During strabismus surgery using illumination from a light source, patients often complain of photophobia. The NGENUITY® (Alcon) system is equipped with a high-dynamic-range (HDR) camera. A 4K display viewed by wearing circularly polarized glasses provides clear three-dimensional images of the operative field. A light source is usually required for surgeries of the anterior segment (including strabismic surgery), but the digital processing function of the NGENUITY® system allows image display in relatively dark regions even without a light source. We devised a novel ‘lights-out’ surgery that does not use a microscope’s light source, and we examined the usefulness of this technique in 2 cases of strabismic surgery. We performed strabismus surgery using the NGENUITY® system in two patients between January and June 2018. The HDR function was used, and the aperture was opened to the maximum while the gain was adjusted. Surgery was conducted without using the microscope’s light source. We report the 2 cases’ results and evaluate the novel method. The surgeries were performed without problem even though the microscope’s light source was not used. The patients’ photophobia was alleviated. Lights-out surgery is a potentially useful modality for strabismus surgery.

**Key words:** head-up surgery, 3D vision system, high dynamic range, video enhancement, strabismus surgery

**During strabismus surgery using illumination from a light source, patients often complain of photophobia, and physicians must be mindful of the risks of phototoxic injury and dryness during the surgery. The NGENUITY® system (Alcon Laboratories, Fort Worth, TX, USA) is a three-dimensional (3D) visualization system for use in ophthalmic surgery. It was developed for the field of vitreoretinal surgery and launched in Japan on January 23, 2017. The system is equipped with a high-dynamic-range (HDR) camera. A film patterned retarder (FPR)-type 4K display ("4K" refers to the horizontal display resolution of approx. 4,000 pixels) viewed by wearing circularly polarized glasses allows the wearer to see clear 3D images of the operative field. Several reports about surgery conducted with the use of the NGENUITY® system and a 3D display have been published in recent years [1-6].

Using HDR technology, the NGENUITY® system is capable of displaying a surgical field brightly even when the aperture is closed and the amount of light is limited. Since this function also allows deepening of the depth of focus, it is possible to display clearly focused images from the keratoconjunctiva to the inferior oblique muscle located at the posterior side of the globe. However, for surgeries of the anterior segment—including strabismic surgeries—a light source is usually required. We hypothesized that by using digital processing, the NGENUITY® system could be used to display relatively dark regions even without a light source, to the extent that the images can be visualized. We devised a novel ‘lights-out surgery’ that does not use the light source of
the microscope, and we examined the usefulness of this method in two cases of strabismic surgery.

Patients and Methods

Between January and June 2018, we performed the lights-out surgery for strabismus using the NGENUITY® system in 2 patients at Okayama University Hospital. The surgeries were a lateral rectus muscle recession in one patient and an inferior oblique muscle recession in the other patient. We report the merits of the method based on the results of these 2 cases and evaluate the novel method.

We define 'lights-out surgery' as surgery conducted under the illumination of the operating room's general lighting and not using any surgical light or the light source of the microscope. Imaging was conducted by fully opening the NGENUITY® system's camera aperture to capture the maximum amount of light. With the illumination of the microscope turned off, digital processing was performed using the HDR function with regulation of the white balance by using the white balance card. Images with the brightness of the display regulated by adjusting the gain were displayed on a 3D monitor (55-inch OLED55E6P-U; LG Electronics, Seoul, Korea).

For a comparison of the illuminance provided by the possible minimum illumination from the halogen lamp of the microscope (Lumera-T, Carl Zeiss, Oberkochen, Germany) and without illumination from the microscope (but with room lighting), we measured the luminance of the surgical field 20 times with each set-up, using the perimeter's built-in light meter (Goldmann 940, Haag-Streit Holding, Koeniz, Switzerland) under the two conditions. The readings were corrected and converted for analysis.

Since the maximum value of measurement was 2,000 apostilb (asb), NGENUITY® polarized glasses were used as a filter, and the proportion of luminance reduced by the filter was corrected. For the conversion of luminance (asb) to illuminance (lux), the measured value was multiplied by 1/0.7. The data were compared using the Mann-Whitney U-test. A p-value < 0.05 was considered significant.

The patients' written informed consent was obtained for all surgical procedures. Permission has been obtained for use of the video images. The guidelines of the Declaration of Helsinki were followed. Approval for the study was obtained from the Ethics Committee of Okayama University Hospital (No. 1507-021). This work was supported by the JSPS KAKENHI, grant nos. JP23791987 and JP26861450.

Results

Both patients' surgeries were performed without problems even though the light source of the microscope was not used. Figure 1 provides photographs of the set-up for performing lights-out surgery. Figure 2 shows the main images of the surgical procedures over time for the lateral rectus posterior recession performed with lights-out surgery. There was no problem during the passing of the suture through the sclera.

Figure 3 shows the procedures of the inferior oblique muscle recession. Even when the inferior oblique muscle located behind the eyeball was manipulated, the HDR function displayed this region to an extent that allowed surgical procedures. The patients did not complain of photophobia during the surgeries. In addition, the need to supply saline for eye dryness was less without-exposure compared to with-exposure to the microscope's light source.

