

Images created in a model eye during simulated cataract surgery can be the basis for images perceived by patients during cataract surgery

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Abstract

Purpose To evaluate the images created in a model eye during simulated cataract surgery.

Patients and methods This study was conducted as a laboratory investigation and interventional case series. An artificial opaque lens, a clear intraocular lens (IOL), or an irrigation/aspiration (I/A) tip was inserted into the 'anterior chamber' of a model eye with the frosted posterior surface corresponding to the retina. Video images were recorded of the posterior surface of the model eye from the rear during simulated cataract surgery. The video clips were shown to 20 patients before cataract surgery, and the similarity of their visual perceptions to these images was evaluated postoperatively.

Results The images of the moving lens fragments and I/A tip and the insertion of the IOL were seen from the rear. The image through the opaque lens and the IOL without moving objects was the light of the surgical microscope from the rear. However, when the microscope light was turned off after IOL insertion, the images of the microscope and operating room were observed by the room illumination from the rear. Seventy percent of the patients answered that the visual perceptions of moving lens fragments were similar to the video clips and 55% reported similarity with the IOL insertion. Eighty percent of the patients recommended that patients watch the video clip before their scheduled cataract surgery.

Conclusions The patients' visual perceptions during cataract surgery can be reproduced in

the model eye. Watching the video images preoperatively may help relax the patients during surgery.

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Introduction

More than 80% of patients who have undergone cataract or vitreous surgery have reported experiencing visual sensations during the surgery.^{1–10} The visual sensations include flashing white or colored lights, movement of objects and instruments, and the surgeon's fingers or hands.^{1–5} About 60% of the patients who reported seeing movements or moving objects also saw objects that resembled surgical instruments.^{11–14}

Although most of the descriptions have been verbal, one patient expressed her cataract surgical experiences through two paintings; one consisted of pink and blue rings, and the second consisted of a bright orange line she perceived for a short time.⁶ The author suggested that these images represented the movement of a phacoemulsification probe into the eye with a possible stimulation of the color photoreceptors by the ultrasonographic energy.⁶ However, similar experiences have been described by patients who underwent extracapsular extraction without ultrasonography.^{5,15} Another patient was a professional computer graphics artist who underwent intravitreal surgery for an epiretinal membrane.¹⁶ His drawings corresponded relatively accurately with the

intraocular instruments used during different phases of vitrectomy.

Despite these reports, the exact mechanism causing these sensations has not been determined because of the difficulty in reproducing the images. At present, the best evidence suggests that these sensations are created by the shadows cast by the instruments inserted into the anterior chamber during cataract surgery or during vitrectomy.¹⁷ Similarly, the entopic images of the eyes have been reported to arise from the shadows cast by tissue fragments floating in the vitreous of the eye.¹⁸ However, the exact images falling on the retina during the different phases of cataract surgery have not been determined.

Thus, the aim of this study was to try to reproduce the images that stimulate the retina and give rise to the visual perceptions experienced by patients during cataract surgery. To accomplish this, we used a model eye with a frosted posterior surface and recorded the images formed on it. Objects were placed in the 'anterior chamber' of the model eye, and the images formed on the frosted surface were recorded from the rear of the model eye. In addition, the anterior chamber of the model eye was photographed through the operating microscope during the simulated cataract surgery.

Materials and methods

Model eye

A model eye was constructed based on Gullstrand's model of the human eye (Figure 1). The body of the eye was made of metal with an axial length of 24 mm. The power of the objective lens (cornea) was 44.0 diopters (D), and its central thickness was 0.5 mm. The spherical aberration of the cornea was $+0.22 \mu\text{m}$, which is comparable to the spherical aberration of the human eye. The diameter of the pupil was 7.0 mm, and the anterior chamber depth was 5 mm. The cornea and the posterior surface of the model eye were made of transparent

polymethylmethacrylate. The inner surface of the posterior surface was uniformly frosted by sandblasting with air pressure of 1 atm so that images on the surface could be seen from the rear.

