Special Focus on Cataract, Original Article

Contrast, visibility, and color balance between the microscope versus intracameral illumination in cataract surgery using a 3D visualization system

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Purpose: To compare image resolution and depth between the microscope versus intracameral illumination images during 3D heads-up cataract surgery. **Methods:** We collected 25 consecutive patients who had cataract surgery using the 3D viewing system. Based on bright, contrast, visibility, and color balance, the digital images (RGB color and three monochromes) extracted at the same point of the procedures were compared between the two illuminations. **Results:** Contrast values of green and blue channels except for red channel and visibility values of all three channels were higher in the intracameral illumination images than in the microscope images ($P < 0.001$, *t*-test). Color balance values of both green/red and blue/red were higher in the intracameral illumination images than in the microscope images ($P < 0.001$, *t*-test). **Conclusion:** The digital images in the digitally assisted cataract surgery were enhanced by using the intracameral illumination. Considering the contrast and color balance in the 3D cataract surgery, the intracameral illumination may be better than the microscope illumination.

Key words: 3D visualization, cataract surgery, image analysis, intracameral illumination, microscope

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Three-dimensional (3D) heads-up visualization system during the anterior and posterior segment ophthalmic procedures have been used since 2008. The high-definition, 3D visualization is revolutionizing both vitreoretinal surgery and cataract surgery. Compared with traditional optical microscopes, this novel viewing system offers many advantages including superior ergonomics for the surgeon, lower illumination levels, enhanced depth of field, amplified stereopsis, digitally enhanced imaging, high dynamic range imaging, and the same view between the surgeon and the surgical team (fellows, residents, and nurses).[1-5]

An advanced cataract surgery technique using the intracameral illumination has been introduced with an enhanced 3D effect and an improved depth perception of the lens, even under the traditional microscopes.[6-11] Under the 3D heads-up viewing on a large flat panel display, clinical experience using the intracameral illumination provided us with a better understanding of certain features of the two new technologies. In our subjective point of view, a more enhanced stereoscopic depth perception and a better image resolution were achieved under the intracameral illumination rather than the microscope illumination.

There have been no studies till date that show the measurement of image resolution and depth of field in cataract surgery using the 3D heads-up viewing system. Therefore, we performed a comparative observation to assess brightness, contrast, visibility, and color balance between microscope versus intracameral illumination images during phacoemulsification cataract surgery using the new viewing system.

Methods

Institutional Review Board (IRB) (no. GBIRB2017-65) approved this study before its initiation. Subjects participated with full, informed consent, and the study adhered to the tenets of the Declaration of Helsinki. From October 2017 to November

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2017, all cataract surgery cases were routinely performed at the Department of Ophthalmology, Gachon University Gil Hospital Hospital using the Ngenuity 3D visualization system (Alcon, Fort Worth, Texas, USA). For the best 3D effect, the flat-panel display was positioned next to the operating table (right side) 1.5 m away from the surgeon as recommended [Fig. 1].

All procedures were performed by one physician (D.H.N.) with an operating microscope coaxial illumination (M844 C40, Leica Microsystems, Wetzlar, Germany) (microscope illumination) or a 23-gauge endoillumination (Xenon BrightStar, DORC, Ziudland, Netherlands) (intracameral illumination). The surgical technique described in our previous studies[6-10] was used in all cataract surgeries including the advanced lens capsule polishing. A 3.0-mm clear corneal wound for the phacoemulsification handpiece and a 0.8-mm side port wound for the illuminator was created at the 9 o'clock and 2 o'clock positions, respectively. In the phacoemulsification, irrigation and aspiration (I&A) including capsule polishing, and removal of viscoelastic material, the phaco tip or I&A tip was inserted into the anterior chamber. Then, a running 23-G illuminator was introduced into the anterior chamber through the side port, and the microscope light was extinguished. Dark ambient lighting is recommended while operating. To optimize visualization at all stages of the cataract surgery, the orientation and position of the illuminator in the anterior chamber was intuitively adjusted and the focusing of the microscope was not different from that in the conventional cataract surgery.

