Occlusive IOLs for Intractable Diplopia Demonstrate a Novel Near-Infrared Window of Transmission for SLO/OCT Imaging and Clinical Assessment

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PURPOSE. Occlusive intraocular lens (IOL) implantation is an effective therapeutic option in patients with intractable diplopia, visual confusion, and unsightly leukocoria. However, their use has been restricted by concerns that inability to visualize the retina may prevent the diagnosis of important posterior pole diseases. In this study, transmission spectra of occlusive IOLs were defined as a basis for acquiring scanning laser ophthalmoscopy/optical coherence tomography (SLO/OCT) images.

METHODS. Fifteen IOLs of three designs were examined: black small and large PMMA and black Lotus (Morcher GmbH, Stuttgart, Germany). Each IOL was placed between a broad-spectrum white light source and a spectroradiometer, to generate transmission spectra for each lens and determine the cutoff wavelength. Transmission in the near-infrared (NIR) range was confirmed with an 850-nm LED. A model eye was implanted with occlusive IOLs, and SLO/OCT scans were acquired with seven clinical SLO/OCT imaging systems.

RESULTS. Occlusive IOLs demonstrated high levels of transmission of NIR light. It was determined that most SLO/OCT scanners would achieve 99% to 100% transmission at their operational wavelengths of NIR light. Furthermore, all clinical SLO/OCT imaging systems were capable of imaging fine retinal features without attenuation through occlusive IOLs in a model eye.

CONCLUSIONS. In this study, a novel NIR window of high-level transmission was identified across the occlusive IOLs with applications to SLO/OCT imaging and NIR-based clinical assessment. The ability to acquire high-quality SLO/OCT scans to detect posterior pole disease may fundamentally change the current view on occlusive IOLs and encourage their use in patients with intractable diplopia. (*Invest Ophthalmol Vis Sci*. 2011;52:3737–3743) DOI:10.1167/iops.10-6767

Therapeutic occlusion of ocular media is indicated for patients with intractable diplopia that is refractory to optical, medical, and surgical treatment strategies¹; for visual confusion where it is able to improve functional vision²; or for unsightly

leukocoria, to achieve superior cosmesis.^{3–5} Occlusive strategies include permanent eye-patching or tarsorrhaphy, use of occlusive contact lenses, corneal tattooing (keratopigmentation),^{6,7} or insertion of an occlusive, or black intraocular lens (IOL).^{1–5,8,9}

The use of black occlusive IOLs as a therapeutic solution, particularly for intractable diplopia, has been restricted by concern that such media prevent ophthalmologists from detecting important clinical signs and diseases including papilledema or choroidal melanoma of the optic disc, macula, and retina by slit lamp biomicroscopy and other instruments that use wavelengths of light across the visible spectrum. Interference with ocular examination and imaging may negatively influence ophthalmologists from offering—and patients from selecting—occlusive IOL implantation as a treatment modality.

Despite these uncertainties, occlusive IOLs are offered and implanted in specific patient groups, particularly among those refractory to other treatment strategies such as prismatic correction or surgery in diplopia. The incidence of intractable diplopia has been estimated at 0.8% of patients after strabismus surgery,¹⁰ although the true prevalences of visual confusion and unsightly leukocoria remain unknown. However, these conditions are particularly disabling for patients who suffer from them,¹¹ often requiring permanent occlusion to restore functional vision.¹² In this patient group, occlusive IOL implantation has been shown to be an effective management strategy; it requires no maintenance and is inconspicuous once implanted, factors that contribute to the high levels of postoperative satisfaction, particularly in patients with intractable diplopia.^{1,2,8,9,13}

Recently, it was discovered that macular imaging was possible through the 85F Morcher PMMA occlusive IOL with scanning laser ophthalmoscopy (SLO) and optical coherence tomography (OCT) scanner (Spectralis SLO/OCT; Heidelberg Engineering, Heidelberg Germany).¹² The SLO/OCT imaging systems in clinical use have near-infrared (NIR) spectrum light (820–870 nm), and it was the assumption of this observation that the Morcher (Stuttgart, Germany) PMMA occlusive IOL transmits sufficient NIR light to permit retinal and macular imaging.

