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The effect of peripheral curve modifications on the forces which hold the contact lens on the eye using gas permeable contact lenses

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Abstract

The experiment consisted of removing a contact lens from the subject's cornea following modification of the contact lens. Modification consisted of flattening the peripheral curve. The question that we hoped to answer was whether or not the amount of force required to remove the contact lens would increase as the peripheral curve was modified. Our contention was that while flattening the peripheral curve effectively "loosens" the lens the amount of force required to remove the lens from the contact will increase. The experiment showed that in 2 out of 3 subjects there was an increase in the adhesive forces acting on the lens between monocurve and the first peripheral curve. Subsequent flattening of the peripheral curve resulted in a gradual decrease in adhesion force with each modification to flatten the peripheral curve. We would expect such a result since a monocurve has less surf ace area contact between l ens and cornea than a bicurve. However, the data do not support the thought that the adhesion force will increase with each successive flattening of the peripheral curve.

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THE EFFECT OF PERIPHERAL CURVE MODIFICATIONS ON THE FORCES WHICH HOLD THE CONTACT LENS ON THE EYE USING GAS PERMEABLE CONTACT LENSES

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And last, but not least, may I express thanks to my wife, Lanette, for her support, assistance and ingenuity in making the entire experiment a reality.

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ABSTRACT

The experiment consisted of removing a contact lens from the subject's cornea following modification of the contact lens. Modification consisted of flattening the peripheral curve. The question that we hoped to answer was whether or not the amount of force required to remove the contact lens would increase as the peripheral curve was modified. Our contention was that while flattening the peripheral curve effectively "loosens" the lens the amount of force required to remove the lens from the contact will increase. The experiment showed that in 2 out of 3 subjects there was an increase in the adhesive forces acting on the lens between monocurve and the first peripheral curve. Subsequent flattening of the peripheral curve resulted in a gradual decrease in adhesion force with each modification to flatten the peripheral curve. We would expect such a result since a monocurve has less surface area contact between lens and cornea than a bicurve. However, the data do not support the thought that the adhesion force will increase with each successive flattening of the peripheral curve.

INTRODUCTION

Comfortable, well-fitting contact lenses are the desire of every practitioner and the hope of every patient. Understanding the relationship between lens design and the forces acting to hold the lens to the cornea can be very helpful when making contact lens modifications. It is generally recognized that the following forces are involved in the adherence of the lens to the cornea: fluid attraction, frictional forces, adherence, gravity, surface tension, lid force, atmospheric pressure and capillary attraction.[1]

Selecting the proper lens parameters for a given cornea are essential for achieving an optimal fit. Frequently, the practitioner must make changes or modifications in these parameters in order to loosen or tighten the lens fit on the cornea. Previous investigations have identified the forces which act to hold the contact lens to the eye. In 1947 Pascal[2] talked about the adhesion forces. Gordon (1961)[3] examined the influences of molecular forces, surface tension, and atmospheric pressure on the retention of corneal lenses on the eye. Wray (1963)[4] and Miller (1963)[5] considered the theoretical aspects associated with mathematical analysis and the laws of physics. Miller identifies six basic forces, i.e. atmospheric pressure, hydrostatic pressure, tear viscosity, force of gravity, surface tension and lid force. He emphasized the importance of the prelens tear film in holding the lens to the cornea. Poster (1964)[6] examined the hydro-dynamics of corneal contact lenses as but one of several forces functioning to hold a lens in place. Roucher (1964 and 1968)[7] utilized a physics approach to the identification of the adhesion forces and concluded that molecular attraction, surface tension and capillary attraction were not critical to holding the lens to the cornea but rather, three other forces existed which were of prime importance, namely:

1. Cornea/tear force of adherence which causes the film of tears to adhere to the cornea.

2. The force of cohesion of the tears which causes the film of tears not to be torn and

3. The lens/tear force of adherence.

This last force of adherence is the most important since the two preceding forces exist independently of the lens. The lens/tear force is the basis of the whole principle of the corneal lens according to Roucher. Kikkawa (1970)[8] examined the tear fluid interface at the edge of the contact lens. Utilizing a slit lamp photographic technique he measured the radius of curvature of the interface on female subjects. He concluded that centralization and adherence of the lens to the cornea are both accomplished by means of negative pressure. Mackie et. al.[9] considered those factors influencing corneal contact lens centration and in particular, upward movement of the contact lens against the pull of gravity. They also stated that the greater the elasticity of the lens, the greater the suction. Yorke (1971)[10] talked about attractive forces between molecules in solids, liquids and gases. And how these forces in conjunction with the deformation of the corneal surface gave rise to the forces retaining a contact lens on the eye. These forces then act in combination to hold the lens to the eye. Further investigations looked at specific design features of contact lenses and how modifying these features altered the adhesion forces holding the lens to the eye. In 1967 Dr. George Jessen presented a paper entitled, "A study of capillary attraction between corneal lens and cornea."[11] His experiment consisted of altering the base curve of PMMA corneal lenses and measuring the force required to remove the contact lens from the eye. He found that a steeper than K base curve required more force to remove than the on K or flatter than K lenses. Earlier in 1963 Miller[4] had used a similar technique to examine the physical forces acting on the contact lens. Lowther and Hill (1967)[12] made use of an anesthetized rabbit's eye to perform experiments in which the following lens design features were studied: the diameter of the lens, the circumference of the lens, the area under the lens, and the base curve of the lens. Commenting on their experiment they stated: "That a steeper base curve (containing larger tear volumes) required greater force to detach a lens appears, at first contradictory to the general observation first given; but, in fact, the increase in saggital separation between corneal apex and the lens back surface had less effect on the force required than thinning of the tear layer at the lens perimeter. The meniscus geometry of the last condition also should promote a "tighter" bonding between lens and cornea"

Numerous studies have addressed the issue of modification and lens "tightness and looseness." For example, in a 1960 experiment by Martin and Jensen[13] it was concluded that the proper peripheral curve is the key to success in fitting small lenses. Steele (1962)[14] studied problems associated with the fitting of corneal contact lenses. Williams[15] in 1967 did a study on the minimum compression concept. The minimum compression concept is a method of balancing the area of the lens touching the tear layer to attain the least possible change in the cornea's normal environment. The central area paralleling the cornea and the secondary curve sufficiently flatter than the cornea to allow tears between it and the eye. A study by Atkinson (1975)[16] looked at modification of lenses -- bi-curves, tri-curves and multi-curves.

Bibby (1979),[17] in a study on factors affecting peripheral curve design states that peripheral curve width and radius are important in providing adequate edge clearance. The result of properly constructed peripheral curves is adequate circulation of tears beneath the lens providing oxygen to the cornea and removing metabolic by-products. Also, the peripheral curve serves to support the tear meniscus at the edge of the lens. This meniscus provides forces needed to cause the lens to center.

These studies reinforce the importance of proper lens design and in particular proper peripheral curve design. What effect would flattening of the peripheral curve have on the forces holding the contact lens to the eye? Very little work with peripheral curve modification and adhesion forces has been done. And no peripheral curve modifying has been done using gas permeable hard lenses.

Current knowledge contends that one way to "loosen" a lens which fits too tightly is to flatten and/or widen the peripheral curve. The present project is designed to measure the amount of force required to remove a contact lens from the eye subsequent to changing the peripheral curve width and radius. It is our contention that flattening or widening the peripheral curve to loosen the lens will not result in less force required to pull the lens off the eye, but rather more force. Ultimately, this information will be useful in improving contact lens fitting procedures. The end result being a contact lens which has good centration, good tear pump action and is comfortable to wear.

