Effect of Heparin Surface Modification (HSM) in Reducing Silicone Oil Adherence to Various Intraocular Lenses

Authors:
Stella N Arthur, MD
Qun Peng, MD
David J Apple, MD
Marcela Escobar-Gomez, MD
Roberto Bianchi, MD
Suresh K Pandey, MD
Liliana Werner, MD, PhD

Center for Research on Ocular Therapeutics and Biodevices, Storm Eye Institute, Medical University of South Carolina, Charleston, South Carolina.

Presented in part at the European Society of Cataract and Refractive Surgery Congress, Brussels, Belgium, 2-6 September 2000.

Supported in part by a grant from Pharmacia, Inc., Peapack, New Jersey, and an unrestricted grant from Research to Prevent Blindness, Inc., New York, NY.

The authors have no personal or proprietary interest in any of the techniques, materials or equipment used in this study.

Reprint requests to: David J. Apple, MD, Department of Ophthalmology, Storm Eye Institute, Medical University of South Carolina, 167 Ashley Avenue, Charleston, SC, 29425-2236. E-mail: appledj@musc.edu
Synopsis.

Heparin-surface-modified (HSM) silicone IOLs, as well as appropriately manufactured and selected hydrophilic designs provide good foldable IOL options for patients with active or potential vitreo-retinal disease who may require silicone oil treatment.
Abstract

Purpose: To evaluate surface properties of various IOLs, including a newly-fabricated heparin-surface-modified (HSM) silicone IOL, with special reference to testing their efficiency in reducing potential silicone oil adherence to their IOL optics.

Setting: Center for Research on Ocular Therapeutics and Biodevices, Department of Ophthalmology, Storm Eye Institute, Medical University of South Carolina, Charleston, USA.

Methods: Five rigid and foldable IOL designs were analyzed in an in-vitro test for percentage of silicone oil adherence: 1) one-piece foldable hydrophilic-acrylic IOLs (n=9); 2) 1-piece rigid PMMA IOLs with HSM coating of the lens optic (n=9); 3) 3-piece foldable silicone-optic IOLs with HSM coating of the lens optic (n=10); 4) 1-piece standard rigid poly(methyl methacrylate) (PMMA) IOLs (n=7); 5) Standard 3-piece foldable silicone optic IOLs (n=9). The IOLs were immersed in silicone oil and gross photographs of each IOL were made. Image analysis was performed to evaluate the percentage of silicone oil coverage of the anterior and posterior surfaces of each IOL optic.
**Results:** The mean silicone oil coverage on the hydrophilic-acrylic IOLs was 5.6%±2.54%. The mean coverage of the HSM PMMA IOLs and HSM silicone optic IOLs was 6.2%±4.32% and 6.73%±3.2% respectively. Mean coverage of the standard PMMA IOLs was 20.35%±13.34%. Silicone oil coverage was maximal on standard silicone optic IOLs (mean score of 98.25%±3.17%).

**Conclusion:** Intraocular lenses with a hydrophilic optic surface have a lesser tendency towards adherence to silicone oil as opposed to more hydrophobic designs. To date there has been no experimental study focusing on and confirming the efficiency of foldable IOL designs in avoiding silicone oil-IOL adherence. This study shows for the first time that a foldable silicone IOL with heparin-surface-modification can result in significant reduction of potential silicone oil adherence, comparable to the level achievable with the rigid HSM PMMA designs. We now confirm that there are two possible choices of foldable IOL styles that are highly efficacious with regards to the reduction of silicone oil adherence: 1) the HSM silicone IOL and 2) lenses in the general class of hydrophilic-acrylic IOLs. We now have a real choice of foldable implants for patients with actual or potential vitreo-retinal diseases.
Introduction.

