Original Article

Scanning electron microscopic features of explanted degraded hydrophobic acrylic intraocular lenses which were *in vivo* for a prolonged period

Harsha Bhattacharjee, Suklengmung Buragohain, Henal J Javeri, Dipankar Das

Purpose: To study and document electron microscopic features in explanted hydrophobic microvacuoles affected acrylic intraocular lenses (IOL) which were *in vivo* for an average duration of 11 years. **Methods:** Scanning electron microscopic (SEM; Hitachi S 3000 N EXAX Genesis VP SEM) study of five explanted hydrophobic acrylic IOL which had clinically evident microvacuoles prior to explantation, was done. The IOLs were *in vivo* for a prolonged period and needed explantation for various indications. Only those hydrophobic acrylic IOLs which fulfilled the inclusion criteria were included. The findings were compared with control specimens. **Results:** The IOLs were *in vivo* for an average duration of 11.6 ± 4.21 years. The cause of explantation of IOL was subluxation in four cases and low visual acuity in one case. Bulk degradation and microvacuoles on cut sections throughout the IOL optics and undulating surface patterns over both the surfaces of the IOL has been documented in all the specimens. No such findings were noted in the control specimens where the surface and texture were homogenous. **Conclusion:** SEM findings of the structural changes in explanted IOL documented in the study demonstrate that hydrophobic acrylic IOL is degradable *in vivo*. Microvacuoles are a clinical manifestation of the structural changes that occur at a microscopic and molecular level. These changes are not seen in IOLs which have not undergone intraocular implantation. To our knowledge, a similar study of this kind has not been done.

Key words: Explanted hydrophobic intraocular lenses, intraocular lens degradation, IOL microvacuoles, scanning electron microscopy, surface changes

Access this article online
Website: www.ijo.in
DOI: 10.4103/ijo.IJO_2168_19
Quick Response Code:

Scanning electron microscopic (SEM) features of acrylic hydrophobic intraocular lenses (IOL) affected with microvacuoles have not been studied previously. The microvacuole formation, commonly known as "glistening" is a common phenomenon, although the exact mechanism by which it occurs remains elusive.

Glistenings in recent literature have been defined as fluid-filled microvacuoles or cavities in the optic of an IOLs when kept in an aqueous environment.[1] These changes have been reported not only in hydrophobic acrylic IOLs but also in IOLs made of other materials such as hydrophilic acrylic, polymethylmethacrylate (PMMA), and silicone.[2-5] The incidence of glistenings in three-piece AcrySof MA60BM (Alcon, Inc.) was reported to be 20%, 51%, and 55% after 3, 6, and 12 months postoperatively, respectively, in a study conducted by Miyata *et al*.[6] Peetermans *et al*. found that after 14 months 56% of the IOLs showed glistening and this increased to 87% after 18 months.[7] Christiansen *et al*. also found 100% glistenings after 14–44 months postoperatively.[8]

Various factors responsible for the formation of glistenings include the material of the IOL, the glass transition temperature, hygroscopic property, manufacturing technique, packaging methods, etc.[1]

The use of SEM in ophthalmology is quite popular and seems to be very helpful in showing a perspective not visible to the naked eye. Drews *et al*. used SEM to view the surface of IOLs and described a microscopic picture of the IOL surface and edges.[9] Other studies involving SEM, has mainly been used to study the optic-haptic junction and surface characteristics of different IOLs.[10] Dai *et al*. carried out laboratory analysis of two explanted hydrophobic acrylic IOLs with microvacuoles, where SEM revealed a smooth IOL surface, however, the cut-sections of the IOL were not studied.[11] Tandogan *et al*. observed numerous fine, granular, crystalline-like deposits distributed over the surface on SEM of the cross-section of opacified hydrophilic IOLs after explantation.[12]

Our study was aimed at documenting the changes occurring internally as well as on the surface of the explanted hydrophobic acrylic IOLs with microvacuoles with the help of SEM and compare the findings with that of control specimens.

Methods

The study adhered to the tenets of the Declaration of Helsinki and was conducted after obtaining proper informed consent from the subjects. Our study involved SEM (SEM; Hitachi S 3000 N EXAX Genesis VP SEM) analysis of five explanted hydrophobic acrylic IOLs with microvacuoles, which were

Department of Ophthalmology, Sri Sankaradeva Nethralaya, Guwahati, Assam, India

Correspondence to: Dr. Suklengmung Buragohain, Sri Sankaradeva Nethralaya, 96 Basistha Road, Guwahati, Assam - 781 028, India. E-mail: suklen.bgohain@gmail.com

Received: 23-Nov-2019 Revision: 04-Jan-2020
Accepted: 30-Jan-2020 Published: 25-May-2020