The model eye was filled with balanced salt solution at room temperature with care taken to remove all air bubbles. The eye was placed so that the light from a surgical microscope entered the pupil along the optical axis of the model eye as during cataract surgery. The eye was set so that the optic axis was vertical. A digital camera (EOS KISS X3, Canon, Inc., Tokyo, Japan) was set beneath the model eye and aligned and focused on the center of the frosted posterior surface. The video images and picture images cast on the frosted surface were recorded by the digital camera during simulated cataract surgery with a superior approach (surgeon sitting at 12 o'clock position to the patient's head). The images of the objects in the anterior chamber as seen through the surgical microscope (OPMI VISU210, Carl Zeiss Meditec, Tokyo, Japan) were simultaneously recorded with a video camera in the microscope with the focus on the objects in the anterior chamber. The intensity of the xenon light of the microscope was set at 0.7, which is used regularly for cataract surgery. The surgical microscope was set for the surgeon's view in the superior approach to look down the model eye from the 12 o'clock position, and the images of the objects in the anterior chamber seen by the surgeons through the surgical microscope were inverted to the model eye. The position of the digital camera was inverted because the images projected on the human retina are inverted images, and the images are re-inverted in the brain.

Images through different types of opaque lenses and clear IOL in the model eye

Four types of lenses were implanted in the model eye: one simulating a moderate cataract; one simulating a

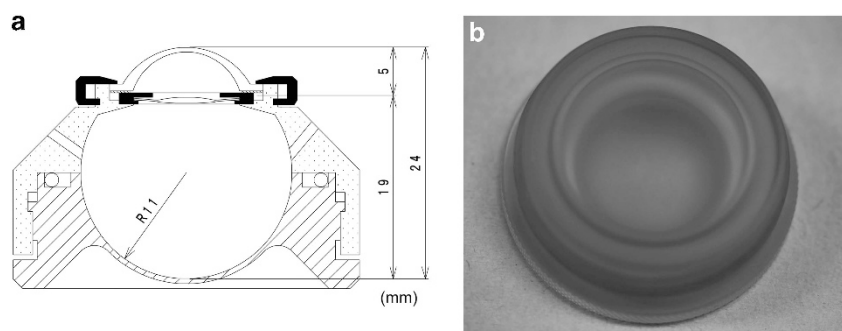


Figure 1 Cross-sectional drawing and photograph of the model eye used to study the images created on the posterior surface, which corresponds to the retina of the eye. (a) Schematic drawing of the model with $+0.22 \mu\text{m}$ spherical aberration of the cornea, which is comparable to the spherical aberration of the human eye. (b) View of the inner frosted surface of the model eye made of transparent polymethylmethacrylate.

dense white cataract; and one simulating a divided white cataract; and a commercial intraocular lens (IOL, SA60AT, +20.0D, AcrySof, Alcon Laboratories, Fort Worth, TX, USA). The simulated opaque lenses had a diameter of 9.5 mm and a thickness of 3 mm, and they were made of silicone mixed with white dye before molding. For the divided lens, a white opaque lens was cut into four pieces as in the human cataract lens that is divided during cataract surgery. Each lens was placed on a thin plastic sheet (artificial posterior lens capsule) and attached to the aperture of the model eye with a diameter of 10 mm. Another aperture with an inner diameter of 7 mm, which simulated the iris, was placed over the anterior surface of the opaque lens and the IOL. Then, the model eye was filled with balanced salt solution. The images of objects inserted into the anterior chamber that formed on the frosted posterior surface were photographed. The images on the frosted surface taken from the rear were compared with those of the objects in the anterior chamber taken through the operating microscope.

Images formed during simulated cataract surgery in the model eye

An irrigation and aspiration (I/A) tip was inserted through a 2.0 mm hole in the peripheral cornea. The three pieces of the divided silicone opaque lenses were rotated in the anterior chamber by the I/A tip with the light of the microscope turned on. The IOL was inserted through the hole in the cornea with a cartridge (Cartridge D. Monarch III) filled with viscoelastic material. After the IOL was inserted, the viscoelastic material was removed with the I/A tip. The images formed on the posterior surface during simulated cataract surgery were recorded from the rear and the images through the microscope were simultaneously recorded. The images from the rear were compared with those recorded through the microscope.