In 1994-95 we presented the first clinico-pathological report of the condition of silicone oil adherence to an IOL (especially silicone optic IOLs) when treatment of present or potential vitreo-retinal disease with silicone oil may be required in a given patient. (Apple, DJ: Presented at the Annual Meeting of the Spanish Ophthalmology Society; Oviedo, Spain 1994. This report was subsequently published in 1997\(^1\)) The initial clinical observations of some of these cases had been made by Dr. Jay Federman, Philadelphia, Pennsylvania. He forwarded explanted silicone IOLs to our laboratory, which we subsequently analyzed. In a subsequent in-vitro experimental study we compared the degree of silicone oil adherence occurring with several other IOL designs\(^2\). Although all IOLs have at least some affinity for silicone oil, IOLs with a silicone optic showed a maximal adherence to silicone oil (up to 100% in the in-vitro study)\(^2\). We concluded that relatively hydrophilic biomaterials with relatively small contact angles and relatively low dispersive surface energy showed lower levels of silicone oil coverage. In general the more hydrophobic biomaterials with higher dispersive energy and relatively higher contact angle values showed the most silicone oil coverage\(^2\).

Heparin-surface-modification (HSM) of an IOL may convert a hydrophobic surface into a hydrophilic one and render a lower contact angle of the biomaterial\(^2,3\). Therefore it was reasonable to postulate that heparinization of the surface of a silicone IOL optic, hence rending the optic more hydrophilic, could result in
reduction of silicone oil adherence. To date there has been no experimental study regarding the possibility of introducing and utilizing a foldable hydrophilic foldable IOL design for patients with potential or actual vitreo-retinal diseases that may require silicone oil treatment. In this study we analyzed for the first time two designs that may fulfill the requirement of a foldable IOL suitable for vitreo-retinal patients: 1) an HSM-coated silicone IOL and 2) a hydrophilic-acrylic IOL design.
Materials and Methods

Five IOL styles were studied: 1) one-piece foldable hydrophilic-acrylic IOL (Centerflex™ 600H Rayner, UK, n=9); 2) a one-piece rigid HSM PMMA IOL ((PMMA HSMTM 811 Pharmacia Corporation, Peapack, New Jersey, USA, n=10); 3) a three-piece foldable HSM silicone IOL (CeeOn™Edge 911 Pharmacia Corporation, Peapack, New Jersey, USA, n=10); 4) a one-piece rigid standard PMMA IOL (CeeOn™Edge 809A Pharmacia Corporation, Peapack, New Jersey, USA, n=7); 5) a three-piece standard foldable silicone optic IOL (CeeOn™Edge 911A Pharmacia Corporation, Peapack, New Jersey, USA, n=9).

Each lens was initially immersed in Balanced Salt Solution (BSS, Alcon® Surgical) for 12 hours. This was done to simulate the in-vivo environment of anterior chamber aqueous. After removal from BSS, the IOLs were immersed in clinical quality silicone oil (Adato Sil 5000, Escalon Ophthalmic) for 12 hours. After removal from the oil, each IOL was photographed under distilled water.

Quantitative measurements of silicone oil coverage and qualitative assessments of adherence and mobility of oil on the anterior and posterior surfaces of each optic were made. The quantitative comparative determination was made using gross photographs obtained with a Nikon N905 AK (Nikon Corporation) camera fitted to a surgical microscope (Leica-Wild MZ-8 zoom, stereomicroscope, Vashaw Scientific, Inc; Micross; 6A, USA). A computer-generated image analysis was then performed on each IOL using Sigma Scan™ Measurements Software (Jandel
Scientific) to determine the percentage of silicone oil coverage of the anterior and posterior surface areas of each IOL optic. Qualitative assessments of adherence and mobility of the oil on each IOL optic were made by applying a mechanical pressure to the oil droplets using a viscoelastic (Healon™ Pharmacia Corporation, Peapack, New Jersey, USA). Attempts were made to dislodge the oil from the IOL optic.

The data were analyzed by using a one way ANOVA test with post hoc multiple comparisons using a Newman-Keuls test.
Results

A summery of the results of the quantitative study of silicone oil percentage coverage of each IOL optic is shown in Table 1. Analysis of the one-piece foldable hydrophilic-acrylic IOL design (Fig. 1 A, B) revealed a mean value of silicone oil coverage, 5.60%±2.54%; range of 0.99% to 7.75%.

HSM PMMA IOLs (Fig.2 A, B) and HSM silicone IOLs (Fig. 3 A, B) had similar values. HSM PMMA IOLs had a mean silicone oil coverage of 6.2%±4.32% (range of 2.36% to 15.78%). HSM silicone IOLs had mean silicone oil adhesion coverage of 6.73%±3.2% (range of 1.56% to 11.79%). The rigid one-piece standard PMMA IOL (Fig.4 A, B) had a mean silicone oil coverage of 20.35%±13.34% (range of 3.39% to 41.76%). With each of these IOLs silicone oil could be moved by pressure from the injected viscoelastic.

