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Extended Depth of Focus Intraocular Lenses as a Correction for Presbyopia

Katarzyna E. Nowik, Justyna Izdebska, Karolina Pielak-Modrzejewska, Jacek P. Szaflik

[1] Department of Ophthalmology, Medical University of Warsaw, Poland
Head: Professor Jacek P. Szaflik, PhD, MD
[2] SPKSO Ophthalmic University Hospital in Warsaw, Poland
Head: Professor Jacek P. Szaflik, PhD, MD

Summary: Presbyopia is pathophysiological process that begins after age of 40 years, associated with the loss of accommodation. This results in blurred vision of nearby objects. In recent years, there has been rapid technological development of premium intraocular lenses, allowing presbyopia correction cataract surgery. Among this type of intraocular lenses are multifocal intraocular lenses and extended depth of focus intraocular lenses.
Extended depth of focus intraocular lenses utilise various optical phenomena – spherical aberrations, chromatic aberrations, diffraction, and refraction – to increase the depth of focus and provide patients with good vision at various distances.
Extended depth of focus intraocular lenses mitigate presbyopia and reduce patients' dependence on glasses.
Proper ophthalmological assessment of patients, combined with a detailed consultation regarding their visual needs and occupational demands, ensures high satisfaction and positive outcomes following surgery with implantation of extended depth of focus intraocular lenses.

Key words: presbyopia, cataract, multifocal intraocular lenses (MFIOL), extended depth of focus (EDOF), intraocular lenses (IOLs).

Introduction

After the age of 40 years, a process associated with a reduction of accommodation begins, known as presbyopia. With ageing, biochemical and pathophysiological changes occur that cause a reduction of accommodative range [1]. Of most significance in the loss of accommodative ability is the reduction in elasticity of the lens capsule and the weakening of the ciliary muscles, which are responsible for changing the shape of the lens during accommodation [2]. The result is a shift in the near point (the smallest distance of sharp vision) from about 25–30 cm to up to 50–100 cm. Total accommodative ability declines after the age of 60 years.

In the recent years, there has been rapid technological development of premium intraocular lenses (IOLs) allowing presbyopia correction cataract surgery [3]. Currently, the main goal of intraocular lens technology is to achieve a balance between high patient independence on glasses, good visual acuity at various distances, tolerance of adverse light phenomena, and a reduced sense of contrast. The term "premium" is used to describe IOLs with special optical properties that allow patients to see not only long distance, but also intermediate and near distance [4]. Among this type of IOLs are multifocal intraocular lenses (MFIOL) and extended depth of focus (EDOF) intraocular lenses. Multifocal (bifocal, trifocal) intraocular lenses produce 2 or 3 foci on the retina to provide smooth transitions between visual zones, resulting in the impression of continuous, sharp vision [5]. These IOLs divide the viewed light into two or three foci on the retina, resulting in the patient having more side effects such as dysphotopsia or reduced contrast sensitivity [6].

1. Extended depth of focus intraocular lenses – definition

Extended depth of focus intraocular lenses combine the characteristics of monofocal intraocular lenses, in which a single focus on the retina is generated, so that, when calculating the implant for normopia, the patient sees well to the distance, whereas for near vision the patient needs spectacle correction and multifocal IOL, in which 2 or 3 focal points are formed on the retina, resulting in the patient seeing well into the far distance, near distance, and sometimes intermediate distance (in the case of trifocal IOLs). In extended depth of focus intraocular lenses, one extended focus is formed, allowing the patient to see well into the far distance, intermediate distance, and have useful near visual acuity, and by not splitting the energy into 3 or 3 foci as with multifocal IOLs, the patient should have less adverse phenomena such as dysphotopsia and better contrast sensitivity [7, 8].

In 2016, the American Ophthalmological Society issued a consensus statement defining EDOF intraocular lenses as those that [9]:

- must have a minimum of 0.5 D greater depth of focus than monofocal intraocular lenses for a minimum visual acuity of 0.2 logMAR,
- extended depth of focus intraocular lenses should have better visual acuity to intermediate distance than monofocal intraocular lenses,
- at least 50% of eyes implanted with EDOF intraocular lenses should achieve a minimum visual acuity to an intermediate distance of 0.2 logMAR,
- extended depth of focus intraocular lenses should achieve no worse visual acuity to distance than monofocal intraocular lenses, and the minimum visual acuity to far distances with best adjacency should be a minimum of 0.2 logMAR.