Postoperative evaluations of photographs and video images by patients who were shown them before cataract surgery

A prospective study was conducted on 20 consecutive patients who were scheduled to undergo phacoemulsification aspiration and IOL implantation on their first eye. The cataract surgery was performed under 0.5% tetracaine hydrochloride topical anesthesia without any tranquilizer or intravenous anesthesia. A clear corneal incision was made at the temporal limbus and the lens nucleus was divided into at least four pieces by a phaco-chopper and phacoemulsified. An acrylic IOL (SN60WF, AcrySof, Alcon Laboratories) was inserted.

The video images (see Supplementary videos 1 and 2) formed through the opaque lens and taken from the rear during simulated cataract surgery were shown to the 20 patients aged 42–82 years (mean \pm SD; 69.4 ± 10.5 years) before the cataract surgery. Immediately after the surgery, the patients were requested to answer a questionnaire on their experiences during the surgery on whether the images of the video clips resembled those that they experienced during the surgery (Table 1). The still photographs and video images in the model eye were taken for the superior approach, and they were rotated to adjust to the temporal approach. The perception of the light, video images of the divided lens fragments rotated with the I/A tip (video clip 1), video images during the insertion of the IOL (video clip 2), video images of removal of the viscoelastic material after IOL was inserted (video clip 2), and video images after the light of the microscope was turned off (video clip 2) were evaluated. The direction of insertion of the I/A tip into the anterior chamber and images after IOL insertion were evaluated. The patients were also asked whether they had any apprehension or pain during the surgery, and whether they would recommend that other patients watch the video clips before their surgery. The degree of pain was compared with that of apprehension to evaluate whether the patients awakened during surgery.

Results

Images of opaque lenses and clear IOL implanted in the model eye recorded from the rear and through the surgical microscope

The images of the silicone opaque lenses in the anterior chamber taken through the operating microscope and the images formed on the posterior surface of the model eye are shown in Figure 2. The image formed on the posterior surface of the model eye through the opaque silicone lens was that of the light of the microscope. With the more opaque silicone lens, the image of the microscope light was more diffused. A blunt 27-gauge needle was inserted through a hole in the peripheral cornea, and the needle was moved circularly on the surface of the silicone lens as in circular capsulorhexis. Examination of the video images taken from the rear did not show an image or movements of the needle.

A cross-like light image was seen through the divided white lens in the still photographs from the rear (Figure 2). The cross-like light was observed as the light of the microscope from the gaps between the divided lenses. The orientation of the light passing through the gaps between the divided lenses indicated that the

Table 1 Questionnaire of visual sensation during the cataract surgery

<i>Question 1. Did you see any light or images during the surgery?</i>	
1. Yes	20 eyes (100%)
2. No	0 eye (0%)
<i>Question 2. How similar was the simulation video (clip 1) to what you have seen during cataract lens removal and when you were told 'you may feel something being pressed to your eye' at the beginning of the surgery?</i>	
1. Same	1 eye (5%)
2. Similar	13 eyes (65%)
3. Different	6 eyes (30%)
4. Do not know	0 eye (0%)
<i>Question 3. How similar was the simulation video (clip 2) to what you have seen when the intraocular lens was inserted and when you were told to 'we will implant the intraocular lens to your eye'?</i>	
1. Same	1 eye (5%)
2. Similar	10 eyes (50%)
3. Different	5 eyes (35%)
4. Do not know	2 eyes (10%)
<i>Question 4. Which direction of your eye did you see the shaft-like material enter your eye?</i>	
1. Temporal side	11 eyes (55%)
2. Nasal side	0 eye (0%)
3. Do not know	9 eyes (45%)
<i>Question 5. How similar was the photo from the simulation video to what you have seen when you were told 'the intraocular lens was implanted successfully'?</i>	
1. Same	4 eyes (20%)
2. Similar	6 eyes (30%)
3. Different	3 eyes (15%)
4. Do not know	7 eyes (35%)
<i>Question 6. Did you feel apprehension when you could see something during the surgery?</i>	
1. Not at all	13 eyes (65%)
2. Not so much	3 eyes (15%)
3. Felt fear	4 eyes (20%)
4. Felt fear strongly	0 eye (0%)
5. Do not know	0 eye (0%)
<i>Question 7. Did you feel pain during the surgery?</i>	
1. Not at all	4 eyes (20%)
2. Not so much	5 eyes (25%)
3. Felt pain	10 eyes (50%)
4. Felt pain strongly	1 eye (5%)
5. Do not know	0 eye (0%)
<i>Question 8. Do you think watching the video before surgery helped to relax you?</i>	
1. Not at all	0 eye (0%)
2. Not so much	5 eyes (25%)
3. I agree so	9 eyes (45%)
4. I strongly agree so	4 eyes (20%)
5. Do not know	2 eyes (10%)
<i>Question 9. Do you recommend other patients to watch the simulation video clips before they will have cataract surgery?</i>	
1. Yes	16 eyes (80%)
2. No	4 eyes (20%)

