Article

Evaluating Red Reflex and Surgeon Preference Between Nearly-Collimated and Focused Beam Microscope Illumination Systems

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Purpose: To evaluate the intensity and stability of the red reflex produced by ophthalmic surgical microscopes with nearly-collimated versus focused illumination systems and to assess surgeon preference in a simulated surgical setting.

Methods: This two-part evaluation consisted of postproduction surgical video analysis of red reflex intensity and a microscope use and preference survey completed by 13 experienced cataract surgeons. Survey responses were based on bench testing and experience in a simulated surgical setting. A microscope with nearly-collimated beam illumination and two focused beam microscopes were assessed.

Results: Red reflex intensity and stability were greater with the nearly-collimated microscope illumination system. In the bench testing survey, surgeons reported that the red reflex was maintained over significantly greater distances away from pupillary center, and depth of focus was numerically greater with nearly-collimated illumination relative to focused illumination. Most participating surgeons ($\geq 64\%$) reported a preference for the microscope with nearly-collimated illumination with regard to red reflex stability, depth of focus, visualization, surgical working distance, and perceived patient comfort.

Conclusions: The microscope with nearly-collimated illumination produced a more intense and significantly more stable red reflex and was preferred overall by more surgeons.

Translational Relevance: This is the first report of an attempt to quantify red reflex intensity and stability and to evaluate surgically-relevant parameters between microscope systems. The data and methods presented here may provide a basis for future studies attempting to quantify differences between surgical microscopes that may affect surgeon preference and microscope use in ophthalmic surgery.

Introduction

The surgical microscope is an integral tool that magnifies visualization of the eye and its substructures during ophthalmic procedures. Technological differences between ophthalmic surgical microscopes may lead to differences in visualization that can impact surgical performance and efficiency as well as surgeon preference. Multiple factors (e.g., intensity and stability of the red reflex; depth of focus) contribute to the overall use of a surgical micro-

scope. The red reflex, produced by reflection of coaxial light from the retina back to the observer, provides background and contrast necessary for visualization during ophthalmic surgery.¹ An inadequate red reflex or an inability to maintain an adequate red reflex within the entire pupil because of eye movement may impair optimum visualization and require frequent microscope repositioning or patient readjustment; thus, red reflex stability is integral for efficient and uninterrupted ophthalmic surgery.¹ Similarly, a shallow depth of focus provides a limited in-focus working range and may

Figure 1. Illumination beams of a nearly-collimated beam microscope system (*left*) and focused beam microscope systems (*right*). Nearly-collimated beam microscopes provide overlapping beams of illumination. Stereo illumination produces two focused light beams that are coaxial to the observation beam. Figure adapted with permission from Alcon Surgical (<http://www.alconsurgical.co.za/about-LuxOR-ophthalmic-microscope.aspx>).

require the surgeon to pause to readjust or refocus the microscope. Decreasing interruptions during ophthalmic procedures to correct for image degradation may shorten surgical times and potentially reduce risk of surgical complications.

In general, ophthalmic surgical microscopes use either halogen or xenon illumination sources that produce different spectra. Surgeon preference of illumination source varies from individual to individual. Some surgeons may prefer the perceived greater brightness of xenon compared with halogen illumination; however, many xenon surgical microscopes include filters to mimic the halogen-produced view of the eye. Beyond illumination source differences that can be immediately appreciated, surgeons may rate microscope performance on image quality and/or anatomical visualization preferences.

Three microscope systems, the LuxOR LX3 (Alcon Laboratories, Inc., Fort Worth, TX), the OPMI Lumera T (Carl Zeiss Meditec, Inc., Dublin, CA), and the Leica M690 (Leica Microsystems, Wetzlar, Germany) share some similarities (e.g., apochromatic optics and Schott-style glass are used in all 3 systems) but also feature important technological differences. The illumination system of the LuxOR was designed to provide a large-diameter red reflex zone that is not affected by pupil size, microscope or lens position, or eye movement.^{2,3} The LuxOR generates two overlapping, nearly-collimated light beams (i.e., parallel rays, each ray with approximately 10° of divergence) from halogen illumination sources located beneath the objective lens and are aligned with the microscope oculars (Fig.