METHODS

Three other optometry students and I acted as subjects for the experiment. The only requirement for subject participation was that they be experienced, well-adapted hard contact lens wearers so as to minimize tearing and associated adaptation problems such as blinking. One eye on each subject was tested. Subjects indicated which eye they preferred to have tested. It turned out that the right eye was selected by all participants. Polycon II gas permeable hard contact lenses were provided by Syntex Opthalmics, Inc. for the experiment. Base curve and overall diameter for the experimental lenses were ordered to match the right eye contact lens parameters of each subject's current contact lens. The following is a list of each subject and the corresponding experimental lens ordered. Each lens was a custom order and came with specified overall diameter, base curve, center thickness and power. Center thickness and power were set at .20 mm and -2.00 D respectively. This provided a lens with an adequate edge thickness so as to facilitate handling and modifying. Coincidentally, all subjects were myopic. Since this was not a contact lens fitting experiment we wanted to use a lens which would match the parameters of the subject's current lenses so as to maximize comfort and eliminate, as much as possible, any adverse effects in the data collection due to a new or poorly fit contact lens.

Here is each subject with the experimental lens parameters as ordered from the laboratory:

	O.A.D.*	B.C.**	C.T.***	POWER
Subject #1:	8.7 mm	7.50 mm	.20 mm	-2.00 D
Subject #2:	9.2 mm	7.40 mm	.20 mm	-2.00 D
Subject #3:	9.2 mm	7.75 mm	.20 mm	-2.00 D
Subject #4:	9.2 mm	7.80 mm	.20 mm	-2.00 D

*overall diameter with edge allowance of .2 mm.
**base curve
***center thickness

Each lens was cut down and the edge rolled prior to beginning the experiment. Final O.A.D. was .2 mm less than the originally ordered amount. A piece of 8 lb. fishing line approximately 14 inches in length was glued to the anterior surface of the contact lens with Super glue. The other end of the fishing line was tied to four loops of string which were tied to the four corners of a small flat paper boat, size 3 inches by 4 inches. A kowa camera stand without the kowa camera was used as a head rest and chin rest. Several two by four wood pieces were nailed together to provide a point in front of the subjects head from which a pulley (3/4 inch) could be suspended and secured using nails. The chin rest could then be lowered or raised to place the subject's eye at the same level as the pulley. Having previously threaded the fishing line through the pulley prior to glueing the fishing line to the lens the apparatus was then ready for making the measurements. With the lens clean and the edges rolled a single drop of wetting solution, in this case liquifilm, was placed on the lens and spread over the posterior lens surface. The contact lens was then placed gently on the subject's eye. The subject was instructed to look straight ahead and avoid blinking if possible. With the lens in place on the cornea sand was added to the paper platform until the lens was pulled off the eye. The sand was emptied onto a small sheet of saran wrap. This procedure was repeated four more times with the exception of the liquifilm being added. This occurred only at the beginning of each group of five trials. Upon completion of each group of five trials each measurement of sand was weighed using a counterbalance. These figures were recorded next to the monocurve notation.

The fishing line was then cut about one inch from where it attaches to the contact lens. Using a suction cup modifying instrument the suction cup was placed over the fishing line and attached to the front surface of the lens. The initial peripheral curve radius (P.C.R.) was 1 mm flatter than the base curve with the peripheral curve width set at 0.5 mm. The O.A.D. and peripheral curve width (P.C.W.) remained constant for all subsequent modifications. A 7x peak scope and microscope were used to verify P.C.R., P.C.W. and edge contour. Brass radius tools with dermicel tape (0.1 mm allowance for tape) were used to make the P.C.R. Following modification and cleaning of the lens the fishing line was spliced together with super glue. This provided a very strong bond which could not be pulled apart in a direction parallel to the fishing line itself. However, it was quite easy to peel the two pieces of fishing line apart at the splice. This method worked quite satisfactorily. The next group of five trials were conducted in exactly the same way as was previously described. Five modifications of the peripheral curve were made with each successive modification flattening the P.C.R. by 1 mm.

