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Principle features of the MICS-IOLs currently available

Have generics saved costs or proved expensive?

The search for other targeted therapies for AMD

Micro-incision intraocular lenses

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The increasingly popular use of smaller cataract incisions means that there is a need for reliable micro-incision intraocular lenses (MICS-IOLs). These lenses require particular physical properties to enable them to pass through 2.0-mm or, preferably, 1.8-mm incisions while maintaining their optical features as they are compressed or rolled for implantation. Durability in terms of centralisation and stabilisation in the capsular bag, biocompatibility, and low rates of posterior capsular opacification are other crucial factors for their safe use. An increasing number of MICS-IOLs are now commercially available. Moreover, these lenses are increasingly incorporating the characteristics of premium IOLs. In this review we will not only describe the monofocal lenses, but also summarise the features of aspherical, toric, accommodative and multifocal types of MICS-IOLs.

The quality of the images formed on the retina after cataract surgery is determined and chiefly limited by two factors: intrinsic aberrations originating from the eye and aberrations arising from the intraocular lens.[1–4] We also know that 80% of ocular aberrations are derived from the cornea.[5] Theoretically, then, if customised intraocular lenses (IOLs) are going to be implanted in the future, our surgery should not affect the optical properties of the cornea. Reliable micro-incision IOLs (MICS-IOLs) are the *sine qua non* component of this surgery.

In recent years, advances in phacoemulsification technology and techniques have meant that the smallest cataract incision size has reduced from 2.2 mm (a small incision) to 2.0 mm (a micro-incision). Now 1.8-mm incisions and even smaller widths are becoming more desirable and more popular because the latest data have demonstrated the importance of some higher-order aberrations (HOAs) that can only be avoided with 1.8-mm and smaller incisions.[6–8]

The well-known benefits of small cataract incisions are shortened recovery time, decreased incidence of wound closure problems and reduction in the risk of endophthalmitis.[9,10] In addition, small incision size is the most effective factor in preserving corneal optical properties.[11,12] While incisions smaller than 2.2 mm are considered to be astigmatically neutral according to the published studies, 1.8-mm incisions seem to be totally safe in terms of HOAs.[6–9,13–16]

Regardless of how well developed the techniques for these operations are, IOLs are still the limiting factor in micro- or small-incision procedures. An ideal MICS-IOL must provide the visual acuity and quality that is provided by a conventional IOL. It must have the ability to be inserted through 1.8-mm or smaller incisions, and when it is folded or rolled it must not undergo any structural and optical changes. It must also have unproblematic capsular and uveal biocompatibility and should not give rise to problems such as tilting or decentralisation. In the past, small-incision IOLs were reported to be associated with significant posterior capsular opacification (PCO), tilting and decentralisation problems.[17–19] These problems were mostly overcome, however, with the new micro-incision IOLs.[3,20–22]

IOL materials are major determinants of the performance of MICS-IOLs. There are four types of lens materials: PMMA, hydrophobic acrylate, hydrophilic acrylate and silicone. Despite the numerous advantages of PMMA, including low PCO rates, high rigidity for good centration and uveal biocompatibility, it is impossible to fold this material.[23] In contrast, hydrophobic acrylate is foldable at room temperature. Low water content, high refractive index and strong plastic memory are the other characteristics of this material that make it suitable for the manufacture of foldable, open-loop, one-piece IOLs. Water inclusions (glistening), positive dysphotopsia (edge glare) and negative dysphotopsia were some of the problems reported with these materials in the past but these have largely been resolved. Hydrophilic acrylate, sometimes known as 'hydrogel', is a high water content material that allows lens epithelial cell (LEC) ingrowth. Moreover, as a result of the difficulty of manufacturing these IOLs with sharp edges, this group of lenses was generally considered to be more prone to cause PCO than other materials.[24] A low refractive index and some reported problems regarding the opacification of the optic material are other well-reported disadvantages of this material. However, the suitability of open-loop haptic or plate-haptic designs of this material allows easy implantation through an injector with a cartridge, which is also made of hydrophilic acrylic material. This is the reason why most current MICS-IOLs are made of hydrophilic material. Silicone, which is another hydrophobic material, was the first foldable IOL material that was used. While the anti-PCO effect is greater, it cannot be manufactured as a one-piece, open-loop lens. In addition, when produced as a plate-haptic design, this material results in higher rates of PCO.[25] This lens can, however, be implanted using preloaded injectors through incisions smaller than 2.2 mm.

