CLINICAL RESEARCH/RECHERCHE CLINIQUE

Compression Testing of Three Soft Lens Polymers with a Simulated Fingernail

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Abstract

An analysis of the mechanical properties of finished lenses utilizing compression testing identifies factors contributing to soft lens damage. Sauflon 70, Snoflex 50, and Toyo 515 PolyHEMA lenses, all of plano power and equal thicknesses were compressed within the optical zone by loads exerted by a simulated fingernail made of guitar pick material. Six lenses of each polymer were used for each of three tests. It was found that Toyo 515 PolyHEMA had a relatively lower compressive strength than the other two non-HEMA materials; that the Sauflon 70 had the least ability to recover once compressed; and that all three polymers did not appear to recover their previous compression strength after undergoing a dehydration/rehydration cycle. In the case of the Toyo 515 lenses, this last result was confirmed statistically.

The problem of soft lens damage is perplexing to practitioners and frustrating to patients. In most practices, every few days a patient complains that a lens has broken for no apparent reason. No matter how meticulous a practitioner may be in instructing his patients in caring for lenses, the problem of soft lens damage continues. One wonders whether great differences exist in the durability of different types of lenses, or whether heretofore unknown factors contribute to soft lens damage.

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Up to now, replacement rates in longitudinal studies have provided manufacturers with a deduced durability of their lenses in a given population,[1,5]. Reports of direct mechanical testing, including comparative studies, are difficult to find in the literature for either finished lenses or larger samples of material,[8,9]. It is worth noting that, the American Society for Testing and Materials (A.S.T.M.), has no reports whatever of tests on soft lens polymers.

When it has been documented, the most commonly used index of durability for soft lens material has been the tensile test, which involves stretching the material to the breaking point. However, it is very difficult to compare such test results without knowing whether a standardized procedure was employed. Table 1 demonstrates the considerable variation in the reported tensile strength values of HEMA material.

A better approach in studying the tendency for soft lens damage might be to subject finished lenses to the types of stresses more similar to those normally encountered in use. Tensile testing is not perfectly relevant since typical wearers do not stretch their lenses. Moreover, tensile testing is not usually performed on finished lenses, but on larger specimens of material. Thus, while tensile strength may be a customary determination for materials in general, it should be questioned as an index for tendency to damage in soft lens materials.

This paper hypothesizes that soft lens damage occurs when a discontinuity is produced in the material by the pressure of a sharp object against it, resulting in a nick or cut. Once developed, this nick may extend as a result of tension on the lens in handling, so that the whole lens is torn. The most frequent sharp object which might come into contact with a soft lens is the edge of a fingernail. As well, fingertips, tongs or tops of storage cases may occasionally compress lenses.

Résumé

Une analyse des propriétés mécaniques de lentilles finies à l'aide d'essais de compression fait ressortir les facteurs qui contribuent à l'endommagement des lentilles souples. Les lentilles Sauflon 70, Snoflex 50 et Toyo 515 PolyHEMA, toutes planes et d'égale épaisseur ont été comprimées dans les limites de la plage optique par une charge exercée par un ongle simulé fait d'un médiator de guitariste. Six lentilles de chaque polymère ont été soumises à l'essai. On a déterminé que la lentille Toyo 515 polyHEMA avait une résistance relativement plus faible à la compression que les deux autres, qui ne sont pas de la catégorie HEMA. On a également constaté que la lentille Sauflon 70 était la moins capable de reprendre sa forme une fois comprimée et que les trois polymères semblent incapables de retrouver leur résistance à la compression après un cycle de déshydratation et d'hydradation. Dans le cas de la lentille Toyo 515, ce dernier résultat est confirmé par la statistique.

Although the problem of possible fingernail damage has been known since soft lenses were first introduced, to the best of the authors' knowledge it has never been investigated by any direct testing methods. The compression testing described in this paper not only simulates more closely the real life situation whereby soft lenses are damaged, but also provides additional information otherwise unapparent from tensile testing alone.

As load is added to a contact lens, using a simulated fingernail, there are two stages of deformation that occur before the "break" point: elastic deformation which is recoverable, and plastic deformation, which is irrecoverable[7]. When the "break" point, or failure point is reached using the experimental technique herein described, the tester does not "crash" through the material as it might in the case of a test of a brittle substance, but rather cuts just enough of it to produce a small perforation. The "break" point can only be determined by a careful examination of the lens each time a load is added.

