ARCH SOC ESP OFTALMOL. 2014;89(10):397–404

ARCHIVOS DE LA SOCIEDAD ESPAÑOLA DE OFTALMOLOGÍA

www.elsevier.es/oftalmologia

Original article

Halos and multifocal intraocular lenses: Origin and interpretation☆,☆☆

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ARTICLE INFO

Article history:
Received 31 July 2013
Accepted 18 January 2014
Available online 4 November 2014

Keywords:
Multifocal intraocular lenses
Halo
Glare
Optical quality
Presbyopia
Optical bench

ABSTRACT

Objective: To present the theoretical and experimental characterization of the halo in multifocal intraocular lenses (MIOL).

Method: The origin of the halo in a MIOL is the overlaying of 2 or more images. Using geometrical optics, it can be demonstrated that the diameter of each halo depends on the addition of the lens (ΔP), the base power (P_d), and the diameter of the IOL that contributes to the "non-focused" focus. In the image plane that corresponds to the distance focus, the halo diameter (δH_d) is given by: $\delta H_d = d_{pn}\ \Delta P/P_d$, where d_{pn} is the diameter of the IOL that contributes to the near focus. Analogously, in the near image plane the halo diameter (δH_n) is: $\delta H_n = d_{pd}\ \Delta P/P_d$, where d_{pd} is the diameter of the IOL that contributes to the distance focus. Patients perceive halos when they see bright objects over a relatively dark background. *In vitro*, the halo can be characterized by analyzing the intensity profile of the image of a pinhole that is focused by each of the foci of a MIOL.

Results and conclusions: A comparison has been made between the halos induced by different MIOL of the same base power (20D) in an optical bench. As predicted by theory, the larger the addition of the MIOL, the larger the halo diameter. For large pupils and with MIOL with similar aspheric designs and addition (SN6AD3 vs. ZMA00), the apodized MIOL has a smaller halo diameter than a non-apodized one in distance vision, while in near vision the size is very similar, but the relative intensity is higher in the apodized MIOL. When comparing lenses with the same diffractive design, but with different spherical-aspheric base design (SN60D3 vs. SN6AD3), the halo in distance vision of the spherical MIOL is larger, while in near vision the spherical IOL induces a smaller halo, but with higher intensity due to the spherical aberration of the distance focus in the near image. In the case of a trifocal-diffractive IOL (AT LISA 839MP) the most noticeable characteristic is the double-halo formation due to the 2 non-focused powers.

☆ Please cite this article as: Alba-Bueno F, Vega F, Millán MS. Halos y lentes intraoculares multifocales: origen e interpretación. Arch Soc Esp Oftalmol. 2014;89:397-404.

☆☆ Paper presented in the 89th Congress of the SEO.

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Halos y lentes intraoculares multifocales: origen e interpretación

RESUMEN

Palabras clave:
Lentes intraoculares multifocales
Halo
Deslumbramiento
Calidad óptica
Presbicia
Banco óptico

Objetivo: Caracterización teórica y experimental del halo en lentes intraoculares (LIO) multifocales.

Método: El halo producido por una LIO multifocal (LIOM) se origina cuando sobre una imagen enfocada se superpone otra desenfocada. Mediante óptica geométrica se demuestra que el diámetro de cada halo depende de la adición de la lente (ΔP), de la potencia base (P^d) y del diámetro de la lente iluminada que contribuye al foco «no-enfocado». En plano imagen que corresponde al foco de lejos, el diámetro del halo (δH^d) viene dado por: $\delta H^d = d^{pn}\ \Delta P/P^d$ donde d^{pn} es el diámetro de la LIO que contribuye al foco cercano. Análogamente, en el plano imagen del foco de cerca del diámetro del halo (δH^n) viene dado por $\delta H^n = d^{pd}\ \Delta P/P^d$, donde d^{pd} es el diámetro de LIO que contribuye al foco lejano. Los pacientes perciben halos cuando observan objetos luminosos sobre un fondo relativamente oscuro. *In vitro*, el halo se puede caracterizar analizando el perfil de intensidad de la imagen de un pinhole que forma cada uno de los focos de una lente multifocal.

Resultados y conclusiones: Hemos comparado los halos producidos por varias LIOM de la misma potencia base (20 D) en un banco óptico. Tal y como predice la teoría, cuanto mayor es la adición de la LIOM de diseños asféricos (SN6AD3 vs. ZMA00), las lentes apodizadas presentan un halo de menor diámetro que las no-apodizadas en visión lejana, mientras que en visión cercana el halo es del mismo tamaño pero la intensidad relativa es mayor en el caso de las apodizadas. Comparando lentes esféricas y asféricas con igual diseño difractivo (SN60D3 vs. SN6AD3) el halo en visión lejana en la lente esférica es mayor, mientras que en visión cercana la lente esférica produce un halo de menor tamaño pero de mayor intensidad debido a la aberración esférica del foco lejano en el plano imagen del foco cercano. En el caso de una lente trifocal (AT LISA 839MP) la característica más distintiva es la aparición de un doble halo debido a los focos lejano e intermedio de la LIO, sobre la imagen enfocada en visión cercana.

Introduction

In most cases, cataract surgery associates the implant of an intraocular lens (IOL). Nowadays, the surgical technique, *i.e.*, phacoemulsification and IOL implant, allows refractive results to be foreseen with very high precision and to perform the surgery even without the presence of lens opacities, known as transparent lens surgery. After surgery, patients lose their accommodative capacity and, if the implant was a monofocal lens, optical correction is required for focusing at specific distances (generally near vision). In order to diminish dependency on spectacles, at present lenses are available with more than one power in order to generate 2 or more focal points to initially cover the patient requirements for near or intermediate vision.

One of the main complaints of patients with multifocal intraocular lenses (MIOL) is the perception of halos, particularly in low lighting conditions (large pupil diameters) with intense light stimuli and relatively dark backgrounds. These circumstances can occur frequently, for instance when driving by night. The halo concept is utilized to define a blurry circle that the patient perceives around said stimuli. This effect can be due to various factors such as higher order aberrations, particularly spherical aberration (SA) and above all due to the existence and simultaneous perception of more than one image, as in the case of MIOL where the focused image is overlapped to one or more unfocused images. The majority of published works on this effect are based on subjective halo perception assessments by patients (generally by means of questionnaires).[1] Objective methods for said assessments have been used on very few occasions.

This study proposes a theoretical approach in the framework of first order geometrical optics (also known as paraxial optics or Gauss optics) to characterize the halo diameter as well as an experimental method for analyzing *in vitro* the size and relative intensity thereof. The method shall be applied to different mono- and multifocal IOLs.

Method

Paraxial approach for estimating halo diameter

To achieve a better understanding of the formation of halos, a paraxial approach will be taken to determine the influence of IOL power and addition as well as pupil diameter. Accordingly, halo formation in far and near vision is schematically shown in Fig. 1. In this example it is assumed that the patient has been implanted with a dual focus MIOL (far and near) and is pupil-dependent. The central part contributes to the far focus and also to the near focus, while the exterior part only contributes to the far focus. For this reason, in Fig. 1, even though the MIOL is lit with a d_{pd} diameter beam covering the entire aperture,