images from the rear were a mirror image of that seen through the surgical microscope.

With the IOL, the image from the rear was an image of the microscope light with a sharper margin compared with the images through the opaque lens (Figure 3).

When the microscope light was turned off, the view recorded by the rear camera became darker, and an image of the microscope and the ceiling of the illuminated operating room were seen. After the microscope was removed and the surgeon looked down

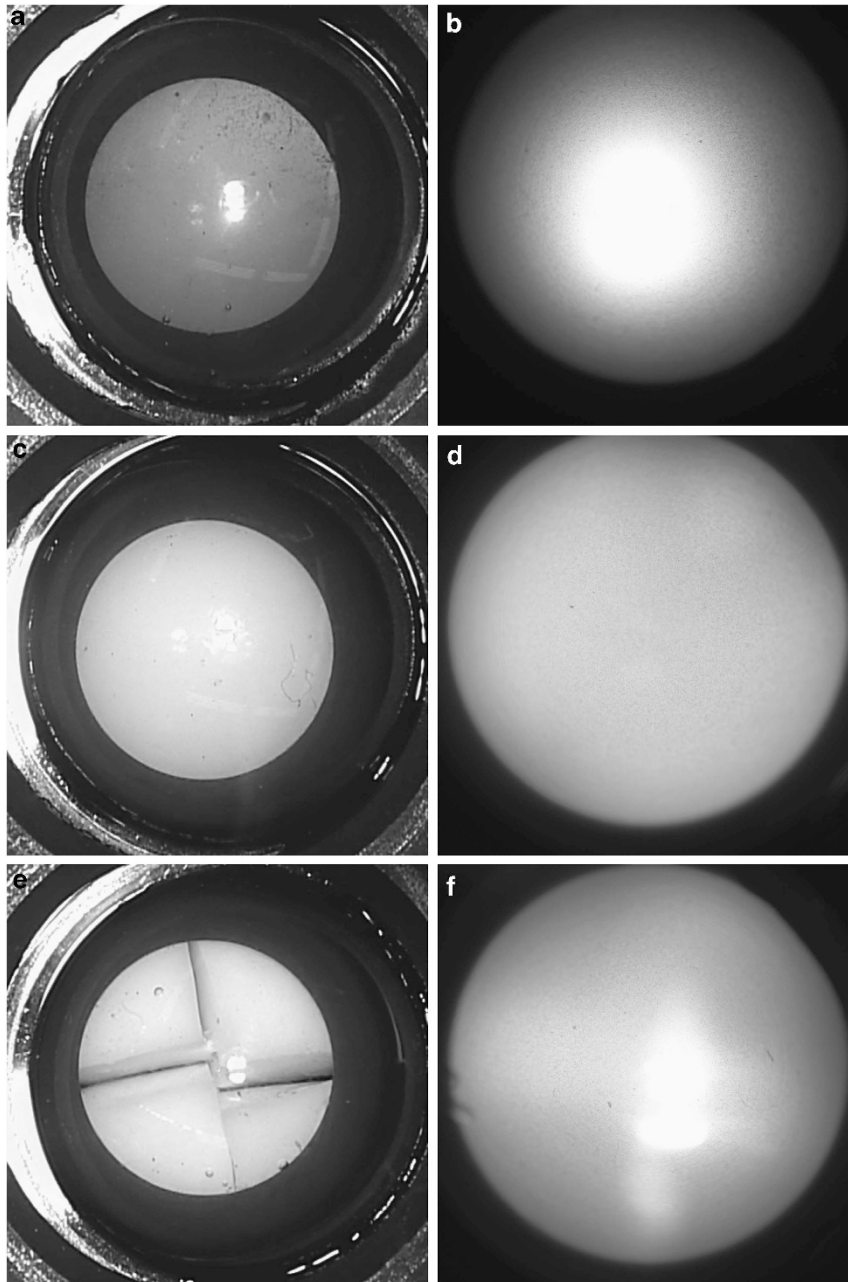


Figure 2 Surgeon's view and rear view of the images through opaque lenses (left column: surgeon's view with microscope focused on the anterior chamber; right column: rear view of the model eye). (a) Opaque lens placed in the anterior chamber of the model eye is observed through the microscope focused on the anterior chamber. (b) The image from the posterior view through the opaque lens is a centered bright and blurred image. (c) White opaque lens placed in the anterior chamber of the model eye is observed from the microscope. (d) Image through the white opaque lens is a diffuse bright light without any image. (e) Divided white opaque lens placed in the anterior chamber of the model eye is observed from the microscope. (f) Image through the divided white opaque lens is a cross-like light transmitted from the gaps between the divided lenses.