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Soft lenses made from three polymers were tested; each was nominally plano power, .13 mm thick and 8.4 mm in base curve. Two of the three were 14.0 mm diameter and the third 14.3 mm. Plano power produced an optical zone of uniform thickness allowing testing to take place anywhere within it. The wet thickness of the lenses was nominally .13 mm, based on the calibrated dry thickness and the expected expansion factor on hydration. Since Nakajima[6] had previously reported that the tensile strength of hydrogel material declines with age, all lenses were tested within fourteen days of the day they arrived from the laboratory.

The first polymer tested was poly(methylmethacrylate-N-vinylopyrrolidone) with water content adjusted to 70%. This is Sauflon 70 or Lidofilcon A, and is produced in the United States by American Medical Optics. The second was a terpolymer composed of "G-Mema" methylmethacrylate and vinyl pyrrolidone with a water content of 52.5%. It is known as Snoflex 50, and is produced by Smith and Nephew Optics of the United Kingdom. The third was a polyHEMA material of 2 hydroxyethylmethacrylate, 35.6% water, known as Toyo 515, and produced by Toyo Contact Lens Co. in Japan.

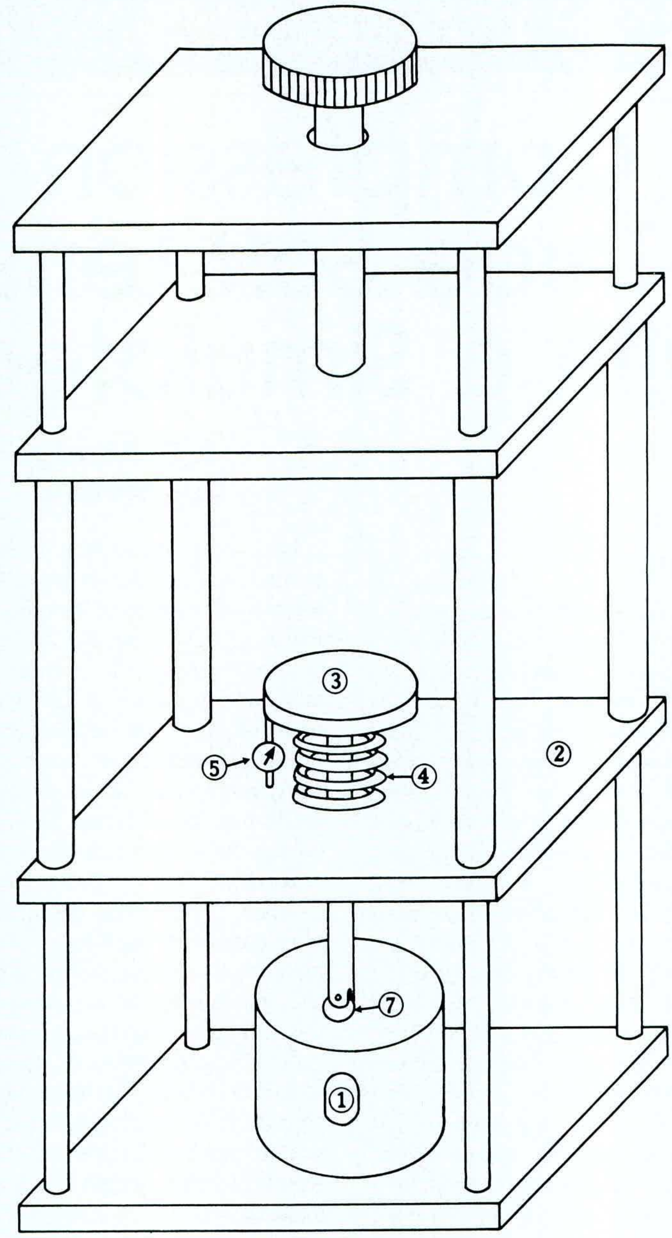

Figure 1

Table 1
Reported Tensile Strength Data for Conventional HEMA Material

Source	Tensile Strength in Units Given	Tensile Strength in Kg/cm²
Hales[11]	48 p.s.i.	3.4
Hosaka (PolyHEMA I)[9]	12.2 kgm/cm²	12.2
Hosaka (PolyHEMA II)[9]	10.4 kgm/cm²	10.4
Tighe[8]	$\simeq 0.5 \times 10^7$ dynes/cm² $\simeq$	5.1
Smith & Nephew Optics (company literature)	6.5 kgm/cm²	6.5
Syntex Ophthalmics (company literature)	1.3×10^7 dynes/cm²	13.0

Three parts are involved in this research:

Part I.