Gross photographic analysis of the standard non-coated silicone optic IOLs revealed a high silicone oil adherence (Fig.5 A, B). The image analysis revealed a mean silicone oil coverage of 98.25%±3.17% (range of 90.05% to 100%) (Fig.5 C). The silicone oil could not be dislodged or moved by pressure from injected viscoelastic.

The mean percentage of silicone oil coverage of all IOL biomaterials analyzed in this study is shown graphically in Fig.6. The percentage of oil coverage within each group of biomaterials had a normal distribution.
There was no significant difference in silicone oil coverage found between the HSM silicone IOLs and hydrophilic-acrylic IOLs studied here (P=0.91), nor between the HSM PMMA IOLs and the hydrophilic-acrylic IOLs (P=0.85). There was no difference in the amount of silicone oil coverage found with HSM silicone IOLs compared to HSM PMMA IOLs (P=0.85). Standard PMMA IOLs showed statistically significant greater silicone oil adherence than the HSM PMMA IOLs (P=0.0001). There was a significantly greater extent of silicone oil coverage of the standard non-coated silicone optic IOLs as compared to the HSM silicone IOLs (P=0.0001).
Discussion

Silicone has been and remains an important and efficacious biomaterial for fabrication of foldable IOL optics for small incision cataract surgery. Silicone has proven characteristics of chemical stability, autoclavability, optical properties, no issues of biodegradation, and minimal adverse clinical reactions\textsuperscript{4,5}. Some authors have reported that silicone IOLs are equal to or even more biocompatible than PMMA IOLs\textsuperscript{6-10}. Some studies have demonstrated that cell adherence and endothelial damage caused by standard silicone IOLs, which have a high dispersive energy, is significantly less than that of standard PMMA IOLs, which have an intermediate dispersive energy\textsuperscript{11,12}.

However, in previous studies, Apple and associates\textsuperscript{1,2}, Batterbury and associates\textsuperscript{3}, and Stolba and associates\textsuperscript{13} concluded that a clinically significant high level of silicone oil coverage may occur on the surface of an IOL optic, especially one made from a hydrophobic material, as opposed to more hydrophilic materials. In a pseudophakic patient with either present or a high potential for future vitreo-retinal problems that may require interaction with silicone oil, irreversible adherence of silicone oil to IOL’s optic, especially a silicone optic may cause deleterious sequelae. These include significant visual loss for the patient, as well as obstruction of a surgeon’s view into the eye\textsuperscript{14-16}. Most authors do not recommend implantation of standard silicone IOLs in patients with severe or potentially severe vitreo-retinal
disease. Indeed, until now there is no foldable IOL that has been specifically recommended for these patients.

Since the time of our 1996 clinical report and our 1997 experimental study regarding this complication, the surgeon has had only a limited armamentarium of IOL designs suitable for implantation in patients with present or potential vitreoretinal disease (Fig. 7). Note, in Figure 7 we assume that the value of percentage of silicone oil adherence to crystalline lens (ca 10%) represents a physiologic norm. Until now the only IOL with a hydrophilicity and hence a silicone oil adherence value lower than the human crystalline lens has been the rigid HSM PMMA IOL (Fig. 7). Equivalent foldable IOLs have not yet been identified. There are some IOLs, for example the hydrophobic-acrylic Alcon Acrysof design and the Ciba Vision Memory IOL, that show significantly less silicone oil coverage than standard silicone IOLs (Fig. 7). However, their values of percentage of silicone oil coverage are intermediate or higher than that of the crystalline lens. Note their presence to the right of the value of the human crystalline lens on the group shown in Fig. 7. They are not therefore immune to this complication. Since the mid-1990s two new foldable IOL types that may protect against this complication were manufactured: 1) a 3-piece HSM silicone IOL design and 2) a one-piece foldable hydrophilic acrylic IOL, both characterized by a high hydrophilicity (Table 1, Fig. 6). The former IOL tested in this study is the CeeOn Edge 911, manufactured by Pharmacia Corporation, Peapack, New Jersey, USA. An example of the latter is the Centerflex 600H, manufactured by Rayner, UK.
The results of the current in-vitro study correlate with the findings of our previous in-vitro analysis that compared the interaction of silicone oil with various IOLs (Fig. 7). This study on the additional standard silicone IOLs and standard PMMA IOLs confirms our initial results (Fig. 7). We confirmed that the highest silicone oil coverage occurs on standard silicone IOLs (mean 98.25%=3.17%) (Table 1 and Fig. 5 to 7). This reaffirms that hydrophobic materials such as standard uncoated silicone IOLs having higher contact angles and dispersive energy level values showed more silicone oil adherence. Results obtained on the standard PMMA designs provide an example of an intermediate amount of silicone oil coverage (Table 1 and Fig. 4, 6 and 7).