For comparison between the microscope and intracameral illuminations, we collected both microscope and intracameral illumination images at the same point of the procedures (25 microscope images of halogen 60% intensity, 25 intracameral images of xenon 60% intensity). The images were 1258 × 353 pixels and in 24-bit color JPEG format. We used the ImageJ program (version 1.51j8, NIH, USA) to draw the region of interest (ROI) for the analysis of the microscope and intracameral illumination images. The ROI was targeted to the corneal area which was extracted from the surrounding tissues. The extracted ROI images were split into three monochrome color channels of red, green, and blue to calculate the features [Fig. 2].

For image parameters in this study, brightness was based on the pixel intensity values of each monochrome color channel. Contrast quantified the variation in the pixel intensity and was measured as the difference in the standard deviation of the pixel intensity values in each color channel. We calculated the difference in standard deviation (DSD) by selecting the two regions randomly within the ROI. In this study, the contrast was synonymous with the DSD. Visibility was measured as shown in Equation 1 using the minimum and maximum values. represents the highest intensity value, and represents the lowest intensity value. Therefore, the sharper the image, the closer the visibility is to 1.[12,13] Besides, color balance was measured as the ratio of the green and blue channel brightness values to the brightness of the red channel.

$$Visibility = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} \qquad \text{(Eq. 1)}$$

Statistical analysis

Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS) package (version 20.0, IBM Corp., USA). We performed a normality test because the number of data was small. In both the Kolmogorov-Smirnov test and the Shapiro-Wilk test, all parameters of the microscope and intracameral illumination images were verified to be normalized ($P > 0.05$). An independent *t*-test was performed to analyze the difference between the microscope and intracameral illumination images of red, green, and blue channels, respectively. Besides, a one-way analysis of variance (ANOVA) test was performed to analyze the differences between red, green, and blue channels in the microscope and intracameral illumination images, respectively. *P* values of 0.05 or less were considered statistically significant.

Results

Table 1 summarizes the image properties between the microscope and intracameral illumination images.

The brightness value was higher in the microscope illumination images than in the intracameral images ($P < 0.001$, *t*-test). The contrast (DSD) values of the green and blue channels except for the red channel were higher in the intracameral illumination images than in the microscope images ($P < 0.001$, *t*-test). There was no significant difference in the contrast (DSD) value among red, green, and blue channels in the microscope illumination images ($P = 0.784$, ANOVA test). On the other hand, the contrast (DSD) of the red channel was lower than those of the green and blue channel images in the intracameral illumination image ($P < 0.001$, ANOVA test). The visibility values of all three channels (red, green, and blue) were higher in the intracameral illumination images than in the microscope images ($P < 0.001$, *t*-test). The color balance values of both green/red and blue/red were higher in the intracameral illumination images than in the microscope images ($P < 0.001$, *t*-test) [Table 1].

Discussion

Visualization is one of the most important aspects of performing ophthalmic surgery. Until recently, the only instrument for intraocular visualization was an operating microscope using classical optics, with its associated limitations, in contrast, sharpness, and color. Now, with advances in digital imaging and image-processing capabilities, it can enhance the visualization of the surgical field in real-time. The Ngenuity 3D visualization system (Alcon, Fort Worth, Texas, USA) is one of the complete digital solutions for vitreoretinal surgery and cataract surgery. This digital platform provides a 3D view of the eye with excellent resolution, image depth of focus, clarity, and color contrast.[1-5] With any innovations in medicine, however, objective and quantitative analyses should be done to provide any potential advantages over the current standard paradigm. Furthermore, we must have enough "digital image literacy" to be conversant with the digital parameters.[14,15]

From our subjective standpoint about 3D heads-up cataract surgery, the clinical experience over the past months has been largely positive. However, we have encountered occasional issues with a suboptimal image resolution when working in the microscope illumination. In our subjective point of view, the depth perception and the image resolution were better under the intracameral illumination. Therefore, our study aimed to compare the digital parameters. This was the first time a "digital image literacy" study has been used to measure the brightness, contrast, visibility, and color balance between microscope versus intracameral illumination images during cataract surgery using the 3D heads-up viewing system.[14,15]

In this study, the brightness on a large flat panel display during cataract surgery was higher in the microscope illumination than in the intracameral illumination. It was consistent with previous studies.[6] It suggests that light exposure reaching the patient's retina during cataract surgery is much lower in the intracameral illumination than in the microscope illumination.