(a) A determination of the relative compression strength of the three polymers being tested.

(b) A graphical presentation of the relative softness and elasticity of each.

Part II.

A determination of the facility of each material to recover once compression has taken place upon it.

Part III.

A determination of the change in compressive strength of the three polymers after they have been dehydrated for a given time and subsequently rehydrated.

Apparatus (See Figures 1 and 2)

The lens to be tested rests on an acrylic template[1] set in position at the bottom of a specially designed beaker containing normal saline solution. The beaker rests firmly on a circular cut out area on the base. The "stage" area[2] is supported by a post at each of the four corners, and is designed so it can be racked up or down by turning a knob at the top of the apparatus. Because the shaft with the simulated fingernail is supported at this level, the raising action of the stage effectively raises the simulator. A circular platform[3] on which weights can be added, lies perpendicular to the upper end of the shaft. A spring[4], serving to counterbalance the weight of the platform, lies between the platform and the stage. Also mounted on this level is a dial gauge[5] that records the displacement of the platform to the accuracy of 1/1000th of a mm. Teflon bushings[6], utilized to minimize friction, support the shaft in a vertical position. The last 15 mm of the shaft act as the support area for the simulated fingernail[7]. This part of the shaft is split lengthwise and one half cut out to serve as the "support plate" for the fingernail. A set screw runs through a small hole in the plate and the fingernail into a threaded hole in the shaft. The shaft and supporting posts are made of steel drill rod, and the horizontal levels and platform built of aluminum. Before testing can be carried out, the vertical centreline of the shaft and acrylic template must be made to coincide.

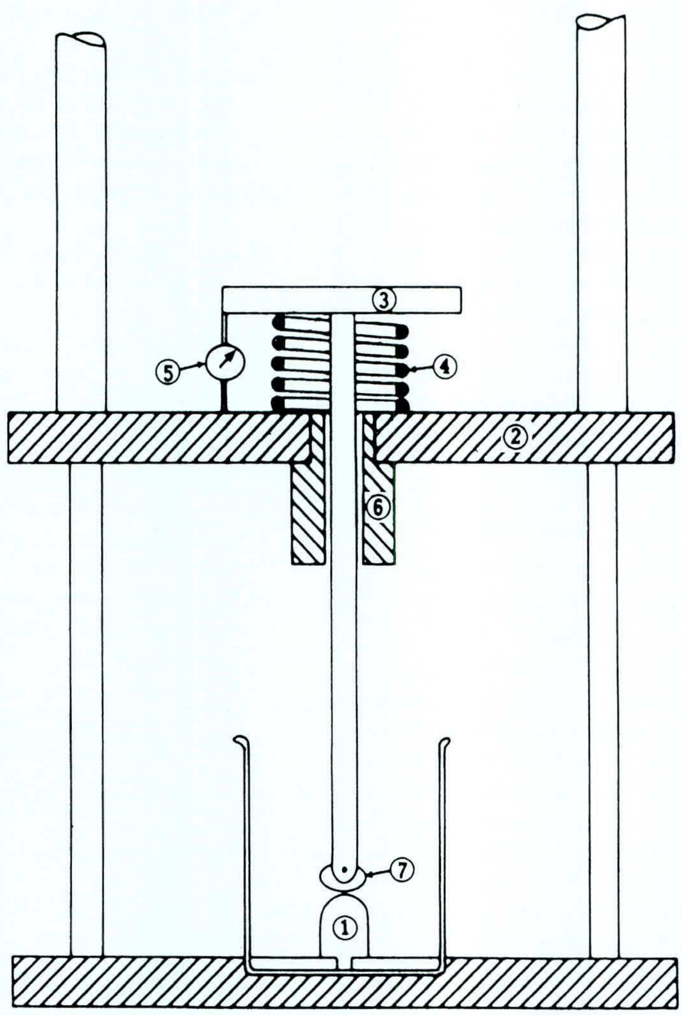

Figure 2

The material utilized as the fingernail simulator was a black Gibson "thin" guitar pick.