2. Extended depth of focus intraocular lenses – principle of operation

Extended depth of focus intraocular lenses make use of various optical phenomena in the creation of a single extended focus, including spherical aberration, chromatic aberration, pinhole effect, diffraction and refraction phenomena.

Spherical aberrations are associated with the different refraction of light rays passing through other parts of the optical system. There is a positive aberration in the human cornea with an average value of +0.31 μm ±0.135 μm for a pupil diameter of 6.0 mm. Extended depth of focus intraocular lenses tend to have negative spherical aberrations, reducing the positive aberrations of the cornea and the native lens, resulting in a single, extended depth of focus, and thus patients have better visual acuity at various distances [10].

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Chromatic aberrations arise because of the different focal points of rays of different wavelengths. The induction of chromatic aberrations is influenced by many factors including dispersion and the design of the optical material. Refractive intraocular lenses amplify chromatic aberrations while diffractive IOLs diminish them, thereby improving visual quality [11].

The pinhole effect is another phenomenon that allows for greater depth of focus. This phenomenon is based on 2 laws: Campbell's law, which states that as the pupil diameter increases, the depth of focus decreases, and Stiles Crawford's law, which states that there is a greater photoreceptor response to light of the same intensity entering through the centre of the pupil than to light entering at the periphery [12].

3. Division of extended depth of focus intraocular lenses

Extended depth of focus intraocular lenses are subdivided into so-called pure EDOF intraocular lenses using spherical aberration and the narrow pinhole effect, diffractive EDOF intraocular lenses, refractive EDOF intraocular lenses, and mixed diffractive-refractive EDOF intraocular lenses.

Diffractive intraocular lenses make use of the effect of diffraction, i.e. deflection and interference – the superposition of waves of light [13]. The creation of an elongated focus depends on the number, size, and arrangement of diffractive rings.

Refractive intraocular lenses feature zones with different refractive powers, which have different refractive indices, and each zone serves to see at different distances [14].

Diffractive intraocular lenses give better visual acuity to distant and near distances compared to refractive intraocular lenses, but they result in more adverse effects – dysphotopsia and poorer contrast sensitivity [15].

The Table I below shows the classification of extended depth of focus intraocular lenses with examples of intraocular lense models.

Pure EDOF intraocular lenses	**Based on spherical aberrations**	Sifi Mini Well Ready, WIOL CF, Tecnis Eyhance
	Using the pinhole effect	IC-8 XtraFocus Pinhole Implant
Diffractive EDOF intraocular lenses	Tecnis Symfony ZXR00, At Lara 829 MP	
Refractive EDOF intraocular lenses	Lentis Mplus, Acunex Vario AN6V Lucidis Vivity LuxSmart Pure See	
Diffractive-refractive EDOF intraocular lenses	InFo EDEN Harmonis Tecnis Synergy	

Tab. I. Division of EDOF intraocular lenses with examples of selected intraocular lenses models.

Conclusion

With the increased longevity of the human population, and increased life and work activities, extended depth of focus intraocular lenses have emerged to overcome the problem of presbyopia occurring after the age of 40 years, allowing patients to become independent of glasses [16]. Currently, premium intraocular lenses are available on the market, including multifocal intraocular lenses and extended depth of focus intraocular lenses. Multifocal intraocular lenses offer good visual acuity to a variety of distances, but result in more side effects, i.e. dysphotopsia and reduced contrast sensitivity. Before choosing the right type of IOLs, it is very important for the patient to be properly and thoroughly qualified, to have an ophthalmological diagnosis, to rule out conditions that may not benefit from the surgical procedure, and to have an interview about their occupation, their visual needs, and their expectations of the results of the surgery. A well-conducted pre-surgical qualification, adequate chair time, and the right choice of implant can ensure patients have a high level of satisfaction and contentment after surgery and the possibility to continue their previous life activities [17].

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Reprint requests to:
Katarzyna E. Nowik, MD (lek.katarzynaolejnik@onet.eu)
SPKSO Ophthalmic University Hospital in Warsaw
Józefa Sierakowskiego 13, 03-709 Warszawa