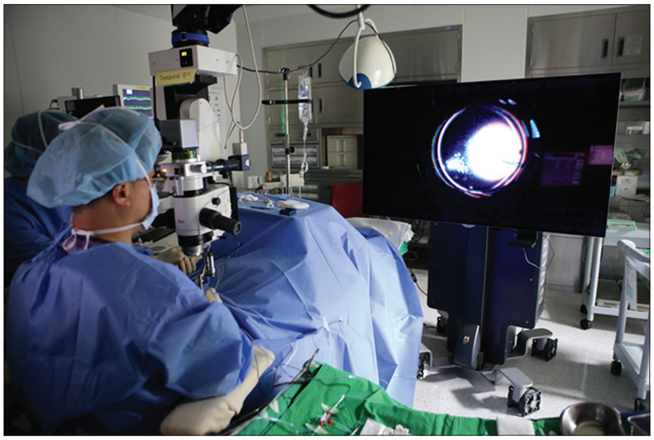

Figure 1: Three-dimensional (3D) heads-up cataract surgery using a stereoscopic image on a flat-panel, high-definition, digital 3D display positioned approximately 1.5 m from the surgeon. The oculars were replaced for the 3D camera

Both the contrast and the visibility (sharpness) were higher in the intracameral illumination than in the microscope illumination. It was consistent with our subjective observation in which a more enhanced stereoscopic depth perception and a better image resolution were achieved under the intracameral illumination rather than the microscope illumination.[10,11]

The retina presents a narrow color gamut with red reflectance being brightest, even though most spatial details occur in the green. Therefore, a higher green/red ratio is perceived as having optimum contrast in the color fundus photograph.[14,15] In vitreoretinal surgery using the 3D digital platform, surgeons can digitally enhance tissue planes by adjusting light balance and contrast and applying digital filters, potentially reducing the concentration of vital dye needed during surgery. It is possible to improve the visualization of epiretinal/internal limiting membranes and facilitate the peeling with a green filter.[1-5] In this study regarding the color balance, higher green/red and blue/red ratios were evident in the intracameral illumination. With the high green/red color balance in the intracameral illumination, it was able to capture intuitively a well-illuminated image and visualize