Cite this article as: Bhattacharjee H, Buragohain S, Javeri HJ, Das D. Scanning electron microscopic features of explanted degraded hydrophobic acrylic intraocular lenses which were *in vivo* for a prolonged period. Indian J Ophthalmol 2020;68:1086-9.

in vivo for a variable extent of time and needed explantation for various reasons. Our criteria included explanted hydrophobic acrylic IOLs which were *in vivo* for a duration of at least 5 years. Only those hydrophobic acrylic IOLs were included which had evidence of microvacuoles any time prior to explantation and which could be retrieved without any iatrogenic damage. Any IOL in which complete SEM documentation could not be done or which got damaged before or during the SEM study or which could not fulfill the abovementioned inclusion criteria were excluded. Subsequently, only five IOLs completely fulfilled the inclusion criteria and hence were included in the final study.

Explanted IOLs were inspected under the microscope, lens capsule was removed and the specimen was transported to the lab immersed in a balanced salt solution (BSS) in borosilicate glass containers. Specimens were processed and examined within 24 h. The IOLs were first air-dried and then cut into three pieces that included a cross-section, anterior, and posterior surface. The pieces then underwent gold sputter coating 30 min before microscopy and were mounted on specimen stub, one piece each in both horizontal and vertical positions with the help of adhesive tape. Subsequently, microphotography of the various regions was done at various magnifications such as 501×, 1000×, and 2000×. The changes were then compared with control specimens of acrylic hydrophobic IOLs, which had not undergone intraocular implantation (virgin IOLs from a wagon wheel pack). All clinical history such as past ocular disease, medication use, and systemic diseases were taken into account.

Results

The microphotographs of the IOL surfaces and cut-sections revealed unique findings. All of the IOLs had clinically evident microvacuole formation prior to explantation. In all the specimens, glistenings were seen in the central and mid-peripheral part of the IOL optic, and the margin of the IOL optics was covered partly or 360° by the anterior capsules [Fig. 1]. The mean age of the patients at the time of explantation was 69.4 ± 11.41 years and the mean duration of pseudophakia was 11.6 ± 4.21 years [Table 1].

On SEM, the anterior surface of all the IOLs showed a number of undulating topographical changes that appeared similar to a "maze" pattern [Fig. 2]. These surface changes are slightly different from what was observed over the posterior surface of the IOLs. The posterior surface of the IOLs [Fig. 3] showed a finer undulating pattern that resembled "sand dunes" in the desert. The central cut-section of the optic of the IOLs [Fig. 4a and b] showed multiple "magic coral" pattern with void spaces and microvacuoles of various sizes throughout the thickness of the IOL optics. In addition, the cut-section also revealed that the apposition of the posterior lens capsule and the IOL was absent in certain areas [Fig. 4c]. The control specimens that we used had a homogenous structure and showed no cracks or undulating pattern, nor were there any features of bulk degradation seen at the cut-section [Fig. 4d].

Discussion

An IOL should ideally remain transparent throughout the pseudophakic life and for that to occur, it is critical that the material is biologically stable and compatible with the intraocular environment, failure of which may give rise to changes such as opacification and deterioration of the material as a whole due to degradation, and thus, hamper with the sole purpose of the IOL, which is to provide unhindered and clear visual rehabilitation.

The science behind glistening formation in the IOL has been well-described in the literature.[1,13,14] The back-bone of the acrylic polymer is constituted by carbon-carbon double bonds to the monomers which are open and join each other. Due to the inherent dynamics of polymerization, the whole of the acrylic polymer network is not connected or folded uniformly and this results in areas (pockets) of different density in the acrylic polymer substance. IOL material is made of acrylic polymer and similar pockets may exist in the IOL substance as well. Equilibrium mechanisms lead to diffusion of water into the polymer network of the IOL and collect in these areas of less density and thereby form water pockets.[1,8,14]

Noncrystalline polymers can be considered as fluids and their fluidity changes along with the temperature. The temperature that changes the physical state of the polymer from solid-like fluid to rubber-like fluid (foldable state) is the glass transition temperature of an acrylic IOL material.[14] Acrylic IOL material is known to be hygroscopic and has the propensity to absorb water.[15] Absorption of water can lead to the physical deterioration of a polymer after implantation by acting as a

Table 1: Clinical information of the subjects

Indication for IOL explantation	Ocular diagnosis	Systemic diagnosis/conditions	*In-vivo* duration (Years)	IOL
IOL subluxation	Post-vitrectomy Silicone oil and silicone oil removal Glaucoma Myopia	Diabetes mellitus Hypertension	11	Single-piece acrylic
IOL subluxation	Complicated pseudophakia Posterior capsular rupture	None	7	Three-piece acrylic
IOL subluxation	Myopia Pseudo-exfoliation syndrome	Thyroiditis Diabetes mellitus Hypertension Chronic kidney disease	18	Three-piece acrylic
Traumatic IOL subluxation	Myopia	Diabetes mellitus	9	Single-piece acrylic
Blurring of vision	Anterior Capsular Opacification Blunt trauma	Diabetes mellitus Hypertension Chronic	13	Single-piece acrylic