1); these two illumination beams are encompassed by a third, oblique light beam. The illumination sources of both the Lumera (xenon) microscope and the Leica (halogen) microscope create focused beams that are aligned with the microscope oculars (Fig. 1). The focused beam illumination is reported to provide a stable red reflex.^{4,5}

Interestingly, unlike other technologies used in ophthalmic surgery (e.g., the femtosecond laser or the phacoemulsifier/aspirator system) surgical microscopes are commonly viewed simply as facilitators of ophthalmic procedures. Methods for evaluating and comparing the performance of ophthalmic surgical microscopes remain to be developed and standardized. The goal of the current evaluation was to evaluate the intensity and stability of the red reflex produced by microscopes with nearly-collimated illumination versus focused illumination and to assess surgeon preference in a simulated surgical setting.

Methods

Design

There were two components to this evaluation. Each component was completed at a single US center. In the first component, illumination quality and red reflex intensity and stability in a surgical setting (Center for Minimally Invasive Surgery, Mokena, IL) were assessed by digital video capture and postproduction analysis of surgical videos.

In the second component, 13 experienced cataract

surgeons participated in bench testing to assess clinically important microscope parameters (i.e., red reflex, depth of focus, illumination), and completed a subjective microscope use and preference survey (Eye Surgery Center of San Francisco, San Francisco, CA).

Postproduction Analysis of Surgical Videos

To evaluate the intensity and stability of the red reflex produced by microscopes with nearly-collimated beam illumination and focused beam illumination in a surgical setting, video was recorded for eight patients undergoing planned phacoemulsification cataract extraction, performed by DL. The red reflex produced by the LuxOR microscope with nearly-collimated beam illumination and by the Leica M690 microscope with focused beam illumination was imaged using the same Panasonic camera (Panasonic Corp., Osaka, Japan), which was transferred between microscopes to limit equipment discrepancies. The camera was calibrated to the microscope with the nearly-collimated beam illumination used for surgery, and the luminosity of both microscopes was measured using a light meter (Starlite 2, model GO4046; Gossen Foto - und Lichtmesstechnik GmbH, Nuremberg, Germany) to ensure that light intensity was equivalent between microscope systems.

A capture device (MediCap USB300HD; Medi-Capture, Inc., Philadelphia, PA) was used to convert images from the camera into MP4 files. MP4 files were transcoded into editing software (ProRes 4.22; Apple, Inc., Cupertino, CA) and imported into Final Cut Pro software (version 7.0.3; Apple, Inc.) for analysis. Videos were manipulated as necessary so that eye size and movement were aligned between recordings with both microscope systems. No exposure settings were altered in the postproduction analysis. Films were then edited to enable side-by-side comparison of videos produced with the nearly-collimated and focused beam illumination microscopes. To quantify the red reflex with each microscope, the intensity of the red channel was measured in Institute of Radio Engineers units (IREs) using the video scopes included in the analysis software (luminosity scale, 0 IREs [completely dark] to 110 IREs [fully white, overexposed]).

Upon completion of surgery, the stability of the red reflex produced with the nearly-collimated and the focused beam illumination microscopes was assessed postoperatively for eight patient eyes. Each microscope was used to examine the same patient eye. Range was determined by moving the microscope

along the x - and y -axes away from the pupillary axis or center in both directions.

Bench Testing and Preference Survey

Thirteen surgeons performed bench testing and conducted a subjective microscope performance and preference survey in two phases. First, surgeons evaluated red reflex, visualization, and depth of focus with the LuxOR microscope with nearly-collimated illumination and the Lumera microscope with focused illumination in a bench setting. Second, the microscope preference and perceived patient comfort were evaluated in a simulated patient/surgeon experience with both microscope illumination systems.