The material utilized as the fingernail simulator was a black Gibson "thin" guitar pick, which is much stiffer than any soft lens material and similar in mechanical properties to the human fingernail. The thickness and edge contour of a new pick was also similar to that of an uncut fingernail. The pick had to be cut and a hole drilled into it in order to be fitted onto the shaft. Two mm of it extended below the support plate, as shown in Figure 3. In an attempt to maintain consistency in the edge contour of the pick as the testing continued, a new pick was fitted on the testing apparatus each time a different polymer was tested.

The weights used in this experiment belonged to a pressure gauge calibration apparatus which was produced by Chandler Engineering Company of Tulsa, Oklahoma. They were cylindrical metal interlocking weights, each with a hole in the centre. They consisted of 1 at 63 gm, 1 at 126 gm, 4 at 252 gm, and 2 at 1260 gm.

The above were occasionally supplemented by weights from a standard Ohaus scientific weight set. Of these, the most frequently used were the 50, 100 and 200 gm loads.

In graphing displacement with respect to load, the most reliable results were obtained using the interlocking weights. Using these, once the load was positioned in the centre of the platform, the centre of gravity would be maintained directly over the loading pick.

Methods in Preparation for Testing:

1. The lenses to be tested were inspected for damage and then verified for plano

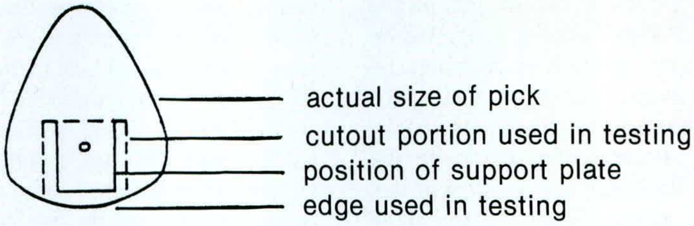

Figure 3

power in the lensometer, and for approximate base curve on the hydrovue lens analyser.[10]

2. The guitar pick material, after being examined for defects was cut to the shape and size shown in Figure 3, and mounted on the shaft of the tester.
3. The template was mounted on the bottom of the beaker corresponding to the base curve of the lenses to be tested. (Toyo 515 lenses measured 8.8 mm base curve, the other two polymers were 8.4 mm base curve).
4. The beaker was filled with normal saline, such that the template was at least 5 mm below the surface.
5. The 63 gm cylindrical weight was centred on the testing platform. This served to bring the platform down to the action button of the gauge, and to overcome most of the friction within the gauge.
6. A test lens was removed from its container and blotted with tissue. An indelible mark was put at the edge of the lens opposite which the lens was to be tested. Tests were avoided within 2.5 mm of a previous compression mark.
7. The lens was mounted with its verified base curve on the template so that the tester would make contact at the point desired.
8. While looking through the beaker, the observer would screw down the stage until the pick just made contact with the lens. If a space existed between the action button on the dial gauge and the platform, the initial contact point had been passed. A 50 gm load was applied to the centre of the platform to standardize the starting point. The tip of a WEN electrical engraver/vibrator was then put in contact with the horizontal support bar of the gauge beyond the vertical pillar supporting the gauge. This vibrator assisted the gauge to move freely by minimizing the effects of friction in the bushing. While the vibrator was operating, the stage was screwed back to the point that the 50 gm load produced a displacement of .01 mm.
9. Loading could now take place.

In loading it was important not to drop the weights one on top of the other as they were added. One was let go only when the interlocking portions were in perfect contact. With the total load in place, the vibrator/engraver was used to free up the gauge. Having completed an individual test, the weights were carefully removed, the stage screwed up and the lens removed from the template. It was dried, and then inspected in front of a bright fluorescent source with a +20.00 Diopter trial lens. Recall that the sample lens tested had to be inspected for damage after each load application.

When lens failure occurred, there were characteristic ragged tear marks at the break. A lens completely split exhibited an unmistakable reflective line. Unbroken lenses exhibited a compression line only. If they were rewetted and flexed at right angles to the break, a split would not be induced.

> The load values obtained should not be considered absolute for a number of reasons.