Confirmation of NIR transmission and proof of SLO/OCT imaging capabilities across occlusive IOLs may allow more patients with intractable diplopia to benefit from this effective therapeutic strategy, as the reluctance to implant them due to difficulties in visualizing the retina would no longer influence clinical judgment.

MATERIALS AND METHODS

Lenses

We obtained three designs of occlusive IOLs: rigid black PMMA IOLs in large and small designs and foldable, hydrophobic, black occlusive Lotus IOLs (Morcher); Fig. 1. Five IOLs of each of these three designs

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were included in the study, a total of 15 lenses. Full technical details of the occlusive IOLs are provided in Table 1. Morcher occlusive IOLs are treated with a proprietary black copolymer, rendering both the haptics and the optics black.¹⁴ The black copolymer is produced as for the transparent PMMA lenses with four different high-purity dyestuffs that are used as tints and added to the monomer mixture before polymerization.

Spectral Transmission of Occlusive IOLs

Transmission spectra of each IOL were determined with a 120-W mercury vapor short arc to provide high-intensity, broad-spectrum white light (X-cite 120Q microscope light source system; Exfo Life Sciences, Mississauga, Ontario, Canada) (Supplementary Fig. S1, <http://www.iovs.org/lookup/suppl/doi:10.1167/iovs.10-6767/-DCSupplemental>). Light transmission was measured with a spectroradiometer (USB2000; Ocean Optics, Dunedin, FL). This light source produced an output irradiance of 3.73×10^3 mW/cm² between the UV and NIR range (350–800 nm). The spectral profile of five lenses of each type was then determined by placing these media between the light source fiber optic and the spectroradiometer detector. We recorded three spectral transmission profiles for each lens to eliminate any variations in transmission due to potential differences in the angle of lens suspension. To determine the relative spectral transmission of the different IOLs (as a

percentage of the incident light), we divided the spectral profile of the IOL by the light source emission spectrum. A 3-nm boxcar average was used on the transmission dataset to produce the presented spectra (Fig. 2).

Confirmation of NIR Transmission

To confirm that all IOLs transmitted light in the NIR range (>800 nm), we used an 850-nm NIR LED light source (Osram GmbH, Munich, Germany) that produced an output irradiance of 42.8 mW/cm² (Supplementary Fig. S2, <http://www.iovs.org/lookup/suppl/doi:10.1167/iovs.10-6767/-DCSupplemental>). Equivalently, transmission spectra were recorded for the three types of IOLs, with three recordings of transmission spectra for each lens, by using the spectroradiometer as just described. An average of these three recordings with a 3-nm boxcar average was used to generate more detailed NIR transmission spectra data for the occlusive IOLs (Fig. 3).

Transmission of Black IOLs with Commercially Available SLO/OCT Scanners

To determine the optimal SLO/OCT scanner for each occlusive IOL, we fitted each transmission spectrum to a sigmoid curve to determine the cutoff wavelength. Each category of occlusive lens from our data was

TABLE 1. Technical Details of Occlusive IOLs

Occlusive IOL	Model	Optic (mm)	Haptic (mm)	Overall (mm)	IOL Thickness (mm)	Haptic Angulation (deg)	Dioptric Power
Small PMMA	85F	6	0.15/0.20	12	0.70	10	No optical function
Large PMMA	6S	10	0.17–0.26/0.20	13.5	0.6	10	No optical function
Lotus IOL (foldable)	80D	6	0.16–0.26/0.20	13.5	0.61	0	No optical function

FIGURE 2. Transmission spectra of occlusive IOLs (X-Cite 120Q microscope light source system; Exfo Life Sciences). Each trace represents the mean transmission of five lenses from each category of IOL with 10 nm data-points presented. Cutoff wavelengths for each occlusive IOL are demonstrated at 751 nm for small PMMA, 750 nm for large PMMA, and 747 nm for black Lotus. Occlusive IOLs do not transmit light below these wavelengths, either in the visible spectrum or ultraviolet range. The data permit a comparison of spectra between occlusive lenses. The transmission varied between the lower cutoff wavelengths and the maximum transmission of 100%, in the IOLs, with 100% transmission through Lotus occlusive IOLs at 794 nm and the small and large PMMA IOLs at 809 and 803 nm, respectively. Lotus occlusive IOLs demonstrated greater transmission at shorter wavelengths. Error bars, SEM.

fitted with a sigmoid function (Table 2; Fig. 4). Using technical information available from manufacturers concerning the mean operational wavelengths of the NIR light used by commercially available SLO/OCT scanners, we calculated the theoretical percentage of transmission of scanning wavelength SLO and OCT NIR light through the three types of occlusive IOLs, by using the mathematical model shown in Table 2.