RESULTS

Table 1 is a compilation of the actual amount of weight used to remove the contact lens from the eye. Please note that not all brass radius tools in the desired diameters were available. Also, subject #1 is not included because of poor data collection procedures. Problems arose from placing a drop of Barnes-Hinds wetting solution after each trial which placed too much fluid in the eye causing premature removal of the lens. The subject also complained of a burning sensation in the eye most likely related to the wetting solution. This resulted in an activation of the blink reflex causing the lens to be ejected from the eye prematurely. Additionally, subject #4 was unable to tolerate the lens on his cornea without blinking. Since my base curve was very nearly identical to subject #4's I acted as the subject again.

Figure 1 shows the relationship of the peripheral curve radius to the amount of force required to remove the lens from the cornea.

Table 1

Trial Number

	1	2	3	4	5	Ave.
Subject #2						
B.C. 7.4 mm	0*	5.25	8.90	0*	29.25	14.47
P.C.R. 8.4 mm	0*	0*	23.95	30.25	27.85	27.35
9.4 mm	17.40	24.45	28.35	14.05	12.85	19.54
10.4 mm	4.05	25.15	12.05	12.05	11.25	12.91
11.4 mm	7.00	6.55	2.95	5.90	9.15	6.31
12.4 mm	3.85	5.25	6.35	4.55	8.25	5.65
Subject #3						
B.C. 7.75 mm	13.25	10.85	39.35	13.10	13.65	18.04
P.C.R. 8.8 mm	9.95	7.55	3.35	3.55	17.00	8.28
9.8 mm	8.50	4.80	5.20	6.05	11.45	7.20
10.8 mm	9.70	3.25	4.15	4.10	4.40	5.11
11.9 mm	3.50	4.50	2.65	6.05	7.85	4.91
12.3 mm	4.55	3.50	2.55	3.40	3.40	3.48
Subject #4						
B.C. 7.8 mm	4.25	5.25	5.75	6.05	6.80	5.62
P.C.R. 8.8 mm	16.85	12.15	15.55	16.65	13.85	15.01
9.8 mm	12.95	7.45	13.25	13.05	3.65	10.07
10.8 mm	6.85	8.65	9.95	6.05	8.95	8.09
11.9 mm	4.35	5.75	10.65	14.55	9.05	8.87
12.3 mm	9.15	6.25	6.35	9.05	7.15	7.59

Note: All measurements are in grams

*A measurement of "0" means that the contact lens was pulled off the cornea by the weight of the fishing line, string and platform with no weights being added. The measurements were not included in the average score values.

The weight of the fishing line, string, and paper platform was 1.4 grams. The balance was zeroed at 0.85 g. These values have been incorporated into the above data set.