In Parts I and III of this experiment, testing was repeated using different loads in a bracketing technique until a not broken/broken sequence was obtained. In Part II, various loads were added which had been determined by pretesting. The graph produced in Part I was produced by recording the displacement reading on the gauge, (with the assistance of the vibrator) as each load was added. This graph, Figure 5, is the average of six lenses of each of the three polymers. The usual increment of testing was 252 gm, although smaller increments were attempted early in the experiment in the hope of refining the results. The maximum load that could be accommodated by the apparatus was 3150 gm. (See Figure 4.)

Before describing the results of the testing, it should be pointed out that the load values obtained should not be considered absolute for a number of reasons. First of all, the artificial starting point using a 50 gm load to produce a displacement of .01 mm introduced a small error. Also, the unreliable gauge values were found when the displacement exceeded the thickness of the lens being tested, indicating the testing apparatus was being compressed as well as the lens. Finally, friction could not be totally eliminated, even though the teflon bushings permitted the shaft to move quite freely.

Results

Part I: Relative Compression Strength of the Three Polymers Tested:

(a) Six lenses of each polymer were tested.

All six lenses of Sauflon 70 remained unperforated when the maximum load of 3150 gm was applied to the tester.

All six of Snoflex 50 also remained unperforated with the same 3150 gm load.

The loads that produced perforation with Toyo 515 polyHEMA were less than 3150 gm.

This failure load data for the Toyo 515 lenses is recorded according to the following scheme:

$$\bar{X}_{min} < \bar{X}_m < \bar{X}_{max}$$

where $\bar{X}_{min}$ is the six trial average of the maximum load (gm) in which failure did not occur.

$\bar{X}_{max}$ is the six trial average of the minimum load (gm) in which failure occurred.

$\bar{X}_m$ is the estimated average failure load (gm) (the median between $\bar{X}_{min}$ and $\bar{X}_{max}$)

here, $\bar{X}_{min} = 1810$

$\bar{X}_{max} = 1930$

Thus, $1810 < \bar{X}_m < 1930$

and $\bar{X}_m = 1870$

(b) In Figure 5, deflection (mm) is plotted with respect to mass (gm) for the three polymers. The Y axis value is limited to .15 mm since deflection values above this were considered unreliable as they exceeded lens thickness. The slope is similar for all three polymers, indicating they exhibit similar elastic properties. However, it will be noted that the deflection is consistently greater per load with Sauflon 70, indicating it to be the softest material of the three. Snoflex 50 appears to be the hardest.

Part II: Facility of Each Material to Recover Completely Once Compressed

Again, six lenses of each polymer were tested. Different loads, the range of which had been predetermined, were applied at different points within the optical zone of each lens. The lenses were returned to their containers in saline and then removed 24 hours later for inspection. The lenses were blotted and examined with a +20D. lens over a bright fluorescent source. It was noted which loads had still left a compression mark on the lens, and which did not.

Recording the data in a similar fashion to that of Part 1,

$$\bar{P}_{min} < \bar{P}_m < \bar{P}_{max}$$

where $\bar{P}_{min}$ is the six trial average of the maximum load that did not produce a compression mark after 24 hours.

$\bar{P}_{max}$ is the six trial average of the minimum load that just produced a compression mark after 24 hours.

$\bar{P}_m$ is the estimated average load that just produced a compression mark after 24 hours, (the median between P_{min} and P_{max}).

The data found (in gm) can be summarized as follows:

	$\bar{P}_{min}$	$\bar{P}_m$	$\bar{P}_{max}$
Sauflon 70	96	122	147
Snoflex 50	1220	1390	1550
Toyo 515	840	950	1070

Part III: Compression Strength of the Three Polymers After They Had Been Allowed to Dehydrate and Were Rehydrated Again:

In the initial pretesting of the apparatus using Toyo 515 lenses taken from office stock there was enormous variability found in the load required to perforate a lens. Then it was remembered that some of these lenses had dried out in their containers and had been rehydrated. According to Douglas Keller[12] of the McMaster Institute for Polymer Production Technology, polymer chains can break in a shrink (dehydrate)/swell (hydrate) cycle. If it could be established that the compression strength of soft lenses is less after undergoing a dehydration/rehydration cycle, it would have practical significance for both wearers and practitioners. Hence the rationale for this part of the experiment.