Each functional parameter (i.e., red reflex, luminance, and depth of focus) was measured in triplicate; for red reflex assessments, magnification was set to $\times 1$, and illumination intensity was set at the lowest acceptable level for the nearly-collimated beam microscope. The same illumination and magnification was then applied to the focused beam microscope. The quality and stability of the red reflex was evaluated with each microscope using a 0.22-mm diameter model eye (Retina View 8-mm Iris; S.M.R. Ophthalmic Pvt., Ltd., Mumbai, India) seated on a translational stage (Fig. 2A). To simulate patient eye movement during surgery, the stage was displaced along x - and y -axes (corresponding to the superior-inferior and temporal-nasal directions, respectively), and the distance relative to the virtual pupillary center of the model eye to the first noticeable degradation of the red reflex (i.e., the diminished zone) was measured (Fig. 2B). Distance was measured from the center to beyond the diminished zone, where the red reflex was no longer visible (i.e., the unusable zone). The distances of x - and y -axis displacement were averaged to produce a mean zone diameter for the diminished and unusable zones.

Surgeons then measured luminance in a model eye under each microscope using a light meter (Starlite 2; Gossen Foto - und Lichtmesstechnik GmbH). While viewing the model eye, surgeons increased microscope luminance from zero until a red reflex adequate for their surgery was observed, and recorded their preferred luminance level.

Next, with illumination intensity matched for both microscopes, surgeons measured their perceived depth of focus of each microscope at $\times 0.5$ magnification using a standardized, angled target block (Depth of Focus Target, model DA035E; Edmund Optics, Barrington, NJ) with 15 lp/mm markings and demarcations in 0.5-mm increments (Fig. 2C). With

Figure 2. Experimental setup for quantitative measurement of the red reflex and depth of focus. (A) Bench testing setup including a model eye mounted to a translation stage. (B) Schematic of microscope displacement relative to pupillary center along the x- and y-axes. Movement from center outward to zones where the red reflex becomes diminished or unusable is indicated. (C) Target block used to assess depth of focus.

each microscope focused on the target block set point, surgeons subjectively determined the range of markings (i.e., the maximum and minimum) that could be clearly seen in focus on the block. The difference, or distance, between markings was calculated and recorded as the depth of focus.

To evaluate simulated patient comfort, surgeons were grouped in pairs where one was examined by their peer while lying undilated under each microscope system. The observing surgeon adjusted the luminance to their preferred intensity for visualization and reported their selected microscope preference based on observation of the red reflex at calibration/baseline and with x- and y-axis displacement and tilt, depth of focus, surgical working

distance, and illumination intensity. When acting as simulated patients, surgeons rated the comfort of the illumination of each microscope with the settings selected by their observing peers. The paired surgeons then alternated positions to determine their microscope preference and comfort rating in the same manner.

Data Analysis

Differences between the nearly-collimated beam and the focused beam microscopes in the averaged diameter of the diminished and unusable red reflex zones and the mean depth of focus for 13 surgeons were assessed using Student's *t*-tests with a significance level of *P* less than 0.05.

Figure 3. Red reflex observed in the live surgical setting. (A) Split-view visualization of same-eye red reflex with a nearly-collimated beam microscope and a focused beam microscope is shown. (B) Side-by-side view of same-eye red reflex (*top*) and red channel magnitude (*bottom*) with a nearly-collimated beam microscope and a focused beam microscope.

Results

Postproduction Analysis of Surgical Videos

With equal illumination settings for all eight patient eyes assessed, the surgeon (DL) reported that the red reflex appeared markedly more intense with the microscope with nearly-collimated beam illumination compared to the microscope with focused beam illumination (Fig. 3A). A representative image was quantitatively analyzed and is presented here (Fig. 3B). Analysis of the isolated red channel revealed that the

mean intensity of the red reflex was approximately 97 IREs with the nearly-collimated beam microscope (range, 92–101 IREs) and approximately 60 IREs with the focused beam microscope (range, 55–65 IREs; Fig. 3B). Subjectively, image quality also differed between microscope systems. Despite a dimmer red reflex, illumination with the focused beam microscope appeared to have washed out the sclera and sclera vessels due to overexposed brightness of these structures in the video capture images.

