Measuring the Adhesion Level of a Contact Lens

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Abstract
A soft contact lens is comprised of mostly water; it adheres to the tears in a human eye in a process known as cohesion. When removing the contact lens, the adhesion between the tears and the lens can cause damage to the epithelial layer of the eye. The sponsors of this project are interested in calculating the adhesion of a contact lens to the eye while the lens is being removed. To achieve this a force first must be applied to the lens and then removed, the deformation that occurs at every incremental step must be analyzed. After the lens is compressed the force will then be removed from the lens, the force needed to lift the lens will be measured incremental also. The device that will achieve this will consist of four separate parts: a contact lens holder, a microbalance, an adjustable rack and pinion device, and a deformation analysis device known as the Moiré Interferometer. The contact lens holder will be set on a flat stand resting on the microbalance. A movable glass slide will be attached to a rack and pinion system which will move this slide up and down above the contact lens, the slide will be used to apply the force on the lens. Once the lens is compressed the desired amount the Moiré Interferometer will be used to measure the deformation of the lens as the microbalance records the pressure being applied at every increment. A graph of Force applied at each step vs. y-displacement will then be generated using LabVIEW. At each point on the graph the user will be able to see the deformation of the lens at each respective interval. By gathering data on the deformation of the lens while it is being compressed as well as the change in the vertical y-direction as a function of the applied force, it will be possible to calculate the adhesion of the contact lens to the eye through a series of yet to be determined equations.
The Need for Project

To measure the mechanical properties of a contact lens to more accurately determine adhesion strength.

Contact lenses attach to the human eye by a process known as cohesion. When the lens is removed this cohesion force causes damage on the epithelial layer of the eye. Repeated removal of contact lenses from the eye can leave the wearer’s cornea vulnerable to permanent and irreversible damage.

Currently test are only performed on polymers (material of lens) when in its planar form, before it is formed into a curved shape. There are currently no tests done on the polymer once it is in its curved shape. After testing the mechanical properties of a curved lens it is possible to derive the adhesion force of the lens through a series of derived calculations.

The Design Project Objectives and Requirements

Create a device that captures the deformation of lens when applying a compressive force. The force applied and the distance compressed will also be measured using the device.

Design Objectives
To be able to call the designed device a success, it must be capable of holding a contact lens in place while a glass slide slowly compresses it a controlled distance and then is removed again. While the load is being applied then removed from the lens, the force and deformation at each step must also be captured simultaneously.

Design Requirements
In order to capture accurate and reliable data the deformation analysis must occur at a very slow rate. While the lens is held in place a glass slide will be lowered onto the lens, compressing it at a rate of 1mm/min. This rate will allow the deformation of the lens and the applied force to be easily captured at every incremental step, approximately every 5 seconds. In order to obtain proper deformation images it is imperative that the slide compressing the lens remain completely level throughout the process. The design must also be capable to record the force being applied to the lens in the area of 1 mN.

Design Concepts considered
The first two design concepts considered fulfilled most requirements but lacked in...
would be responsible for measuring the contact area of the lens as it is being compressed and the microbalance that the lens is resting on will then be responsible for recording the force applied. As the lens is compressed a series of image analyzing cameras will capture detail images of the lens as it is deformed.

The second design concept that was developed inverted the contact lens and held in place with a custom designed lens holder that would then be lowered onto a glass slide compressing the lens. The glass slide would be resting on a microbalance that would record the force applied as the lens is compressed. A Moiré Interferometer (Rep. 3.1.1) would be set up above the lens which aims a laser through the contact lens, then through two diffraction patterned glass slides, and then to a video camera that records an image created by the changing shape of the lens. The image recorded by the camera change as the contact lens deforms during compression. These images would then be used to determine the overall deformation of the contact lens throughout the process.

The third design concept is a combination of the two previous proposed concepts into a functional final design. The contact lens is positioned as in the first design and laid on a custom design lens holder. A glass slide is then lowered onto the contact lens causing it to deform and the deformation will be captured using the Moiré Interferometer. The lens holder is then resting on a stand which sits on the microbalance allowing force to be recorded as the contact lens is being compressed. The stand will position the contact lens holder so that a laser can shine through concaved side of the contact lens and then be recorded by the camera.