SLO/OCT Imaging through Occlusive IOLs in a Model Eye

To prove that the theoretical calculations concerning the possibility of SLO/OCT imaging through occlusive IOLs were accurate, we implanted a model eye (GWB International, Marshfield Hills, MA; Fig. 1D) containing a dual-layered, painted retina (Fig. 1E) and elevated optic disc profile (Fig. 1F; Supplementary Movie S1, <http://www.iovs.org/lookup/suppl/doi:10.1167/iovs.10-6767/-DCSupplemental>) with occlusive large PMMA and occlusive Lotus IOLs. The model eye has dimensions that closely approximate those of the human adult eye,

with a 6-mm pupillary aperture and a painted retina simulating the optic disc and retinal vascular arcades. There is a prominent blood vessel on the superficial retinal layer that casts an optical shadow on the deeper retinal layer on OCT images, demonstrated in Supplementary Movie S1. The eye model's simulation of the optical properties of the human eye permits analysis with clinical imaging systems.

Experienced imaging technicians were asked to acquire images with their clinical SLO/OCT scanners through each implanted occlusive IOL and additionally without an occlusive IOL (Fig. 5). Seven commercially available SLO/OCT imaging systems were included in the study. Manufacturers include Carl Zeiss Meditec, Oberkochen, Germany (Cirrus HD-OCT), Optovue (iVue; Fremont, CA), BiopTigen (3D SD-OCT; Research Triangle Park, NC), Canon USA, Inc. (SPOCT HR OCT; Melville, NY), Topcon Medical Systems, Inc. (3D OCT-2000 SDOCT; Oakland, NJ), Opko Instrumentation (Spectral OCT/SLO; Miami, FL) and Heidelberg Engineering (Spectralis OCT). The primary end point was to determine which of these SLO/OCT scanners is

FIGURE 3. Confirmation of NIR transmission through occlusive IOLs with an NIR LED light source. Each line represents the mean transmission of five lenses from each category of IOL with 10-nm data points presented. The data permit a comparison between occlusive IOLs which transmit NIR light similarly from the NIR LED, with a peak at 865 nm. Data demonstrate strong transmission in each occlusive IOL category of NIR light produced from an NIR LED light source (Supplementary Fig. S2, <http://www.iovs.org/lookup/suppl/doi:10.1167/iovs.10-6767/-DCSupplemental>). Error bars, SEM.

TABLE 2. A Model for Occlusive IOL Transmission

A. Model Equation Defining Transmission at Any Wavelength of Light				
$\text{Transmission}(\lambda) = \frac{\lambda^{\lambda_{\text{Max}} - \lambda_{\text{Min}}}}{1 + 10^{[(T_{50} - \lambda)/k]}}$				
B. Summary of Transmission Characteristics of Occlusive IOLs				
Lens Design	T_{50}	k	SS Regression	R^2
Black PMMA small	784.27	17.85	22.68	0.90
Black PMMA large	780.28	18.34	30.20	0.86
Black lotus	775.55	13.56	26.26	0.92

The calculated constants for the three occlusive lens designs in this study are presented. T_{50} , wavelength of light at 50% transmission; k , gradient; SS regression, linear regression; R^2 , coefficient of determination.

capable of identifying the dual-layered retina and optic disc profile through Lotus and PMMA occlusive IOLs.