Which material is the most suitable for MICS-IOLs is a controversial subject. Briefly, two influential factors are capsular (PCO incidence) and uveal biocompatibility of the materials. With regard to PCO, hydrophobic materials (both hydrophobic acrylic and silicone) seem to have the advantage, with lower rates of PCO and Nd-YAG capsulotomy reported in the literature.[26,27] On the other hand, hydrophilic acrylic materials show better uveal biocompatibility with less cellular reaction on the IOL optic surface, unlike hydrophobic materials with their higher incidence of giant-cell reactions.[28] In the face of this dilemma, both hydrophobic and hydrophilic MICS-IOLs are now commercially available.

In this review we will provide an overview of current MICS-IOLs. Almost every premium IOL is now available as an MICS-IOL. Although the number of MICS-IOLs is small, monofocal, accommodative, multifocal, aspheric and toric options are available. In addition, manufacturers offer variable IOL delivery systems with these lenses.

MONOFOCAL MICS-IOLS

Akreos MI-60

An Akreos AO (Advanced Optic) micro-incision IOL (Bausch + Lomb, Rochester, NY, USA), the Akreos MI-60 is an innovative lens that is made of hydrophilic acrylic material with a 26% water content. It can be implanted through a 1.8-mm incision using a cardridge-injector system. For micro-incisional implantation, this lens is manufactured with 10.5-mm, 10.7-mm and 11.0-mm the overall optic diameters and 5.6-mm, 6.0-mm and 6.2-mm optic diameters respectively, depending on their dioptres. The mean final incision width was found to be 1.82 ± 0.09 mm after implantation of 100 Akreos AO MI-60 lenses in our previously published study.[29] This resulted in 0.20 ± 0.22 D surgically induced astigmatism and nearly the same total and higher-order aberrations compared with preoperative values. Alio *et al*. reported top-level modular transfer function results with this lens in addition to optical quality analysis.[30] The Akreos MI-60 has a neutral spherical aberration, and modifying the ocular spherical aberration to compensate for corneal spherical aberration is not expected. Our results and those of and Alio *et al*. support this idea where the ocular aberration values were found to be in normal range.[29,30] Unlike the negative spherical aberration lenses, neutral aberration lenses are less affected by IOL tilt or decentration and allow better depth of field.[31,32] Visual acuity and contrast sensitivity results of these MICS lenses were also found to be as good as those of the conventional model and as those of the older model of the same lenses.[29,30,33]

Akreos AO MI-60 lenses offer a four-point fixation design with four thin 10°-angled haptics that consist of three zones: a foundation zone, an absorption zone and the conforming tips. This enables the lens to be stabilised and centralised in the bag under postoperative contraction pressure (Figure 1). The optic is pushed backwards with this mechanism. Also, the 360°, square-edged design is another feature of the lens that should prevent PCO. Despite all of these features, however, PCO still seems to be the main problem with this micro-incision lens. Two published series with Akreos AO lenses reported PCO rates of 20% and 35% at 1 year follow-up.[29,30] A number of sporadic complications have also been described with this lens, such as capsulorhexis phimosis,[34] severe anterior chamber reaction[29] and calcification[35] (with the older model). However, the Akreos AO MI-60 micro-incision lens can be a very satisfactory option in micro-incisional cataract surgery.

Acri.Smart lenses

Acri.Tec (Zeiss AcriTec, Berlin, Germany) was the first company to launch IOLs for micro-incision cataract surgery. Acri.Smart-group IOLs are made of 25% water content hydrophilic material with a hydrophobic surface and apart from their monofocal lenses they also provide multifocal and bitoric options. All the MICS models are designed in a single-piece, square-edge, plate-haptic configuration, with an 11.0-mm overall diameter. There are three types of monofocal lenses with a 6.0-mm optic diameter: the Acri.Smart 46S, 36A and 46LC have spherical, aspherical (–0.18 μm) and neutral aspherical optical properties respectively. Exceptionally, the aspheric Acri.Smart 48S model has a smaller optic size, with a diameter of 5.5 mm. They can all be implanted through 1.5-mm or 1.7-mm incisions using an injector-cartridge set. In their 2005 study Alio *et al*. reported very good visual results with these lenses, which were implanted through incisions with a mean width of 1.5 mm; none of the eyes required Nd-YAG capsulotomy for PCO.[36] In two recent studies comparing Acri.Smart 36A and 46LC lenses, which produce negative and zero spherical aberrations respectively, Nochez *et al*. reported better vision quality with significantly higher modulation transfer function (MTF) and contrast sensitivity values but reduced depth of focus with the 36A model.[37,38] These studies highlight the importance of aspherical optics for quality of vision in MICS-IOLs.