The present study also demonstrates that the 2 new foldable designs the hydrophilic-acrylic design (Table 1 and Fig. 1) and the HSM silicone IOLs (Table 1 and Fig. 3) are indeed effective in combating the problem of silicone oil adherence to IOL. They both are situated to the left of the crystalline lens in Fig. 7, and both have lower contact angle and dispersive energy level values. Hence they showed less silicone oil adherence (Table 1).

The basis of the silicone oil-IOL biomaterials interaction is not well understood. Adherence to silicone oil is a physiochemical phenomenon that depends on the hydrophobic or hydrophilic nature of the material. Hydrophobic materials, as opposed to hydrophilic materials, possess a greater interfacial energy and contact angle. Interfacial free energy relates to the degree to which a liquid will spread across and coat a material’s surface. The energy has polar and non-polar forces. Polar forces include acidic and basic components. Non-polar (dispersive) forces that
include Van der Waal’s and London dispersive forces. Another important factor that affects wettability of a solid material is a contact angle. When a liquid is placed on a solid surface, it will remain as a cohesive drop, having a definite angle of contact between the liquid and solid phases. The higher the contact angle, the less spreading of a liquid on a solid surface will be\textsuperscript{2,12}.

Our data demonstrate that interaction of silicone oil with a silicone IOL is dramatically decreased if the latter is surface modified with heparin. Hydrophilic chains of heparin bound to the surface of the IOL extend into the aqueous media and form, by trapping water molecules, a highly hydrated layer around the lens. This results in reduction of silicone oil adherence to the IOL. Batterbury and associates\textsuperscript{3} observed this phenomenon with rigid HSM PMMA IOLs. It was concluded that from a thermodynamic point of view, the interfacial energy of the oil-PMMA interface is lower than that of the oil-aqueous interface. In other words, the driving force for the oil to attach to the PMMA IOLs is stronger, and for HSM PMMA IOLs is weaker\textsuperscript{3}.

Heparin has been successfully used for surface modification of rigid PMMA IOLs. Many clinical and experimental studies\textsuperscript{17-24} have shown that a heparin-surface-modification of PMMA IOL may enhance IOL’s biocompatibility by reducing adherence and growth of fibroblasts, monocytes, platelets, granulocytes, and macrophages. Bacterial adherence to surface-modified IOLs has also found to be decreased. A recent randomized trial in a United States Patient population has reported an excellent performance of HSM PMMA IOLs in reducing postoperative inflammatory responses\textsuperscript{24}. However, the main disadvantage of the classic rigid HSM
PMMA IOL has been its rigidity, which therefore precludes implantation via modern small incision procedure. In contrast, a HSM silicone-optic IOLs appears to combine the advantages of both minimal silicone oil adherence and excellent foldability of the IOL.

In addition to appropriate IOL choice when addressing the complication of silicone oil-IOL interaction, investigators are finding new means to remove silicone oil from an IOL surface in cases where the condition has become manifest\textsuperscript{25-29}. For example, Langefeld and associates\textsuperscript{25}, and Zeana and associates\textsuperscript{26} demonstrated the effectiveness of Perfluorhexyl-octan (C\textsubscript{14}F\textsubscript{13}H\textsubscript{17}(F6H8)) in removing silicone oil from a silicone IOL surface. Furthermore, Dick and Augustin demonstrated that this solvent is more effective in removing silicone oil from an IOL with hydrophilic surface then from an hydrophobic IOL\textsuperscript{27}. This solvent appears to be tolerated by surrounding intraocular tissues. Hoerauf and associates\textsuperscript{28} have reported on the effectiveness of using 044 as a solvent for removal of silicone oil from the IOL surface. Kageyama and Yaguchi\textsuperscript{29} have demonstrated a mechanical method of removing silicone oil from an IOL surface. All described techniques are very effective; the main disadvantage being that these procedures are invasive, requiring another visit to an operating room.