RESULTS

Broad-Spectrum Transmission of Occlusive IOLs

The black occlusive IOLs of PMMA and Lotus designs blocked transmission of light at wavelengths below 750 nm after which there was an exponential increase in transmission (Fig. 2). There was no difference in this lower threshold between the different varieties of occlusive lenses, although the gradient of the increase in transmission varied. In the NIR range, the transmission of all occlusive IOLs approached 100%, although the long-wavelength cutoff of transmission differed between lenses. The black Lotus lens transmitted more fully at lower NIR wavelengths than did either the small or large PMMA lenses (Fig. 4). The occlusive IOLs, consistent with their intended purpose, did not transmit any light below 750 nm in the visible range and, more important, to blocked all ultraviolet wavelength light from transmitting beyond it (Fig. 4). The transmission spectrum of the X-cite broad-spectrum white light source is shown in Supplementary Figure S1 (<http://www.iovs.org/lookup/suppl/doi:10.1167/iovs.10-6767/-DCSupplemental>). It generates high-intensity broad-spectrum white light with emission peaks at 314, 350, 363, and 583 nm. Despite the characteristics of this light source, it displays a decrease in emission over 800 nm in the NIR range. As a consequence, the signal-to-noise ratio at emissions >800 nm made it difficult to be certain whether the occlusive IOLs would influence light transmission over 800 nm. To investigate, we used a monochromatic NIR LED light source, with emission peak at 865 nm.

Confirmation of NIR Transmission

To confirm the presence of transmission of NIR light through occlusive IOL media, we repeated our experiments with an NIR LED, generating transmission spectra for each occlusive IOL (Fig. 3). These experiments confirmed that the occlusive media transmitted the NIR light fully, and therefore the transmission spectra of all IOLs were almost identical with the spectra generated by the NIR LED, with an identical peak transmission of 865 nm (Supplementary Fig. S2, <http://www.iovs.org/lookup/suppl/doi:10.1167/iovs.10-6767/-DCSupplemental>). Furthermore, in the NIR range, occlusive and clear media transmitted light comparably (data not shown), confirming the

high levels of transmission of NIR light evident with the broad-spectrum light source. The NIR LED achieved peak irradiance at 865 nm of 1160 $\mu\text{W}/\text{cm}^2/\text{nm}$, greater than the irradiance of 237 $\mu\text{W}/\text{cm}^2/\text{nm}$ generated by the microscope light source system (X-cite 120Q; Exfo Life Sciences) at this wavelength (Supplementary Fig. S2).

Mathematical Model for Calculating Occlusive IOL Transmission at SLO/OCT Operational Wavelengths

We used data from the exponential gradient of transmission from 750 to 800 nm for each of the occlusive IOLs, to create a mathematical model to calculate the theoretical percentage transmission at any wavelength of light. The formula is presented in Table 2A, and the calculated constants for black small PMMA, large PMMA, and Lotus lenses are given in Table 2B and include the theoretical wavelength of light at 50% transmission (T_{50}), the gradient of the exponential phase of transmission (k), and error calculations (SS regression and R^2 value). We used data available from manufacturers of commercially available SLO/OCT scanners to calculate on the basis of this model, the theoretical percentage transmission through these occlusive media of operational wavelength NIR light used by these scanners. These calculations suggest that using any of the SLO/OCT scanners listed in this study would achieve 99% to 100% transmission of operational wavelength NIR light, with the exception of the laser (L)SLO function of the Cirrus OCT system (Carl Zeiss Meditec), which transmitted at 1% to 2%, using the mean NIR light source wavelength (a superluminescent diode, with an average wavelength of 750 nm). We predicted therefore that the remaining SLO/OCT imaging systems could be used to acquire high-quality images with any of the studied occlusive media (Table 3).

Acquiring SLO/OCT Images through Occlusive IOLs in a Model Eye

All SLO/OCT imaging systems were able to identify the elevated optic disc and dual-layered retinal profile through both the PMMA and Lotus occlusive IOLs with both SLO and OCT functions, including the LSLO function of the Zeiss OCT system (Fig. 5). Six SLO/OCT scanning systems (manufactured by Carl Zeiss, Optovue, Biophtigen, Canon, Opko, Heidelberg Engineer-

FIGURE 4. Transmission spectra of occlusive IOLs based on the model data presented in Table 2. The sigmoid curves demonstrate the cutoff wavelengths for each occlusive IOL and the threshold wavelengths for 100% transmission. Between these extremes, the sigmoid curves demonstrate differences in the exponential phase of spectral transmission. The PMMA lenses (small and large) demonstrated similar properties according to this lens model (with the curve for the large PMMA lens displaced to the left of small PMMA lenses) when compared to Lotus lenses. Note the high levels of transmission at 820 to 870 nm at the operating frequencies of clinically used SLO/OCT scanners.