Ultrachoice 1.0 lenses

The plate-haptic, hydrophilic acrylic Ultrachoice 1.0 lens (Thinoptx, Abingdon, VA, USA) was the first lens that could be implanted through the smallest incision. Amar Agarwal implanted it through a 0.7-mm incision.[39] Thinness is the most important feature of this lens and it can be rolled to pass through an incision smaller than 1.5 mm. The plate-haptic design has four foot plates that are 50 μm in width. The implant has a 5.5-mm spherical optic with refractive–diffractive design, and the central optic zone shows five diffractive segments on the posterior surface. Each of the five spherical optical-zone steps are 50 μm in height, creating a central optical zone that is only 300 μm to 400 μm thick. The overall length is 11.0 mm and the 50-μm edge surrounding the implant reduces the incidence of dysphotopsia, glare and reflection. According to the thin lens theory, a decrease in the eye's optical aberrations and some accommodation can be expected.[40] High rates of destabilisation problems and PCO were reported early on with this lens.[18,19,41] However, some publications have reported quite good results for visual quality and contrast sensitivity,[42,43] and one recent study reported a 33.3% Nd-YAG laser rate with a postoperative follow-up of approximately 3 years.[44] According to this study, this was the highest rate of the four when compared with the other three MICS-IOLs.[44] Alio *et al*. compared the retinal image quality of a conventional IOL (Acrysof MA60BM) and two MICS-IOLs (Ultrachoice 1.0 and Acri.Smart 48S) and found no difference between them.[12]

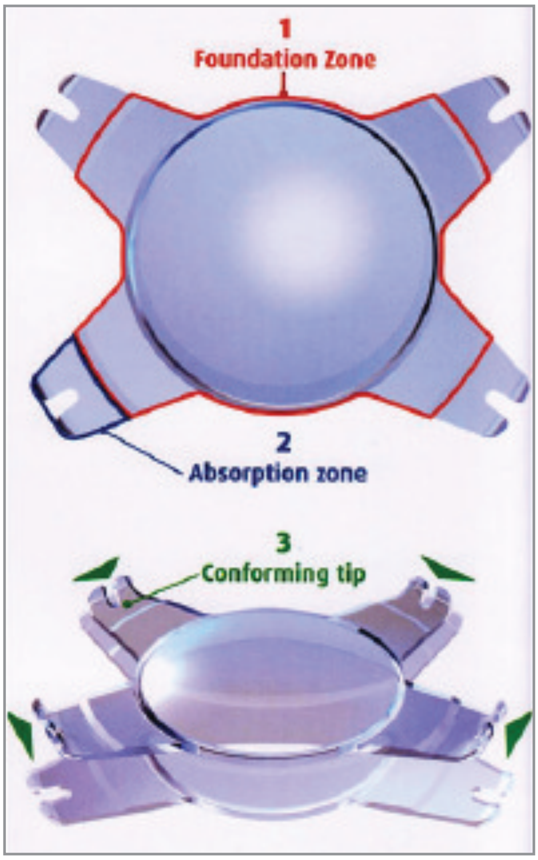

Figure 1. The Akreos MI-60 lens (Bausch + Lomb).

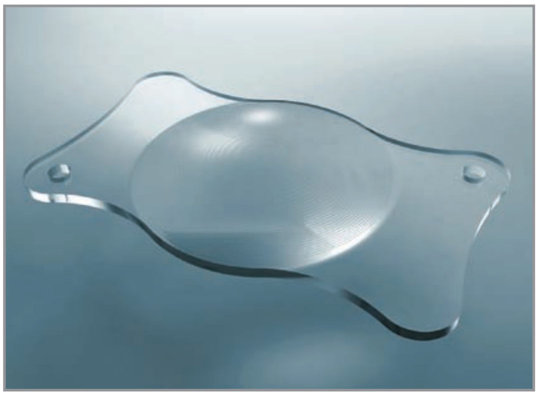

Figure 2. The Acri.Lisa 366D lens (Zeiss AcriTec).