Although the incidence of this complication is purported to be relatively low, it is probably higher then generally assumed clinically because affected patients or potentially affected patients are usually seen later by a vitreo-retinal surgeon rather by the implanting surgeon. Rarely are both subspecialty surgeons are involved in working with a single, particular patient. Therefore the incidence of this
complication may appear to be artificially low as visualized by any given specialist. Also the complication may be more common in countries outside of the United States because silicone oil is used more commonly in several other countries (eg. some European countries) than domestically.

It is true that regardless of the degree of oil-induced cloudiness of the IOL, visual loss is often severe by the time most patients develop severe vitreo-retinal disease that requires radical treatment with silicone oil. Therefore the clinical importance of this report actually relates most significantly to patients who may be deemed to have a high propensity or potential for severe vitreoretinal disease that may require silicone oil treatment at a later date. Indeed Aaberg has listed seven common conditions that may fall into this category\textsuperscript{30}. These are the patients who should proactively receive an appropriate IOL with future complications in mind.

Until now there was only been one highly effective design and biomaterial suitable for this purpose – the HSM rigid PMMA IOL -- obviously unsuitable for modern small incision surgery. We have now described and analyzed two separate foldable IOL types that may be inserted via small incision and serve to protect this particular group of patients who may have a protensity for later iatrogenic induction of this complication. These are 1) an approved hydrophilic-acrylic design such as Centerflex\textsuperscript{TM} 600H Rayner, UK and 2) a HSM silicone IOL CeeOn\textsuperscript{TM} Edge 911 Pharmacia Corporation, Peapack, New Jersey, USA.

An awareness of these innovations should be useful in lowering the incidence of this complication. Impetus should be made to increase the use of such IOLs for
this specific purpose in all countries. Timely and appropriate Food and Drug Administration, (or its equivalent) approval is warranted.

To close, the reader should be forewarned regarding possible negative factors regarding the latter IOLs category described here, namely the various hydrophilic acrylic IOL designs now being marketed. The quality of any hydrophilic IOL differs in relation to the particular technique of biomaterial preparation and fabrication by each manufacturer. For example each IOL has a varying amount of water content. Although most do have a ready made hydrophilicity that renders the IOL efficacious in reducing silicone oil adherence, when choosing out of the myriad and relatively new hydrophilic-acrylic IOL designs (including hydrophilic hydrogel materials) that are now being marketed and distributed, one must be very selective and be aware of all known specific complications that have been shown to occur with the various IOL biomaterial formulations. To date most of these IOLs appear to be safe, including the Rayner Centerflex™ 600H IOL tested in the current study.

However, at least two hydrophilic IOLs have recently been shown to have problematic sequelae\textsuperscript{31-33}. An example of a problematic design is a single-piece hydrophilic-acrylic design, the SC 60B-OUV, composed from a biomaterial obtained from Vista Optics, UK and manufactured by Medical Developmental Research Inc. (MDR), Clearwater, Florida\textsuperscript{32,33}. In some countries this IOL has been shown to undergo a serious postoperative opacification of the optical component, and is therefore unsuitable for clinical use (Apple DJ, Werner L, Pandey SK. Opacification of hydrophilic acrylic intraocular lenses. EyeWorld, 2000). The manufacturer has changed its polymer source, so hopefully further experience with their new material
and design will eliminate the problem. In addition the Bausch and Lomb Hydroview IOL, a one-piece hydrophilic design that has a relatively low silicone oil adherence (Fig. 7, Hydrogel) has recently been shown in some Centers to be susceptible to surface calcification/opacification\textsuperscript{31}. Approval in the United States has been postponed and urgent studies are undergoing to prove that this IOL in suitable for further implantation are undergoing. We are currently studying their urgent problems in our laboratory and details of our findings to date are recorded in separate publications\textsuperscript{31-33}. \textsuperscript{31-33}.
References.