FIGURE 5. SLO/OCT imaging through occlusive IOLs in a model eye. Each panel of images is a paired SLO fundus scan (*left*) and OCT line scan (*right*) acquired by experienced technicians through black PMMA and black Lotus occlusive IOLs with seven clinically used SLO/OCT imaging systems in the model eye. Control images represent those captured without any occlusive IOL in situ. The dual-layered model eye retina and optic disc profile can be visualized through occlusive IOLs without apparent attenuation in quality of image with the Zeiss, Optovue, Biotigen, Canon, Opko, and Heidelberg imaging systems. The Topcon SLO/OCT imaging system was able to visualize the dual-layered OCT retinal profile and optic disc images through occlusive IOLs, although an automated focusing system resulted in relatively poor adaptation to the model eye. In addition, the SLO images were not possible through occlusive IOLs with the Topcon imaging system due to fundus photography with a white light source resulting in a true color SLO image in the control eye. In other imaging systems, paired SLO/OCT images reveal sensitive detection and correlation between optic disc profile (OCT) with the optic disc image on the fundus (SLO). Incidentally, the fine surface retinal vessels present on the inner retinal layer were demonstrated where the SLO/OCT scans intersected them, particularly in the three Heidelberg scans. Optical shadows were projected onto the inner retinal layer beneath the identified retinal vessels. Zeiss, Optovue, and Topcon OCT images are presented in pseudocolor. The lines on the SLO images correspond to plane of tomography of the paired OCT images.

ing) were able to acquire high-quality SLO and OCT images without any obvious attenuation of features or image quality through the black PMMA or black Lotus occlusive IOLs. The Topcon imaging system was not able to acquire SLO images through occlusive IOLs, as it uses visible-spectrum white light at wavelengths that the occlusive IOLs do not transmit. In addition, this imaging system is largely automated to the human eye (it uses the precorneal tear film as an imaging reference point) and was less able to adapt to the properties of the model eye. However, the Topcon system acquired OCT line scans through occlusive IOLs to identify the model optic disc and retina with an NIR light source. In addition, surface retinal vessels were detected with all imaging systems when OCT line

scans intersected them, visible in presented images as a fine elevation on the retinal surface with an optical shadow formed consequently on the deeper retinal layer. These fine details are identified through occlusive IOLs with the Heidelberg, Biotigen, Opko, and Zeiss imaging systems in the presented images in Figure 5.

DISCUSSION

This study demonstrated for the first time the presence of an NIR window of transmission across the occlusive IOL. All the Morcher occlusive lenses studied demonstrated high levels of

TABLE 3. SLO/OCT Imaging through Occlusive IOLs

Manufacturer	SLO/OCT Model	Function	Mean Light Source (nm)	Black PMMA (Small) IOL Transmission (%)	Black PMMA (Large) IOL Transmission (%)	Black Lotus IOL Transmission (%)
Carl Zeiss Meditec	Cirrus HD-OCT	OCT	Mean 840	100	100	100
		LSLO	Mean 750	1	2	2
OptoVue	iVue	OCT	Mean 840	100	100	100
		SLO	Mean 840	100	100	100
Bioptigen	3D SDOCT	OCT	Mean 840	100	100	100
		SLO	Mean 840	100	100	100
Canon	SPOCT HR OCT	OCT	Mean 850	100	100	100
		SLO	Mean 850	100	100	100
Topcon	3D OCT-2000	OCT	Mean 840	100	100	100
		SLO	White light	0	0	0
Opko	Spectral OCT/SLO	OCT	Mean 830	100	100	100
		SLO	Mean 830	100	100	100
Heidelberg Engineering	Spectralis OCT	OCT	Mean 870	100	100	100
		SLO	Mean 820	99	99	100

Shown are the calculated percentage transmissions of operational NIR wavelength light by the occlusive IOLs at commercial SLO/OCT wavelengths. Transmission at peak light source emission was determined by using the model of transmission in Table 2A.

transmission across the NIR range (99%–100%) and consequently all clinically used SLO/OCT imaging systems were capable of capturing high-quality retinal images through occlusive media, permitting assessment of the macula, optic nerve head, and central retina without apparent attenuation in image quality.