Other monofocal MICS-IOLs

There are a number of other MICS-IOLs, including: AcriFlex MICS IOL 46CSE (Acrimed GmbH, Berlin, Germany), CareFlex IOL (W20 Medizintechnik AG, Bruchal, Germany), SuperFlex and C-Flex (Rayacryl, Rayner IOL Ltd, UK), IOLTech MICS lens (LaRochelle, France and Carl Zeiss Meditec, Stuttgart, Germany), Microslim and SlimFlex (PhysIOL, Liege, Belgium), which are all made with hydrophilic acrylic material; Hoya Y-60H (Hoya Corporation, Tokyo, Japan), made with hydrophobic acrylic material; Acriva UDM 611 (VSY Technologies, Istanbul, Turkey), made with hydrophilic acrylic but hydrophobic- surfaced materials; Miniflex IOL (Mediphacos Ltd, Minas Gerais, Brasil), made with flexacryl hybrid acrylic material; and NanoFlex (CC4204A) (Staar Surgical Co., Monrovia, CA, USA), made with collamer material.

TORIC LENSES

There are a very limited number of MICS lenses in the area of astigmatism correction. Because rotational stability is the main concern for toric lenses, the small size of these IOLs can be accepted as a handicap. In the face of this, the posterior capsular attachment ability of hydrophobic or hydrophobic-surfaced materials becomes an important factor.

Acri.Comfort 646 TLC

The Acri.Comfort 646 TLC (Zeiss Acri.Tec, Berlin, Germany) is a bitoric, biconvex, aspheric, plate-haptic lens which has a 6.0-mm optic and an 11.0-mm overall diameter. In common with other Acri.Tec lenses it is hydrophilic (25% water content) but has hydrophobic surface material. Its cylinder dioptre range is +1.0 D to +12.0 D. Alio *et al.* reported that 91% of the astigmatism was corrected and the mean IOL axis rotation was –1.75 ± 2.93° 3 months after surgery with this lens.[45]

ACCOMMODATIVE LENSES

TetraFlex KH-3500 micro-incision lens

The TetraFlex KH-3500 micro-incision lens (Lenstec Inc., St Petersburg, FL, USA) is a single-piece lens with a spherical optic, aiming for an accommodative effect with its flexible 10° anteriorly angulated, closed-loop haptics. It is made of 26% water content, hydrophilic acrylic, highly flexible material. It has a 5.75-mm optic and a total length of 11.5 mm. The FDA study reported at least 2.0-D accommodative amplitude in 100% of eyes, 75% spectacle independence and reading ability (better than the Cyrstalens results).[46,47]

1-CU

The 1-CU (Human Optics, Erlangen, Germany), a single-piece, hydrophilic acrylic lens, has four haptic legs with hinged connections to the optic which are thinner near the optic to enable flexibility and movement of the optic anteriorly when accommodative effort begins. Because the optical and overall lengths are 5.5 mm and 11.8 mm respectively, this lens can be implanted through incisions approximately 2.0 mm in width. Stable refraction and subjective accommodation were reported 1 year after implantation.[48] Reported objective static and dynamic accommodation amplitudes were 0.71 D and 0.72 D with this lens, while subjectively it was 2.24 D.[49] According to the Wolffsohn *et al.* the subjective accommodation amplitude was greater than the objective value, probably because of the interaction between the depth of focus and aspheric nature of the 1-CU IOL.[49] Also, some decrease in near visual acuity and the subjective and objective amplitudes of accommodation after 2 years is reported.[49] As an accommodative lens, 1-CU was confirmed as being free of dysphotopsic effects, compared with a 25% rate of these effects in a multifocal IOL group.[50]

MULTIFOCAL AND MULTIFOCAL TORIC LENSES

AT LISA (809M / 809MV) lenses

The AT LISA 809M / 809MV (Acri.Lisa 366D) (Carl Zeiss Meditec, Berlin, Germany) has a 6-mm optic and an 11.0-mm overall length, allowing implantation even through 1.5-mm incisions (Figure 2). The diffractive–refractive optic distributes light 65% for far and 35% for near. It has +3.75 D power for near addition at the centre. It has spherical aberration of –0.165 µm. The AT LISA 809MV model also has a low wavelength filtering feature. The Acri.Lisa 366D (or AT LISA) is one of the most successful lenses in the presbyopia correction field.