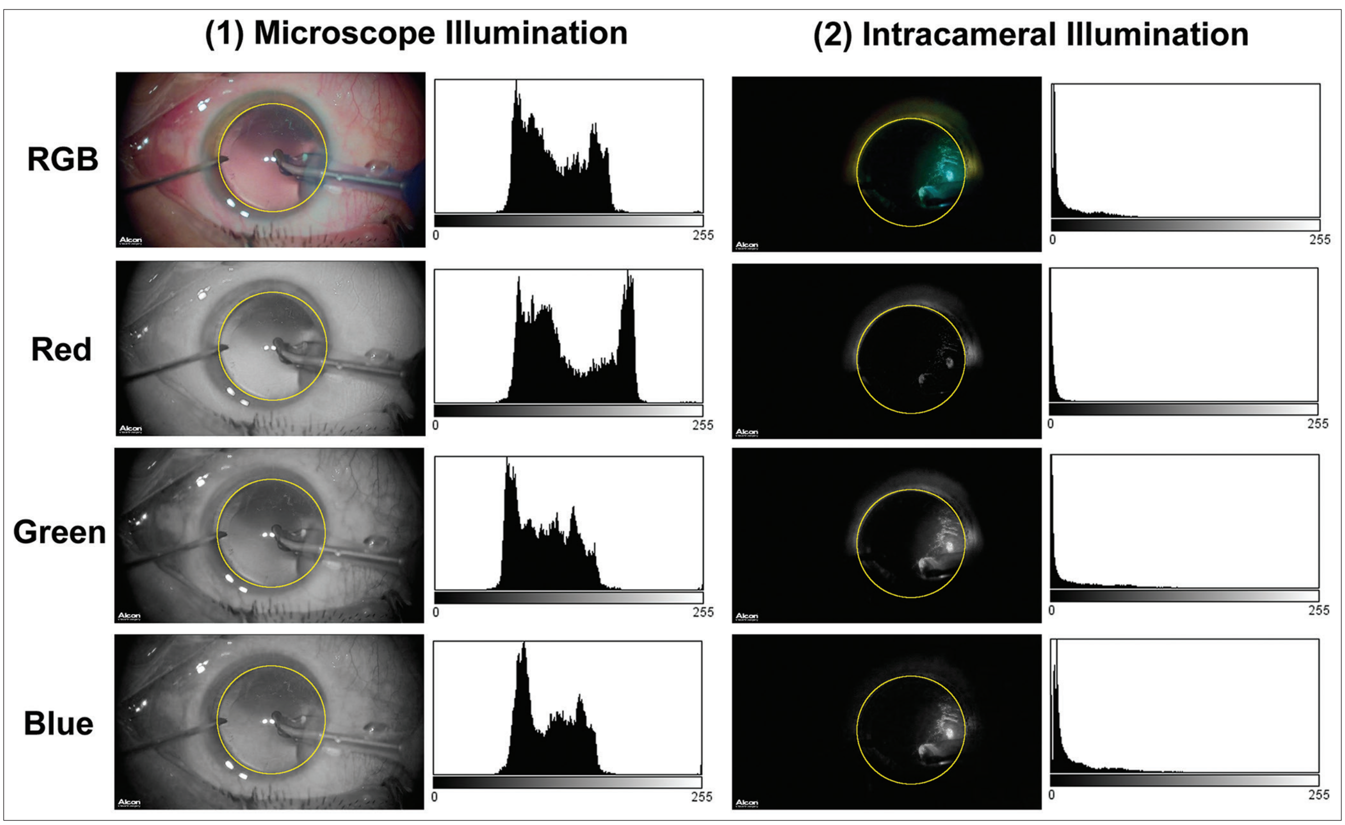

Figure 2: RGB composite color channel and three monochrome colors (red, green, and blue) channel photographs with its luminance histogram between the microscope and intracameral illumination region of interest (ROI) images. (1) In the microscope ROI images, the red, green, blue channels contributed most of the contrast information. The G/R color balance was 0.795, defined as the ratio of the locations of the G and R means in the histogram. The B/R color balance was 0.844. The visibility was 0.594 on RGB composite color channel. The brightness was 91.889, and the contrast (DSD) was 20.767. (2) In the intracameral ROI images, the green and blue channels except the red channel contributed most of the contrast information. The G/R color balance was 7.239. The B/R color balance was 5.102. The visibility was 0.983 on RGB composite color channel. The brightness was 39.275, and the contrast (DSD) was 23.071

Table 1: Comparison of brightness, contrast (DSD), visibility, and color balance between intracameral versus microscope illumination images in cataract surgery using the three-dimensional heads-up viewing system. (*n*=25)

	Intracameral	Microscope	*P*-value
Brightness			
RGB*	38.919 ± 19.740	86.484 ± 12.502	< 0.001
Red	11.829 ± 10.852	99.629 ± 16.292	< 0.001
Green	60.434 ± 26.598	80.082 ± 14.837	0.003
Blue	44.498 ± 29.568	79.752 ± 12.553	< 0.001
Contrast (DSD†)			
RGB*	25.720 ± 10.066	16.685 ± 3.044	< 0.001
Red	15.162 ± 6.136	17.059 ± 4.338	0.213
Green	33.607 ± 10.329	17.678 ± 3.213	< 0.001
Blue	32.653 ± 15.292	17.694 ± 3.342	< 0.001
Visibility			
RGB*	0.968 ± 0.044	0.631 ± 0.053	< 0.001
Red	0.999 ± 0.004	0.649 ± 0.107	< 0.001
Green	0.945 ± 0.073	0.656 ± 0.063	< 0.001
Blue	0.987 ± 0.025	0.668 ± 0.063	< 0.001
Color Valance			
Green/Red	7.921 ± 4.467	0.805 ± 0.076	< 0.001
Blue/Red	5.571 ± 4.335	0.814 ± 0.147	< 0.001