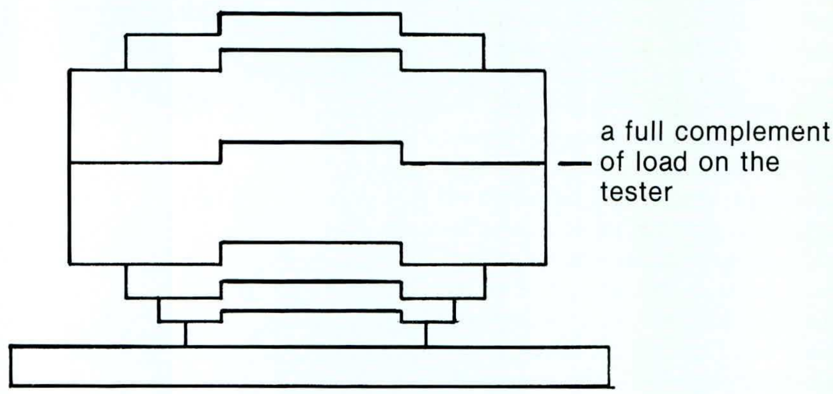

Figure 4

On the bottom of a large ice cube tray, wooden slats 1/8'' thick supported a piece of fibreglass screen. On this screen rested the cubical divider which was used to separate the lenses. Six lenses of each polymer were placed concave down on the screen and left to dry for a period of 48 hours. The testing room, 10' × 8' × 8' contained an Electrohome dehumidifier which prevented the relative humidity from exceeding 40%. At the end of the drying period, normal saline was added to the tray until the lenses easily floated. After 12 hours the lenses were turned over and submerged in the saline. Twelve hours later they were returned to their original containers and taken to the laboratory for testing.

Results

Sauflon 70:

Five of the six lenses remained unperforated when subjected to a load of 3150 gm. One lens broke with a load between 2490 and 2900 gm.

Snoflex 50:

Four lenses withstood 3150 gm. Two broke with a load between 2900 and 3150 gm.

Toyo 515 Poly HEMA:

where $x_{m'}$ is the estimated average failure (breaking) load:

$$949 < \bar{X}_{m'} < 1220$$

and thus

$$\bar{X}_{m'} = 1080$$

Note that this is about half the value found for $\bar{X}_m$ in Part I. (In Part 1, $\bar{X}_m = 1870$.)

Enlarging The Two Test Samples of the Toyo 515 Lenses to 12 Lenses Each:

Six more lenses that had gone through the dehydration/rehydration cycle were also tested, and the results included with those of the previous six.

For these 12,

$$727 < \bar{X}_{m'} < 988$$

$$X_{m'} = 857 \qquad \sigma_n - 1 = 371$$

(Sample standard deviation)

Six more "normal" lenses had also been tested as a result of the work in Part II. In doing Part II, the minimum load required to leave a compression mark after 24 hours was very close to the failure load. These failure loads were also recorded and included with those found in Part I. Thus for the 12 "normal" lenses,

$$1520 < \bar{X}_m < 1720$$

$$\bar{X}_m = 1620 \qquad \sigma_n - 1 = 452$$

A pictorial representation of the two samples of twelve lenses is represented in Figure 6. Note that the dehydration/rehydration cycle weakened the lenses significantly.

Discussion

Hosaka et al.[9] reported that the tensile strength of Sauflon 70 was greater than that of the two polyHEMA materials. The present study demonstrates the superior compressive strength of certain nonHEMA polymers over a polyHEMA.

In the past, certain investigators have assumed that the strength of a soft contact lens varies inversely with the proportion of water in the lens. This is not necessarily the case. As demonstrated, polymers of high water content can be produced having remarkable compressive strength.

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Part II was an attempt to determine the load required to produce the limit of elastic deformation of the material. The evidence presented indicates this load to be greatest in the case of the Snoflex 50 material. As shown, remarkably low loads leave a compression mark on Sauflon 70 lenses even after 24 hours.

The third part of the experiment dealt with the difference in compressive strength between normal lenses and those which had undergone dehydration followed by rehydration. In the case of the Sauflon 70 and Snoflex 50 lens materials, it would appear that the dehydrated lenses were less strong, but with the small sample, the difference could not be supported statistically. In the case of the Toyo 515 lenses, whether the samples compared were the initial six lenses tested, or the combined groups of twelve, the results were the same: those that had gone through the dehydration/rehydration cycle exhibited a lower compressive strength than did normal Toyo 515 PolyHEMA lenses. The difference between either pair of two test samples was confirmed statistically to the 0.1% level by a student's t test. Bar graphs (Figure 6) illustrate the difference between the two distributions of twelve.