There was a significant difference (p < 0.05) in illuminance between without the microscope's light source (876 ± 71 Lx) and with the light source (5,270 ± 198 Lx), with a difference in the mean value of approx. sixfold. There were no intraoperative complications (Fig. 4).

Discussion

With the evolution of digital technology, we devised a lights-out surgery for strabismus that does not use the microscope's light source, surgical light, or special illumination. We used this novel method in two surgeries, and the results confirmed that lights-out surgery can be performed with no problem or intraoperative complications.

The 4K display has a resolution of 3,840 × 2,160 pixels (16 : 9), and the total number of pixels corresponds to four times that for full high definition (1,920 × 1,080 pixels). To display images in three dimensions, odd-numbered columns and even-numbered columns in descending order from the top are imaged separately to the left eye and right eye, respectively. As a result, the resolution is halved. Even though the resolution is halved, the resolution of one pixel from a distance of...
Fig. 1  The lights-out surgery.  
A,  Surgery scene.  
Black arrow: the HDR camera.  Black triangle arrow: The 4K screen surgical monitor with a 3D display.  White arrow: The assistant surgeon uses a binocular microscope.  White triangle arrow: The operator, who sees the surgical monitor;  
B,  Wearing circularly polarized glasses;  
C and D,  The situation without and with the light source of the microscope.

Fig. 2  Recession of left lateral rectus muscle by lights-out surgery.  
A,  Conjunctival incision.  There is no cornea reflection of the light source of the microscope;  
B,  The lateral rectus muscle is held with a muscle clamp.  Although the hand casts a shadow, it does not hinder the surgery;  
C,  The lateral rectus tendon is resected;  
D,  A suture is passed through the posterior site.  A 7-0 monofilament suture is used.  The surgical field is adequately exposed.  These photos were captured from the NGENUITY®, the 3D visualization system.

Fig. 3  Recession of left inferior oblique muscle by lights-out surgery.  
A,  The inferior rectus muscle (pink) is confirmed.  A shadow can be seen;  
B,  The inferior rectus muscle is exposed;  
C,  Surrounding connective tissues are detached, and the inferior rectus muscle is held by forceps;  
D,  A suture is conducted toward the site of recession.  A 6-0 multifilament suture is used.  The surgical field is adequately exposed.  These photos were captured from the NGENUITY®.
2 m corresponds to the minimum separable acuity at a visual angle of 0.6 min and visual acuity of 1.5, and this resolution was sufficient for digitally assisted surgery. HDR is an image processing technology capable of clearly displaying both areas that are darkened by shadows which would be displayed in black by conventional imaging, and areas that are too bright and would otherwise be displayed in white. Here we observed that during surgery, even in regions that were shadowed because of insufficient light, the HDR allowed the visualization of these regions to the extent that the surgery could be conducted safely and effectively.

In the field of vitreous surgery, various attempts have been made to reduce the intensity of illumination as much as possible from the viewpoint of minimally invasive surgery [5, 6]. Our present findings indicate that by using the NGENUITY® system, strabismus surgery can be performed without using special illumination for surgery. Notably, our two patients did not complain of photophobia, and we consider that this method is useful for the prevention of phototoxic injury and dryness during surgery. Although there is no report of phototoxic injury in strabismus surgery, phototoxicity and complaints of photophobia have been reported in short surgeries such as cataract surgery [7-9].

Since mydriasis occurs after sub-Tenon's anesthesia, surgery performed under such a condition is not entirely without risk of phototoxic injury. Caution must be exercised when performing strabismus surgeries such as anterior and posterior recessions of the horizontal rectus muscle, because a study that examined phototoxicity during surgery with a temporal approach found that the microscope's light source produced a hotspot of focal illumination on the fovea depending on the angle of the eye and the microscope [10]. Avoiding the unnecessary use of light sources is the best policy.

As a problem of the lights-out surgery, the depth of focus tends to become shallow when the aperture is widened. We observed that this effect was mild and did not hinder the surgeries. However, if a deeper depth of focus is desirable, closing the aperture to some extent may still provide sufficient visualization for conducting surgery. Another point is that since surgery is conducted under illumination by room lights, the hands and surgical instruments sometimes cast shadows (as shown in Fig. 1B), but again we found that this did not constitute a problem. During strabismus surgery using a microscope, the assistant usually sits at a right or left angle (90° position) to the surgeon. When using the NGENUITY® system, the view displayed on the monitor is at a different angle to the actual operative field seen by the assistant, which makes assistance more difficult. The assistant thus has to observe the surgical field from the assistant's scope in order to provide assistance. As a result, the assistant views the operative field directly from the assistant's scope without digital correction or a light source, and thus the operative field is dark and difficult to see. In the 2 surgeries, however, we found that the microscope's light source was not needed for the purpose of surgical assistance.

The advances in digital enhancement technology such as HDR and 3D display technology, which are used in the lights-out surgery, suggest that there may not be a need for expensive components for optical microscopes and light sources. In the near future, we may witness the arrival of a new era in which surgery is performed using a camera and 3D virtual reality (VR) glasses or a 3D monitor.

In conclusion, lights-out surgery is a potentially useful modality for strabismus surgery. However, further functional improvements considering the surgery assistant's view is desirable.

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