Before this discovery, B-scan ocular ultrasonography was the only posterior pole imaging technique available for this patient group to establish the presence of retinal detachment or advanced intraocular malignancy—the relatively few pathologies that ultrasound scanning is able to detect.¹⁵ We have identified the most sensitive posterior segment imaging modality for patients with occlusive IOL prostheses, and this study is likely to permit a more detailed assessment of disorders of the macula, retinal vasculature, optic nerve head, and the retina.

The novel capacity to detect pathologic states in these structures is likely to permit identification of a broader range of posterior pole diseases in this patient group. The consequent management decisions may be complex, given that there may be less emphasis on treating potentially sight-threatening pathology in an occluded eye. However, in the setting of chronic bilateral disease—primary open-angle glaucoma, for example—it is possible to examine retinal nerve fiber layer integrity using NIR light based SLO/OCT, and evidence of optic neuropathy may necessitate antiglaucoma drug therapy to prevent ocular pain in the occluded eye. The capability of imaging through occlusive IOLs requires consideration from ophthalmologists who manage this patient group as to which should be contacted for SLO/OCT examination and with what degree of urgency. A patient at risk of intraocular malignancy who also has therapeutic occlusion with an occlusive IOL, for example, may benefit from regular SLO/OCT-based screening in the occluded eye. Clinicians responsible for this patient group must be made aware of the capability of SLO/OCT imaging discovered in this study, so that a thorough examination of posterior pole structures can be undertaken to guide further management as appropriate when such patients present for follow-up.

Although occlusion of visible light is the function of occlusive IOLs, it must be considered that in patients with intractable diplopia who have two independently functioning eyes, sight-threatening disease in the unoccluded eye may require therapeutic lens exchange to transparent media. In this setting, preoperative SLO/OCT imaging permits an assessment of structural macular and retinal integrity before intraocular surgery is undertaken with its inherent risks to sight.¹² If SLO/OCT as-

essment demonstrates a severe macula-off retinal detachment, a long-standing macular hole or other gross structural posterior segment abnormalities, this information may inform ophthalmologists of the likely visual potential in the occluded eye before surgery which may assist in the informed consent of these patients and the necessity of the IOL exchange procedure.

It was recently reported that macular imaging through the occlusive PMMA IOL (Morcher GmbH) was possible with the Spectralis SLO/OCT (Heidelberg Engineering Inc.).¹² The wavelength of light used by the Spectralis OCT scanner is in the NIR range at 870 nm, with SLO functioning around 820 nm.¹⁶ Spectral transmission analysis and the mathematical model of lens transmission presented (Table 2A) suggest a transmission of 100% at 870 nm and 99% at 820 nm through the PMMA occlusive IOL. The excellent SLO/OCT images taken through the occlusive IOL¹² are therefore consistent with our data, and this study describes a scientific basis for the described observation in this report (Patel et al.¹²).

Occlusive IOLs are also available in an Artisan phakic anterior chamber iris-claw IOL (Ophtec BV, Groningen, The Netherlands), and further study must evaluate whether this IOL can be similarly optically penetrated for diagnostic purposes with NIR light.

Patients with occlusive IOL media in situ, due to their limited indications and concerns about establishing retinal and macular status, are infrequent.¹⁵ Many ophthalmic units possess a single SLO/OCT scanner, and we suggest that any imaging system presented in this study should be capable of acquiring high-quality images with any of the studied occlusive media. Monitoring retinal, macular, and optic disc status in this patient group would be practical, since it is likely that existing departmental SLO/OCT scanners could be used to acquire high-quality images, without having to purchase additional hardware or ask patients to travel to a particular scanner.