Lastly, in this study of mechanical properties of soft lenses, consider compressive strength versus tensile strength. The cross sectional area involved in this simulated fingernail compression testing was approximately 1 sq. mm., (i.e. thickness of tester = 0.45 mm × length of the mark on the lens = 2.2 mm). The lowest average breaking load was found with Toyo 515 PolyHEMA in Part III, being about 860 gm, which, on interpolation from the graph in Figure 5, would indicate the tester produced a perforation before compressing the lens to its full thickness. Thus the sources of error for this result would be limited to the zeroing problem, and friction, which would not affect significantly its magnitude. It is recognized that the testing described is a simulated fingernail compressive load rather than pure compression testing. However, the 860 gm/mm^2 = 86 kg/cm^2 far exceeds in magnitude any value for tensile strength listed in Table 1, suggesting that the compressive strength of soft lens material is greater than its tensile strength.

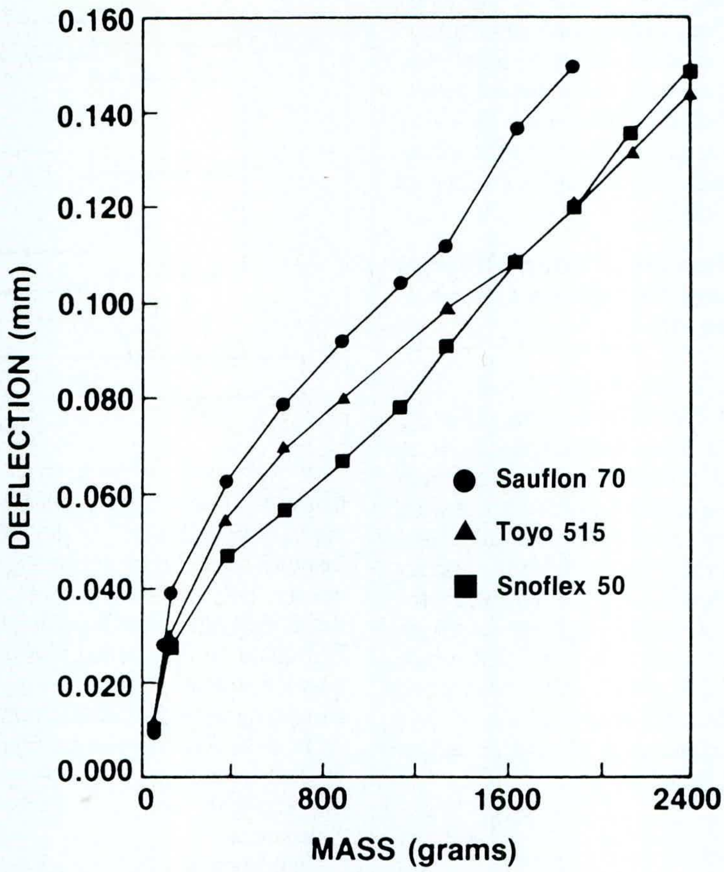

Figure 5

Conclusions

A technique of compression testing for soft lens materials was developed which the authors feel more closely simulates the conditions of lens failure than tensile testing. Actual plano power lenses were studied rather than larger bulk specimens, and the central uniform thickness regions were loaded to ensure that comparison between different materials was valid. It is recognized that lens failures often initiate at the edges but these usually have quite different geometries from one another and, in any event, would be extremely difficult to load properly.

> All three types of lens material tested seemed less strong after they had been dehydrated and hydrated again.

The compression testing demonstrated that the two non-HEMA lenses, Sauflon 70 and Snoflex 50, have a greater compressive strength than Toyo 515 PolyHEMA. It has also been shown that Sauflon 70 material, while having great compressive strength is rather soft, whereas Snowflex 50 material exhibits comparable compressive strength together with a better tendency to recover once deformed. The minimum load leaving a compression mark after 24