The Acri.Lisa 366D lens has proved itself in many ways as a MICS multifocal IOL.[51–54] Satisfactory results have been reported for distance and near visual acuities: in the study done by Alfonso *et al.*[51] (162 eyes) the binocular best corrected visual acuity (BCVA) was reported as 0.89 ± 0.77; in the Kaymak and Mester's study[52] (40 eyes) the BCVA was 1.17 ± 0.81; and in the Alio *et al.* study[53] it was 0.96 ± 0.17. In these three studies the binocular uncorrected near visual acuities (UNVAs) were reported to be 0.96 ± 0.88, 0.91 ± 0.74 and 0.90 ± 0.15 and the distance-corrected near visual acuities (DCNVAs) were 0.97 ± 0.82, 0.91 ± 0.74 and 0.97 ± 0.07 respectively.[51–53] In our recently presented study the monocular uncorrected distance visual acuity (UDVA) was 0.80 ± 0.14, binocular UDVA was 0.98 ± 0.06 and binocular corrected distance visual acuity (CDVA) was 0.98 ± 0.05 with this lens.[54] Dysphotopsic phenomena were reported in 10–25% in patients with Acri.Lisa lenses in these studies.[51–54]

AT LISA Toric (Acri.Lisa Toric 466D)

The AT LISA Toric (Acri.Lisa Toric 466D) (Carl Zeiss) lens has a toric anterior surface and a bifocal posterior surface to achieve both astigmatic and presbyopic correction. Other physical properties are the same as those of the other Acri.Lisa lenses, so this lens can be implanted through a 1.5-mm. incision.

Acriva Reviol 611 MFM

The Acriva Reviol 611 MFM (VSY Biotechnologies, Istanbul, Turkey) multifocal MICS-IOL is a mono-block, plate-haptic, foldable acrylic lens with 25% water content

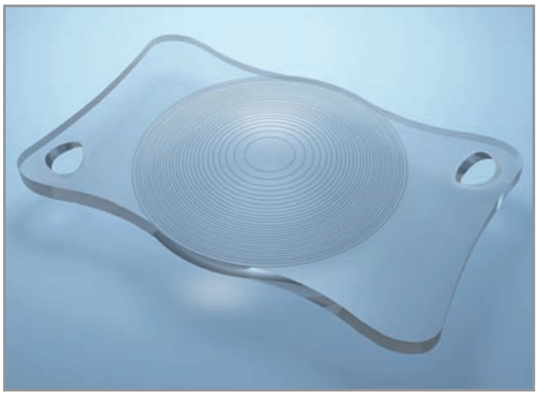

Figure 3. The Acriva Reviol MFM 611 lens (VSY Biotechnologies).

and a hydrophobic surface. It provides multifocality with refractive–diffractive hybrid optical characteristics. With its 6.0-mm optical diameter and 11.0-mm overall diameter it is designed to be implanted through 1.8-mm incisions (Figure 3). While its aspheric optical design provides 0.165 µm negative spherical aberration, it divides light 60% for far focus and 40% for near focus. Its +3.75 D near power addition enables perfect reading functionality. Transitions of 28 active diffractive rings are softened to prevent dysphotopsic problems. Its advanced 360°, sharp-edge optic and haptic design not only aims to prevent PCO but also allows thinner IOL optic manufacture. Our experience has shown that, as well as perfect distance and near visual acuity, a very satisfactory intermediate-distance visual acuity (mean binocular uncorrected intermediate visual acuity or UIVA) of 1.73 ± 0.78 can be obtained with this lens.[54] Slight dysphotopsia was seen in approximately 25% of patients implanted this lens.

CONCLUSION

Advanced techniques and technologies in cataract surgery allow surgeons to carry out their operations through 1.5-mm or smaller incisions. In order to benefit from this development, surgeons need reliable MICS-IOLs to implant through these small incisions. There is now an increasing number of variations of these lenses available and they provide as good functional vision as conventional lenses and are safe in terms of uveal and capsular biocompatibility.

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