IOL: Intraocular lens

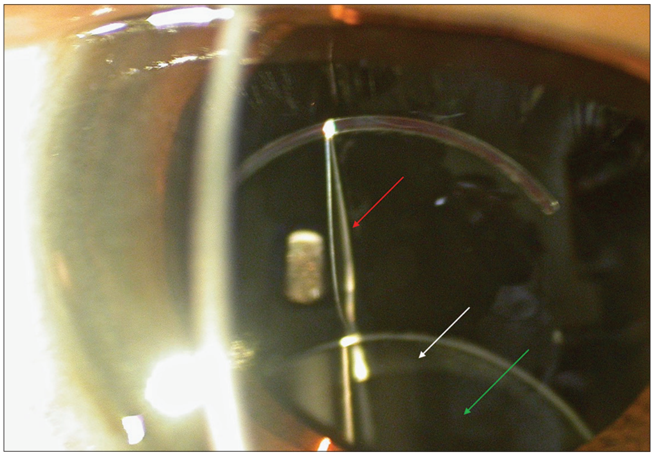

Figure 1: Subluxated intraocular lens (IOL) with glistenings (green arrow). The apposition between the anterior and posterior capsule is lost (red arrow) and through this, a low current of aqueous humor enters and circulates. The capsular overlap is not uniform, with a lesser overlap over the temporal part of the IOL optic (white arrow)

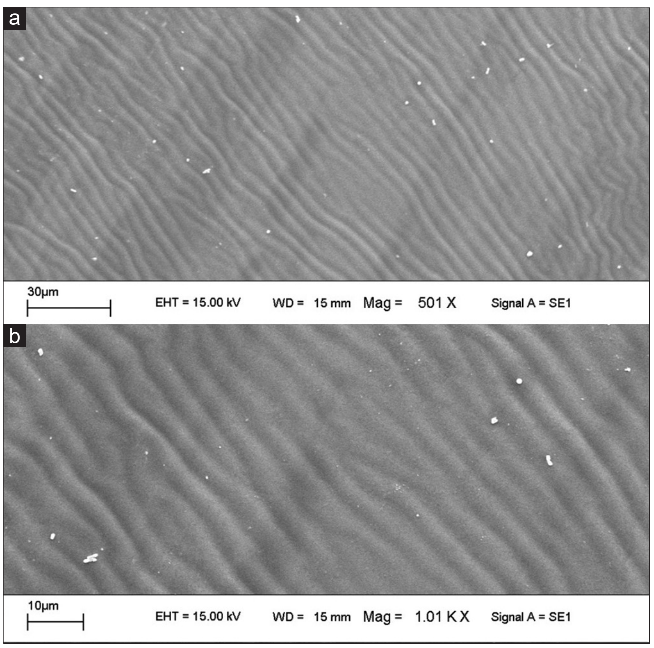

Figure 3: SEM photograph of the posterior surface showing fine "sand dune" like undulations at a magnification of (a) 301 × and (b) 501×

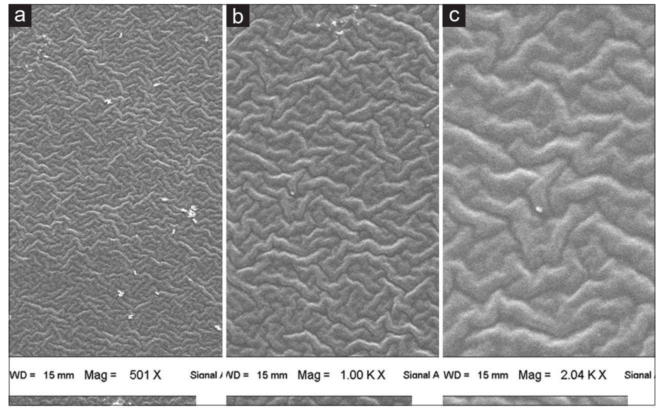

Figure 2: Scanning electron microscope (SEM) photographs of the anterior surface showing undulated "maze" pattern surface degradation at a magnification of (a) 501 × (b) 1000 × and (c) 2000×