Acknowledgment to:

Joyce Edmonds, Histopathologist

Daphne S Hoddinott, BA

Harold T Bottoms, Laboratory Coordinater
Table 1. Percentage Silicone Oil Coverage of the IOLs analyzed in this in-vitro experiment.* Note the correlation of a lens’s silicone oil coverage with contact angle (hydrophilicity-hydrophobicity). The silicone oil adherence (%) value increases in direct proportion to contact angle (°) value of each IOL.

<table>
<thead>
<tr>
<th>IOL designs</th>
<th>Mean Silicone oil coverage (%)</th>
<th>Contact angle (°)**</th>
</tr>
</thead>
<tbody>
<tr>
<td>HYDROPHILIC ACRYLIC</td>
<td>5.6</td>
<td>29</td>
</tr>
<tr>
<td>HSM PMMA</td>
<td>6.2</td>
<td>25-35</td>
</tr>
<tr>
<td>HSM SILICONE</td>
<td>6.7</td>
<td>35-45</td>
</tr>
<tr>
<td>STANDARD PMMA</td>
<td>20.35</td>
<td>60-70</td>
</tr>
<tr>
<td>STANDARD SILICONE</td>
<td>98.25</td>
<td>100-110</td>
</tr>
</tbody>
</table>

*Rated in increasing order according to silicone oil adherence (%) and contact angle (°).

**Personal communication to Erik Luxen, PhD, Pharmacia Corporation, Peapack, New Jersey, USA
**Legends.**

**Figure 1.** Gross photograph of a hydrophilic acrylic IOL Centerflex™ 600H Rayner, UK. (Courtesy Dr. Escobar-Gomez)

A. Frontal view. The mean value for this group was 5.60%±2.54%. With this particular IOL it was ca 2% coverage after computer-assisted addition of all silicone oil deposits on anterior and posterior lens surfaces.

B. Image analysis (yellow area = silicone oil coverage).

**Figure 2.** Gross photograph of a HSM PMMA IOL CeeOn™Edge 811 Pharmacia Corporation, Peapack, New Jersey, USA. (Courtesy Dr. Escobar-Gomez)

A. Frontal view. The mean value for this group was 6.2%±4.32%. With this particular IOL it was ca 4% coverage after computer-assisted addition of all silicone oil deposits on anterior and posterior lens surfaces.

B. Image analysis (yellow area = silicone oil coverage).
**Figure 3.** Gross photograph of a HSM silicone IOL CeeOn™Edge 911 Pharmacia Corporation, Peapack, New Jersey, USA. (Courtesy Dr. Escobar-Gomez)

A. Frontal view. The mean value for this group was 6.73%±3.2%. With this particular IOL it was ca 5% coverage after computer-assisted addition of all silicone oil deposits on anterior and posterior lens surfaces.

B. Image analysis (yellow area = silicone oil coverage)

**Figure 4.** Gross photograph of a standard PMMA IOL CeeOn™Edge 809APharmacia Corporation, Peapack, New Jersey, USA. (Courtesy Dr. Escobar-Gomez)

A. Frontal view. The mean value for this group was 20.35%±13.34%. With this particular IOL it was ca 30% coverage of the anterior and posterior surfaces.

B. Image analysis (yellow area = silicone oil coverage on the posterior surface and red area = silicone oil coverage on the anterior surface).
Figure 5. Gross photographs of a standard silicone IOL after submersion in silicone oil CeeOn™Edge 911A Pharmacia Corporation, Peapack, New Jersey, USA. (Courtesy Dr. Escobar-Gomez)

A. Frontal view. The mean value for this group was 98.25%±3.17%. With this particular IOL it was ca 100% coverage after computer-assisted addition of all silicone oil deposits on the anterior and posterior lens surfaces.

B. Sagittal (side view) of the same IOL. Note the anterior-posterior dome-like thickening of the IOL by the large silicone oil deposit.

C. Image analysis (yellow area) = silicone oil coverage, almost 100%.

Figure 6. Mean silicone oil coverage (percent), with ranges of the 5 IOL designs analyzed in this study.