into the model eye, an image of the surgeon looking into the model eye under the room illumination was seen in the video images. These images that were located outside of the model eye were seen in a right direction and not inverted.

Images recorded during simulated cataract surgery

The insertion of the I/A tip through a hole in the cornea could be clearly seen through the operating microscope. A rotation of the divided opaque lens with the I/A tip in

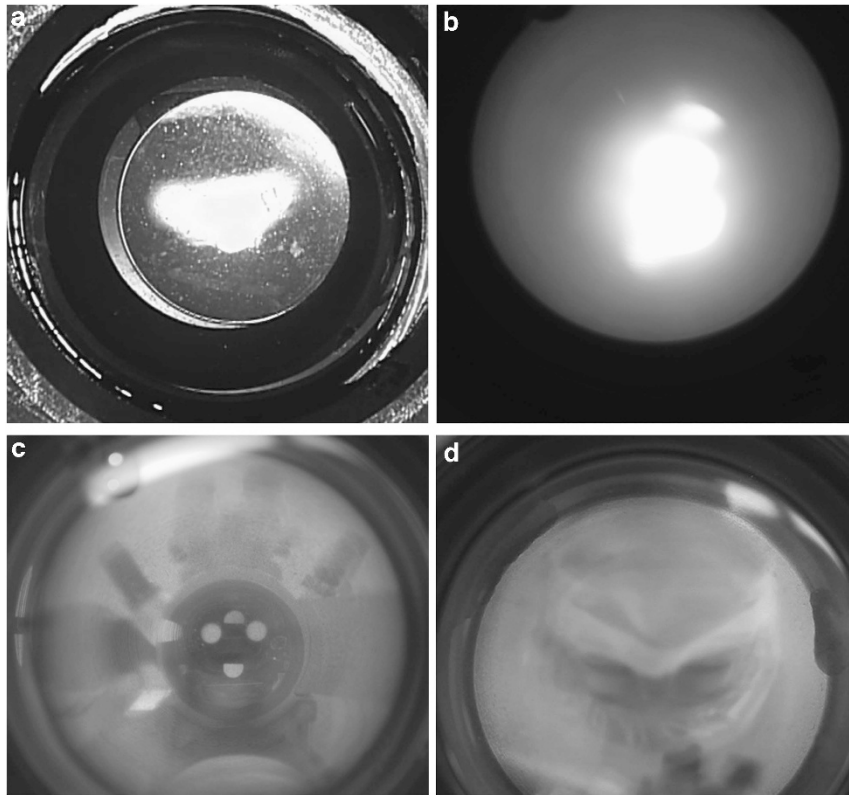


Figure 3 Surgeon's and rear view of the images through the intraocular lens (IOL). (a) The image of the surgeon's view of an IOL placed in the anterior chamber of the model eye observed from the microscope. (b) The rear view through the IOL is the bright light in the center without any clear image, but the margin of the light is more focused with better contrast compared with that through the opaque lens (see Figures 2b and 2d). (c) The image from the rear view with the microscope light turned off is an image of the microscope and the ceiling of the illuminated operating room. (d) The image from the rear view after the microscope is removed is an image of the physician's face when the model eye is looked down from above.