*RGB = Red, Green, and Blue composite color

†DSD = Difference in standard deviation

the lens details optimally. In eyes without a sufficient red reflex, therefore, creating a capsulorhexis is possible without additional support such as vital dyes.[16]

The color balance is one of the most important factors in digital image literacy. The lens shows a narrow color gamut with little red light, but with green and blue reflectance being bright. A red reflex, which is one of the most important features of an ophthalmic microscope for cataract surgery, is produced by the reflection of microscope coaxial light from the retina. Practically speaking, high red reflectance (red reflex) is not ideal for optimal contrast and visibility during cataract surgery. More importantly, it has long been known that the red reflex in cataract surgery can induce retinal phototoxicity.[17,18] Therefore, the high green or blue reflectance in the intracameral illumination seems to be optimal in terms of not only the image contrast and resolution but also the intraoperative phototoxicity [Fig. 3]. Apart from RGB color balance, there are other parameters like YCrCb. The YCrCb space describes the pixel properties using an intensity or luma coordinate (Y) and two chrominance coordinates: Cr, for the red difference, and Cb, for the blue difference. Its potential implications should be addressed in the future.

In this intraindividual, intraeye study, we could objectively measure and compare the digital parameters such as brightness, contrast, visibility, and color balance in cataract surgery using the 3D heads-up viewing system. This study highlights the utility of the intracameral illumination to allow digital enhancement of the lens structures and optimize the digital images in the digitally assisted cataract surgery. However, it is necessary to perform a prospective study comparing the outcomes and safety of the advanced cataract surgery with intracameral illumination versus those of the standard cataract surgery with microscope illumination. Repeatability of this technique and experience of other surgeons could yield more information regarding the universality of the technique. There are possible difficulties encountered using the technique such as the chance of Descemet membrane tears and the narrow field of view. Nonetheless, no complications were observed in this study.

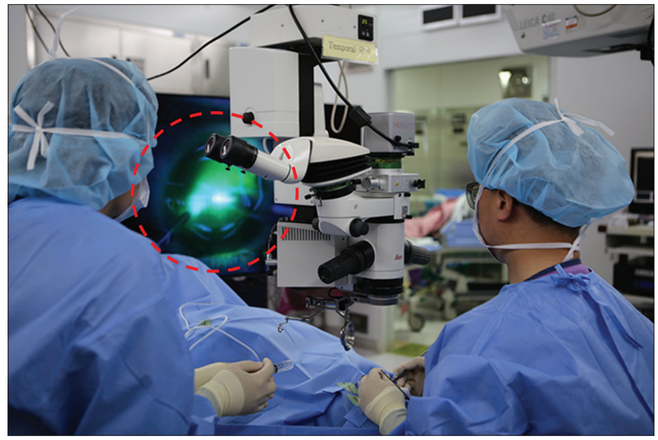

Figure 3: In three-dimensional (3D) heads-up cataract surgery using an intracameral illumination, a high green reflectance was shown on a flat-panel, high-definition, digital 3D display. The high green reflectance (green reflex) was better for the optimal contrast and visibility during cataract surgery than the high red reflectance (red reflex)

Conclusion

We acknowledge that the installation of the illumination system into current cataract setups is necessary for its universal application. Considering the contrast and color balance in the 3D heads-up digital cataract surgery, the intracameral illumination may be better than the microscope illumination.

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Conflicts of interest

There are no conflicts of interest.

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