Figure 7. Graph showing results of the 5 IOL designs analyzed in the present study (red bars) compared with the results of our 1997 study on 6 IOLs and the crystalline lens (green bars).
Legends.

Figure 1. Gross photograph of a hydrophilic acrylic IOL Centerflex™ 600H Rayner, UK. (Courtesy Dr. Escobar-Gomez)

A. Frontal view. The mean value for this group was 5.60%±2.54%. With this particular IOL it was ca 2% coverage after computer-assisted addition of all silicone oil deposits on anterior and posterior lens surfaces.

B. Image analysis (yellow area = silicone oil coverage).

Figure 2. Gross photograph of a HSM PMMA IOL CeeOn™Edge 811 Pharmacia Corporation, Peapack, New Jersey, USA. (Courtesy Dr. Escobar-Gomez)

A. Frontal view. The mean value for this group was 6.2%±4.32%. With this particular IOL it was ca 4% coverage after computer-assisted addition of all silicone oil deposits on anterior and posterior lens surfaces.

B. Image analysis (yellow area = silicone oil coverage).
**Figure 3.** Gross photograph of a HSM silicone IOL CeeOn™Edge 911 Pharmacia Corporation, Peapack, New Jersey, USA. (Courtesy Dr. Escobar-Gomez)

A. Frontal view. The mean value for this group was 6.73% ± 3.2%. With this particular IOL it was ca 5% coverage after computer-assisted addition of all silicone oil deposits on anterior and posterior lens surfaces.

B. Image analysis (yellow area = silicone oil coverage)

**Figure 4.** Gross photograph of a standard PMMA IOL CeeOn™Edge 809A Pharmacia Corporation, Peapack, New Jersey, USA. (Courtesy Dr. Escobar-Gomez)

A. Frontal view. The mean value for this group was 20.35% ± 13.34%. With this particular IOL it was ca 30% coverage of the anterior and posterior surfaces.

B. Image analysis (yellow area = silicone oil coverage on the posterior surface and red area = silicone oil coverage on the anterior surface).
Figure 5. Gross photographs of a standard silicone IOL after submersion in silicone oil CeeOn™Edge 911A Pharmacia Corporation, Peapack, New Jersey, USA. (Courtesy Dr. Escobar-Gomez)

A. Frontal view. The mean value for this group was 98.25%±3.17%. With this particular IOL it was ca 100% coverage after computer-assisted addition of all silicone oil deposits on the anterior and posterior lens surfaces.

B. Sagittal (side view) of the same IOL. Note the anterior-posterior dome-like thickening of the IOL by the large silicone oil deposit.

C. Image analysis (yellow area) = silicone oil coverage, almost 100%.

Figure 6. Mean silicone oil coverage (percent), with ranges of the 5 IOL designs analyzed in this study.

Figure 7. Graph showing results of the 5 IOL designs analyzed in the present study (red bars) compared with the results of our 1997 study on 6 IOLs and the crystalline lens (green bars).
Mean Silicone Oil Coverage

Silicone Oil Coverage (%)

IOL Type

Centerflex: 5.6 ± 2.54
HSM PMMA: 6.2 ± 4.3
HSM Silicone: 6.73 ± 3.21
Std PMMA: 20.35 ± 13.34
Std Silicone: 98.25 ± 3.17
Standard Silicone IOL
Standard Silicone IOL
Image Analysis
Standard PMMA IOL
Standard PMMA IOL

Image Analysis
HSM Silicone IOL
HSM Silicone IOL
Image Analysis
HSM PMMA IOL
Summary of Results

<table>
<thead>
<tr>
<th>IOL Type</th>
<th>Present Study</th>
<th>Previous Study (1997)²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center-flex</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>HSM PMMA</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>HSM Silicone</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Human Lens</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Fluor lens</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Hydrogel</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Std. PMMA</td>
<td>30</td>
<td>60</td>
</tr>
<tr>
<td>Memory Lens</td>
<td>35</td>
<td>70</td>
</tr>
<tr>
<td>Acrylic</td>
<td>40</td>
<td>80</td>
</tr>
<tr>
<td>Std. Silicone</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>
HSM PMMA IOL
Image Analysis
Centerflex IOL
Centerflex IOL
Image Analysis