the anterior chamber could also be seen from the rear (Figure 4). The direction of insertion of the I/A tip in the images from the rear was inverted because the I/A tip was inserted from superior side of the model eye and the images from the rear were mirror images of the surgeon's view. The images of the divided lens and I/A tip taken from the rear were slightly enlarged compared with the images through the microscope against the diameter of the dark rim of the aperture of the model eye. The images of the periphery were not seen in the photographs taken from the rear. When the divided opaque lenses were rotated by the I/A tip in a clockwise direction, the cross-like light moved in a counter-clockwise direction from the rear and the I/A tips appeared to be blinking lights.

When the IOL was inserted into the anterior chamber, the images from the rear showed that the IOL could be seen to be ejected and unfolded in the anterior chamber. The preceding and following optics were seen unfolding in the anterior chamber in the images formed on the frosted surface from the rear. When the viscoelastic material in the anterior chamber was removed with the I/A tip, the water stream of irrigating solution from the

I/A tip could be seen from the rear. These images from the rear were also mirror images of the images seen through the microscope.

Analysis of answers to the questionnaire after cataract surgery

All 20 patients (100%) observed some light and/or images during the surgery (Table 1). Seventy percent of the patients reported that the visual perceptions were exactly the same or similar to the images in the video clip 1 taken from the rear of the model eye when the divided lens fragments were rotated with the I/A tip. Fifty-five percent of the patients answered that the visual perception was exactly the same or similar to the images in video clip 2 taken from the rear of the model eye when the IOL was inserted and the viscoelastic material was removed with the I/A tip. Fifty-five percent of patients answered that the direction from which the shaft-like material was inserted in the eye was 'from the temporal side' but none answered 'from the nasal side.' However, from an analysis of the model eye, the direction of the