It is notable from the theoretical predictions of IOL transmission presented in Table 3 that the LSLO function of the Cirrus HD-OCT (Carl Zeiss Meditec) predicts 1% to 2% of light at its mean wavelength of 750 nm to optically penetrate Morcher occlusive IOLs, and yet LSLO images were obtained through occlusive IOLs. The likely explanation for this observation is that the Cirrus LSLO light source is a superluminescent diode that has a wide spectral bandwidth (100–150 nm), and it is likely that the spectral output extends into the NIR wavelength range that is able to optically penetrate all Morcher occlusive IOLs to illuminate the retina and macula sufficiently

to attain the presented LSLO images. Therefore, although the mathematical model presented is useful as a means of theoretical prediction for monochromatic light sources, imaging systems with a lower wavelength light source may be capable of quality imaging through an occlusive IOL in vivo, provided the spectral bandwidth of the light source is sufficiently wide. The Topcon 3D SLO function uses a white light source and consequently was not able to image through occlusive IOLs in this study, as other instruments using an equivalent light source (e.g., direct and indirect ophthalmoscopes) are similarly unable to image posterior segment structures.

The discovery of a window of NIR light transmission through occlusive IOLs suggests a variety of potential clinical applications relating to visual assessment, since the occlusive IOLs transmit NIR light both in an anterograde and retrograde fashion. Where an SLO/OCT scanner is unavailable, it would be conceivable to use an NIR LED with a digital camera that is sensitive into the NIR range. Alternatively, a bright NIR LED or equivalent light source that transmits in the NIR range (such as the LED used in this study) could be used to assess visual fields in a manner analogous to conventional visual field analysis in response to confrontation with a red hat pin.

The NIR LED used in this study was visible to the unaided eye when switched on, despite the LED operating at a wavelength beyond that described by some as perceptible to humans (400–700 nm). We confirmed that the spectral output of this source does not extend below 750 nm (Supplementary Fig. S2, <http://www.iovs.org/lookup/suppl/doi:10.1167/iovs.10.6767/-/DCSupplemental>), presumably owing to stimulation of the long-wavelength limb of the red cone absorption spectrum. Based on the visual pigment template in Govardovskii et al.,¹⁷ at 750 nm, the absorption is expected to be more than 11,000 times lower than at 557 nm (red cone, λ_{max}). A cone threshold of 10 log quanta¹⁸ would require providing a threshold of 14 log quanta at 750 nm. In addition, we were able to visualize the NIR LED through the occlusive media, suggesting that patients with structurally normal or functional retinas and IOLs in situ would be able to perceive the NIR light source.

The presence of an NIR window has not been reported to have any adverse consequences or optical distraction in this patient group, and there has been no impact on the high rates of postoperative satisfaction in follow-up studies in the setting of intractable diplopia.⁸ We suggest that these patients should be able to detect intense ambient light sources that possess a strong NIR component, as suggested.

Should the use of occlusive IOLs increase as a result of this study, it may become necessary to design and manufacture NIR light-based assessment tools for this group of patients, such as formal perimetry, Amsler's grids, and Snellen charts, in addition to NIR LED instruments for the purposes of visual field assessment which may change the nature of assessment and management of ophthalmic disease in this patient group.

Occlusive IOL insertion has been demonstrated to be an effective treatment in the management of intractable diplopia,^{2,8} with ophthalmologists agreeing on their efficacy across these indications.¹⁹ The reluctance of ophthalmologists to institute a treatment, previously considered as hindering the diagnosis of posterior pole disease,¹⁹ has resulted in the use of occlusive IOL implantation after other occlusive strategies, which do not necessarily confer the same rates of patient satisfaction, have been exhausted.^{1,2,4,8,9,13}

We suggest that this study may fundamentally change the way occlusive IOLs are regarded in the setting of intractable diplopia, encourage their consideration at an earlier stage, and decrease the reluctance of specialists to implant them, as previous anxieties surrounding posterior segment imaging, as discussed, should no longer influence clinical judgment. Ac-

cordingly, the nature of informed consent in patients potentially eligible for occlusive IOLs insertion should be fundamentally changed to reflect the findings of this study.

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