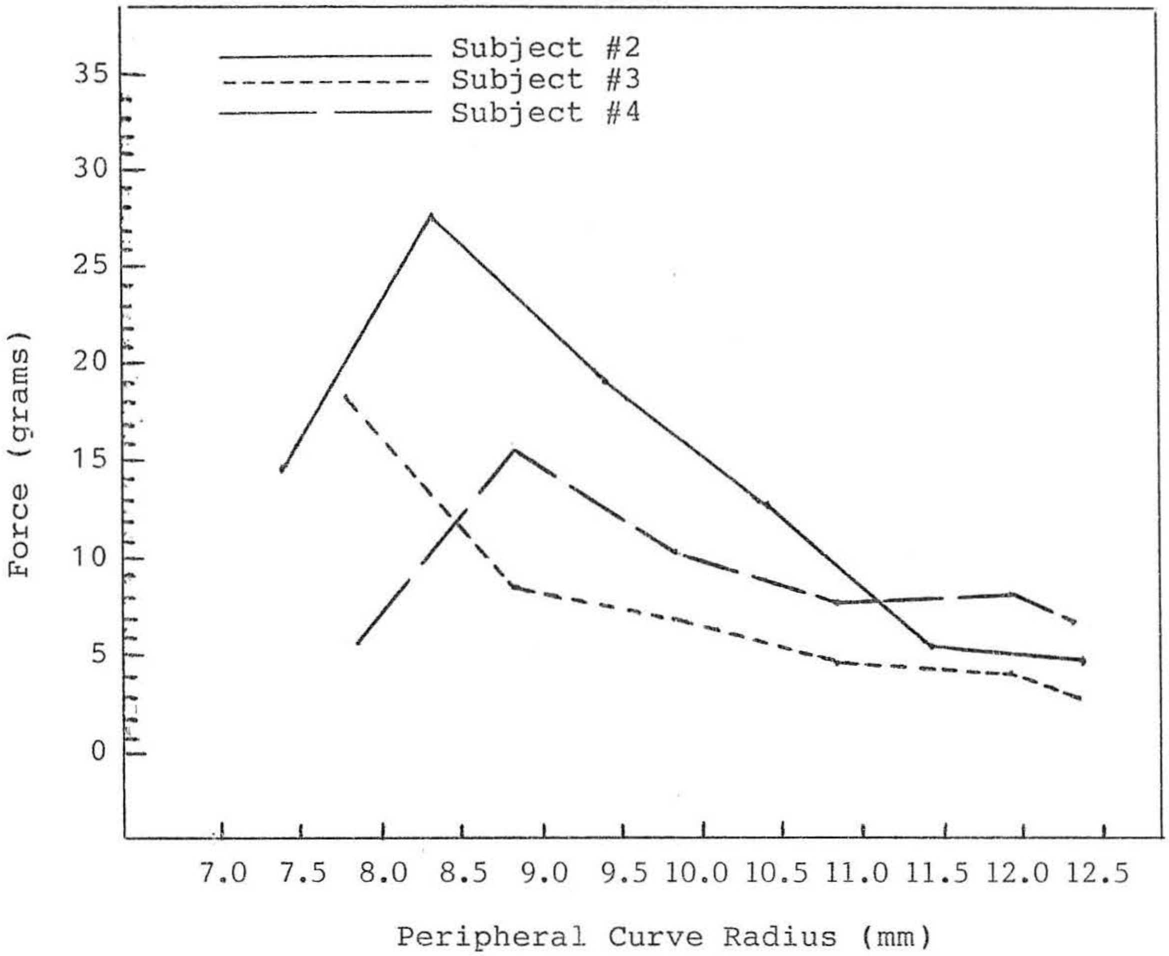

Figure 1. Relationship of peripheral curve radius to the forces holding the lens on the cornea. Each point is the mean of five observations.

Subject #2: Base curve = 7.4
Subject #3: Base curve = 7.75
Subject #4: Base curve = 7.8

DISCUSSION & CONCLUSION

Every effort was made to keep the measurement procedure the same each time. The data gathered indicate several trends. First of all, the monocurve values in 2 of the 3 cases was less than that of the first peripheral curve. This supports the idea that the greater the surface area contact at the periphery the stronger the amount of force necessary to remove the lens. After the first modification there is a corresponding decrease in force or weight with each millimeter of peripheral curve flattening. This is contrary to our original hypothesis that flattening the peripheral curve would result in more force needed to remove the lens.

It would be interesting to obtain ten sets of measurements on each of 3 or 4 subjects. Each subject being a well-adapted hard lens wearer and more importantly capable of tolerating the lens so as not to blink the lens off. Peripheral curve width changes as they related to lens adhesion would be another area of study that could be done utilizing this procedure.

Certainly, we would like to know precisely how a contact lens will respond to a given modification and what it all means in terms of lens centration, tear pump action, and patient comfort. Today's data implies that flatter means looser and less force to remove the lens. Hopefully, this information will serve as a starting point from which to pursue further testing and data gathering.

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