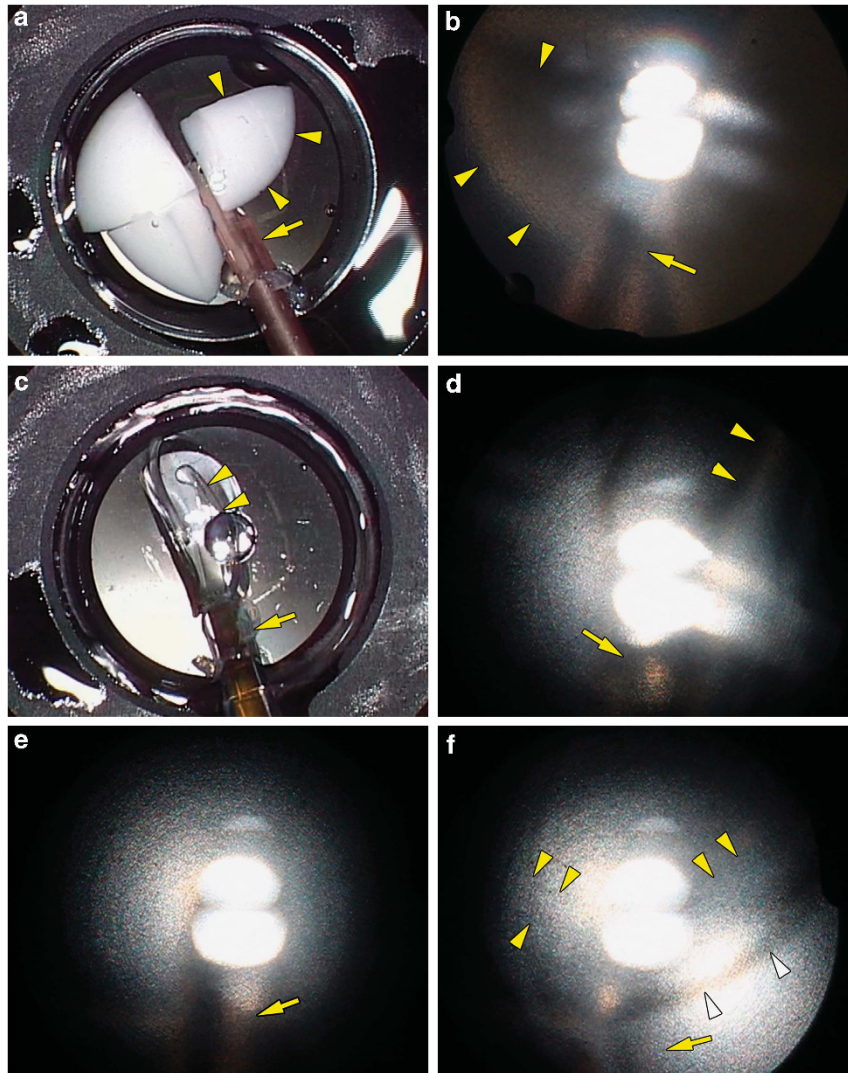


Figure 4 Surgeon's view and rear view of the images during different procedures through opaque lenses or intraocular lenses (IOLs). (a) Surgeon's view of divided white opaque lenses (yellow arrowheads) placed in the anterior chamber of the model eye and the irrigation/aspiration (I/A) tip (yellow arrow) observed from the microscope. (b) Rear view of divided white opaque lens (yellow arrowheads) and the I/A tip (yellow arrow). (c) Surgeon's view of an IOL folded in the cartridge (yellow arrow) inserted with the haptics (yellow arrowheads) folded in the anterior chamber. (d) Rear view of the folded haptics (yellow arrowheads) and the cartridge (yellow arrow) are evident. (e) Image of the rear view from when the viscoelastic material was removed by the I/A tip (yellow arrow) but before irrigation. (f) When the irrigation of the I/A tip was on, the water stream (yellow arrowheads) from the I/A tip (yellow arrow) and the optics of the IOL (white arrowheads) are observed from the rear view.

shaft-like material entering into the eye was suggested to be from the nasal side.

Sixty-five percent of the patients did not have any apprehension from what they experienced during the surgery and 15% expressed slight apprehension. Eighty percent of the patients did not have any or had mild apprehension but none of the patients had severe apprehension. Fifty percent of the patients felt moderate pain during the surgery and 5% of the patients felt severe pain. The percentage of patients who felt apprehension from the visual experiences (4 of 20 eyes) was significantly lower than that of the patients who felt pain

(11 of 20 eyes, $P=0.048$, Fisher's exact probability test). Forty-five percent of the patients agreed and 20% of the patients strongly agreed that watching the video clips preoperatively helped them be more relaxed during the surgery. Eighty percent of the patients recommended that patients about to undergo cataract surgery watch the video clips preoperatively.

Discussion

Our results showed that the objects and instruments in the anterior chamber formed on the frosted posterior

surface were seen as defocused dark masses or dark shafts illuminated by the light from the microscope. The outlines of the tips of these instruments were not as sharp as those seen during vitreous surgery.^{12–14} In addition, they were not as sharp as the images recorded during simulated vitrectomy in the model eye,^{16,17} in which the instruments were closer to the posterior surface. The greater distance of the instruments in the anterior chamber to the posterior surface made the images cast on the posterior surface more blurred. We have examined the images in phakic, pseudophakic, and aphakic (through the gaps of the divided lens) eyes from the rear of the model eye. The images from the rear were similar, which indicates that the presence of the IOL in the anterior chamber does not affect vision experienced by patients during surgery with the light from the microscope.

After the IOL was implanted and the light of the microscope turned off and moved off the visual axis of the model eye, the images of the illuminated operating room were seen more clearly. Thus, the bright light from the microscope probably hampered the formation of the images outside the eye. This was also true for the intracameral lens fragments and instruments during the simulated cataract surgery.

The visual experiences of the patients have been reported to be a combination of images of objects close to but outside the eye, and also included the entopic phenomena produced by objects and structures on the corneal surface and in the eye. Moving objects such as moving fluids and bubbles on the corneal surface and in the eye, moving instruments in the eye, and emulsified and aspirated lens fragments probably produce the changing colors and shapes reported by some patients.^{6,19} We suggest that the basic mechanism causing the visual perceptions in patients undergoing cataract surgery and vitrectomy are similar to that which gives rise to entopic images: for example, vitreal floaters.¹⁸ However, other factors may also contribute to the visual perceptions in patients.