**Recommended Design Concept**

The Ad-Vision design contains a movable glass slide that can be lowered to compress the contact lens. As the lens is compressed a Moiré Interferometer will capture its deformation while the force applied is read off a microbalance. The third design, known as Ad-Vision, consisted of four specific parts: a custom designed contact lens holder, a microbalance, an adjustable rack and pinion system, and a deformation analysis device known as the Moiré Interferometer. The contact lens holder will be set on a flat stand that will be resting on the microbalance. A glass slide will be attached to a rack and pinion system which will move the slide up and down above the contact lens, this slide will be used to apply the force on the lens. The Moiré Interferometer will be used to measure the deformation of the lens while the microbalance records
the force being applied. By gathering data on the deformation of the contact area of the top of the lens while being compressed, and the change in the vertical y-direction all as a function of the applied force, it will be possible to calculate the adhesion of the contact lens to the glass slide through a series of derived equations.

**Analytical Investigations**

Before any experimental data was gathered, a Finite Element Analysis was constructed using Abacus. This developed an understanding of what to expect for force applied as compression occurred. The maximum force that was needed to compress the lens approximately 1mm was 8mN.

The other calculations that Abacus produced was the flattened contact area at each incremental compressed distance. This provides a theoretical estimate of what should be expected from the Moiré Interferometer images that will later be gathered from the Ad-Vision.

**Experimental Investigations**

Two separate experiments were run to test the Ad-Vision’s functionality. The first involved capturing a diffraction pattern from the Moiré Interferometer as the lens is compressed. These images were captured using most of the Ad-Visions systems. This was early in the construction process therefore not yet capable to rest on the microbalance. The contact lens holder with the lens resting on top sat on the beam expander of the interferometer as the glass slide lowered to deform the lens. No force measurements were recorded. The images produced reassured that the Ad-Vision’s key parts were working as planned.

Another key part to the Ad-Vision’s design is the ability to capture y-displacement as force is applied. The next experiment sat the contact lens holder on the microbalance and slowly lowered a glass slide onto the lens to compress it while monitoring the microbalance. Although there were significant margins for error with this process, 15 trials were constructed that produced very similar results. The force needed to compress the lens is 5.4 mN. This value supplied important information for future design when designing for a motor.

**Key Advantages of Recommended Concept**

Ad-Vision’s design is capable of capturing all the measurements and images needed to define the necessary mechanical properties of a
Contact lens. The final design is capable of weighing light enough to rest on the microbalance without it reaching maximum capacity while also being positioned perfectly to allow the Moiré Interferometer to capture the deformation pattern. The key design to support the glass slides on both sides also ensures stability and levelness as the lens is compressed.

### Financial Issues

In designing Ad-Vision, several financial considerations were taken into account. The decision on the material used for the construction of the apparatus had financial factors. Black delrin was used to construct many of the components in this design, this is not only because delrin is light, fairly durable and easy to machine, but because is very cost efficient, approximately $1.17 per cubic inch. Where weight was not an issue and more strength and durability was needed the components were constructed of multi-purpose 6061 aluminum which cost approximately $28.87 per a cubic inch. The final cost for this project is approximately $1000 at this stage.

### Recommended Improvements

Being that this is a first design, the Ad-Vision will absolutely need and benefit from a phase 2 design. In time the apparatus would be fully automated, time and financial constraints prevented this from being completed. Initially a stepper motor was specified for the design but it was too expensive and was not easily compatible with the LabVIEW programming. For this reason a less expensive motor was chosen with the addition of a worm gear box with a 40:1 reduction ratio. Moving forward the motor and gear box assembly must be attached to the rack and pinion system and the LabVIEW programming written. The rack and pinion system itself needs some modifications; the entire system needs to be secured to a sturdy base to prevent the instability that has been seen during testing. The sponsors requested that Ad-Vision also perform a bulge test of the contact lens in the future as well. This test consisted of a pressure being applied to the underside of the lens expanding it outward while again capturing deformation with the Moiré Interferometer. Modifications were made to the contact lens holder to accommodate this new bulge test, but a design to secure the contact lens to the lens holder during the test must be perfected to get reliable data.