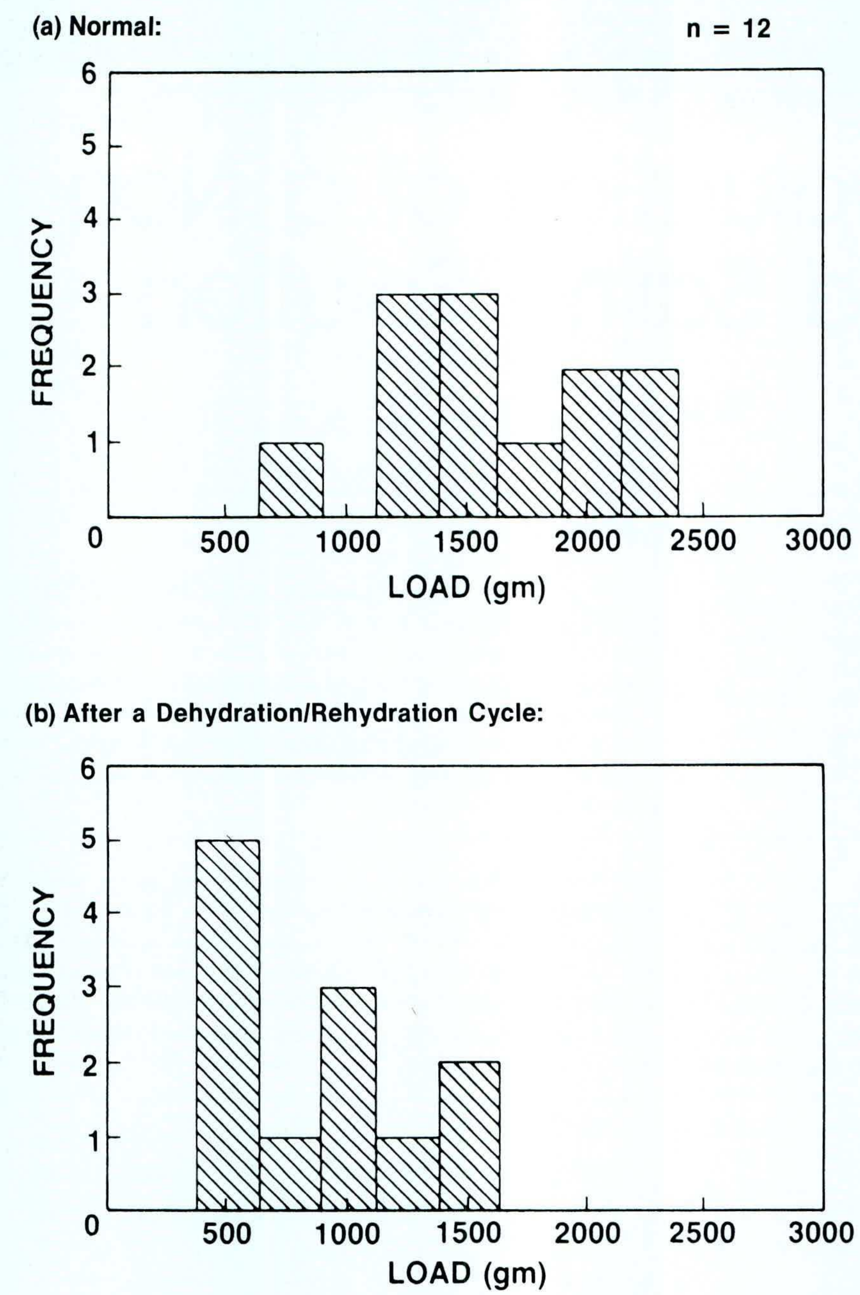

Figure 6 Distribution of Breaking Loads for Toyo 515 Polyhema Material

hours was closest to the point of failure in the case of the Toyo 515 PolyHEMA. All three types of lens material tested seemed less strong after they had been dehydrated and hydrated again: in the case of the Toyo 515 PolyHEMA, this was confirmed statistically.

Implications for Practitioners and Soft Lens Wearers:

It would seem apparent that soft lenses, particularly those made of Toyo 515 Poly HEMA material, must not be allowed to dry out or they will be significantly weaker when they are rehydrated. This means that any spare lenses or trial lenses should be stored in a screw top container to prevent evaporation over time, and the saline level inside monitored periodically. Likewise, lenses put in temporary carrying cases need to be completely immersed to avoid the shrinkage that is associated with drying.

Secondly, as this study demonstrated that certain lenses are more easily damaged by fingernail pressure, and others more easily deformed by it, wearers would reduce the likelihood of either detrimental effect if they kept their fingernails short. Wearers who repeatedly damage their lenses could be given special tongs with soft rubber tips that would facilitate the handling of their lenses.

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