 2
m[g]	0.32	21.4	0.27	7.7
c[Ns/m]	0.13	8.14	0.11	1.54
k[N/m]	240	2680	223	214