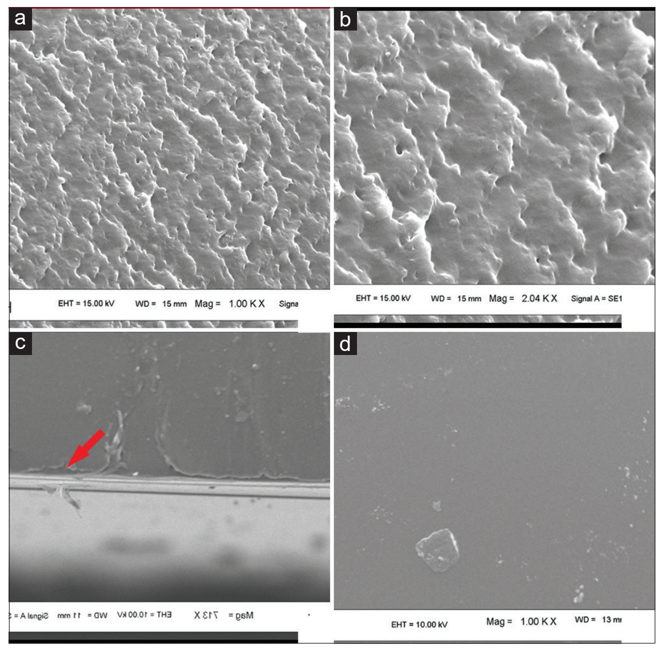

Figure 4: Magic coral pattern and microvacuoles of various sizes throughout the thickness of the IOL optics at a magnification of (a) 1000 × and (b) 2000 × and (c) Loss of contact between the posterior lens capsule and IOL surface (red arrow). (d) No patterns of degradation in the cut-section of the control specimen

plasticizer of the polymer, which reduces the glass transition temperature. Absorbed water can accelerate environmental stress and reduce molecular anchoring, resulting in microcrack formation.[16]

In the explanted IOLs, we found the presence of microvacuoles and peculiar patterns (magic coral appearance) through-out the cut-section of the optic of the IOL. We believe that this is a result of the degradation of the IOL.

The literature describes mainly four degradation mechanisms for biomedical acrylic devices, and they are hydrolysis, oxidation, enzymatic, and physical degradation. Hydrolysis denotes the reaction of the polymer with water, causing fragmentation of the polymer chain and leading to the formation of voids in the polymer material. Surface erosion is also mediated by hydrolysis. Oxidation of polymers is caused by oxidants produced by ocular tissues. The entire process is controlled by chemical reactivity and molecular mobility of the polymer, mostly at the microscopic level.[17]

Degradation of lens polymers can occur in two ways, chain depolymerization and random degradation. Chain depolymerization involves depropagation of the polymer chain leading to the formation of monomer units while random degradation occurs due to chain scission or unzipping at random locations in the polymer chain. Both of these changes can be caused by various factors such as thermal or radiation energy, ozone, and also due to impurities present in the polymers. IOL degradation can also occur due to the molecular rearrangement in the polymer network due to the formation of free radicals after exposure to radiation (photons, electrons, protons or gamma rays).[18]

We also found peculiar patterns over both the anterior and posterior surface of the explanted IOLs. When a fluid flows over a hard surface and the interface is loose, specific patterns are formed over the surface. We know from the existing literature that there is a temperature gradient driven single convection pattern of aqueous flow, rising against gravity toward the back of the chamber and then falling near the front.[19,20] We believe that the surface changes are produced due to the process of leaching when aqueous humor flows over it.[21] The very fine "sand dune" like waves observed over the posterior surface, in contrast to the morphology observed over the anterior surface could be due to streamline flow of aqueous behind the IOL because of the limited potential space which is available between the IOL and the posterior lens capsule, as we have documented in our specimens [Fig. 4c]. It is also possible that the patterns over the posterior surface are a result of the fluid flow that occurs in the vitreous cavity as a result of a temperature gradient, in a way similar to what occurs in the anterior segment.

Various techniques for grading and measurement of glistenings have been described in the literature.[1,6,22] Previous studies on the impact of glistenings on vision have concluded that there is no significant effect on the best-corrected visual acuity (BCVA),[3,23] contrast sensitivity,[22,24] and intraocular light scattering,[25] while others have concluded that effect of glistening on visual acuity and contrast sensitivity is significant.[8,24]

Neuroplasticity is a highly dynamic neuroadaptive process within the brain that occurs at the cellular level and has been studied by different medical disciplines. There is a possibility that the gradual development of glistenings provides for a similar mechanism to occur and compensate for the otherwise deteriorating visual acuity and quality of vision.[26,27]

Conclusion

In conclusion, hydrophobic acrylic IOL undergoes degradation *in vivo* and microvacuoles maybe a clinical manifestation of the various degradation processes that occur at a microscopic and molecular level. With the help of SEM, we have been able to document evidence of such microscopic changes. In contrast, no such changes were seen in the control specimens. To our knowledge, a similar study of this kind has not been done.

Acknowledgements

Sri Kanchi Sankara Health and Educational Foundation, Guwahati, India. Indian Institute of Technology (IIT), Guwahati, India. Apurba Deka, BMLT, Ocular Pathology Department, Sri Sankaradeva Nethralaya, Guwahati, India.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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