The Troxler phenomenon is described as the gradual perceptual disappearance of an image stabilized at an eccentric retinal location after several seconds, and its instantaneous reappearance if the fixation position changes.²⁰ This fading and reappearance of the objects is one of the reasons why the moving instruments were detected more frequently. The entopic phenomenon disappears when the eye is held steady during the cataract surgery. The McCollough effect is a phenomenon of human visual perception, in which colorless gratings appear colored depending on the orientation of the gratings.²¹ The McCollough effect is a persisting after-effect, where the 'after-effects' are opposite to the original stimulus, consistent with the patient's description of

flying colors under the stimulation of colorless microscope light.¹⁹

The intraoperative visual perceptions reported by patients have been described to depend on the type of local anesthesia: namely, retrobulbar, subtenon, or topical anesthesia.^{13,22–24} However, we believe that the effects of anesthesia were minimal in our study because the patients were given only topical anesthesia without any additional retrobulbar, oral, or intravenous drugs. We had expected that the moving objects seen during cataract surgery would be more blurred compared with those reported during vitreous surgery because the instruments were further from the retina.^{5,16}

Our results also indicated that the images seen from the rear were vertically and horizontally inverted to the direction of the instrument entering the eye, which is compatible to that reported.^{6,16,25,26} Our patients who answered the questionnaire underwent cataract surgery with a temporal approach. Theoretically, the patients were expected to see the instruments entering from the nasal side. However, all the patients reported that the instruments entered from the opposite temporal side. We suggest that the visual experiences during the surgery were mixed sensations from being touched around the temporal side of the face by the surgeon, psychological expectation of the images of the instruments entering from the temporal side because the patients knew that the surgeon was sitting and operating on their temporal side. In addition, the visual images were blurred under the bright light from the microscope inhibiting clear identification of the direction of the inserting instruments.

There are limitations of this study. We evaluated the image projected onto a hemisphere of the model eye from the rear, and the images at the peripheral region may be defocused and distorted from the view of the digital camera focused on the center of the frosted posterior surface. In addition, the changes of the intraocular pressure during the surgery may affect subjective visual perception even though cataract surgery has been performed with lower infusion and aspiration pressure, but this visual perception cannot be reproduced in the model eye.

The visual experience during cataract surgery may frighten the patients during surgery, which may cause an intraoperative increase in blood pressure or quickening of the pulse.^{5,15,27,28} Thus, 20% of our patients had some apprehension during the surgery. However, the patients felt pain more frequently, and none of the patients felt apprehension strongly during the surgery. These patients watched the video clips preoperatively, and 65% of the patients agreed that watching the video clips helped to relax them during the surgery. In addition, 80% of the patients recommended that other patients see the video clips preoperatively.

In conclusion, the visual perceptions experienced during cataract surgery can be reproduced in the model eye. The bright light from the microscope may hamper the visibility of the images of the surroundings of the eye and the objects inserted into the anterior chamber during cataract surgery. However, the similarity was found between the photographic and video images projected on to the posterior surface of the model eye and the patient's visual experience during the surgery. To watch the video images preoperatively may help reduce apprehension for visual experiences during the surgery.

Summary

What was known before

- More than 80% of the patients who have undergone cataract or vitreous surgery have reported experiencing visual sensations during the surgery. The visual sensations include flashing white or colored lights, movements of objects and instruments, and the surgeon's fingers or hands.

What this study adds

- The patients' visual perceptions during cataract surgery can be reproduced in the model eye by recording video images projected on the frosted posterior surface corresponding to the retina. Seventy percent of the patients answered that the visual perceptions of moving lens fragments were similar to the video clips and 55% found similarity with the insertion of intraocular lens. Watching the video images preoperatively may help relax the patients during surgery because 80% of the patients recommended that other patients watch the video clips before scheduled cataract surgery.

Conflict of interest

The authors declare no conflict of interest.

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