In the surgical setting, the red reflex was maintained over greater microscope displacement distances

along the x -axis (see [Supplemental video](#)) and the y -axis (data not shown), relative to patient's eyes, with the microscope with nearly-collimated beam illumination compared with microscope with the focused beam illumination.

Surgeon Microscope Performance and Preference Survey

The mean displacement distances along the x - and y -axes of the translation stage holding the model eye prior to the red reflex becoming diminished and unusable, as reported by surgeons participating in the bench testing survey, were significantly greater with the microscope with nearly-collimated beam illumination relative to the microscope with focused beam illumination ($P < 0.0001$ for all comparisons; [Fig. 4A](#)). The microscope with nearly-collimated illumination maintained an undiminished red reflex even at x - and y -axis displacement distances that caused the red reflex of the microscope with focused beam illumination to become unusable. Overall, the diminished red reflex zone limits were 28.8 and 8.7 mm with the nearly-collimated beam and the focused beam microscopes, respectively; the unusable red reflex zone limits were 44.6 and 17.3 mm ([Fig. 4B](#)). In their subjective assessments of luminance quality, lower mean luminance levels were required to produce surgeons' preferred red reflex with the microscope with nearly-collimated illumination versus the microscope with the focused-beam illumination (mean $\pm$ standard deviation, 1180 ± 698 vs. 5287 ± 1832 lux, respectively; [Fig. 5](#)).

The microscope with nearly-collimated beam illumination was reported to provide a numerically greater depth of focus than the microscope with focused beam illumination (21.4 ± 7.5 vs. 17.3 ± 6.8 mm, $P = 0.16$). The full range of depth of focus across all surgeons surveyed was 12 to 34 and 6 to 27 mm for the nearly-collimated and focused beam illumination, respectively.

Surgeon-reported microscope preference survey results demonstrated that most surgeons (64%–100%) favored the microscope with nearly-collimated beam illumination over the microscope with focused beam illumination for all parameters assessed ([Table 1](#)). More surgeons reported a preference for the overall stability of the red reflex produced by the nearly-collimated beam illumination, and all 13 participating surgeons favored the nearly-collimated beam illumination with regard to red reflex stability with movement along the x - and y -axes. Four of 13

surgeons reported having no preference for either microscope, particularly for depth of focus. One surgeon reported a preference for the illumination intensity of the microscope with focused beam illumination; this participant commented that the light was brighter but the luminance quality was not necessarily advantageous. Of the 13 surgeons surveyed when acting as a patient beneath each microscope, 10 reported a comfort preference when lying beneath the microscope with nearly-collimated beam illumination. The remaining three surgeons reported having no microscope preference.

Discussion

Ophthalmic surgical microscopes are generally viewed as passive instruments in that they serve as a simple conduit to provide required visualization of the intraocular and surface structures. With the introduction of new technology, however, surgical microscopes can be considered integral surgical tools with the potential to enhance the surgeon's experience or performance. As microscope technology has advanced, standardized approaches for comparing potential surgical use among modern microscopes have yet to be developed, leaving one to speculate on what newer technology provides beyond its predecessors. The current evaluation of microscope systems with nearly-collimated and focused beam illumination systems qualitatively evaluated red reflex intensity and stability in a surgical setting and assessed surgically-relevant parameters including red reflex, depth of focus, and luminance in a bench testing survey.

Video capture and analysis in the live surgical setting demonstrated a more intense and more stable red reflex with the microscope with nearly-collimated beam illumination compared with a microscope with focused beam illumination. This finding was also supported by surgeon responses in model eye assessment portion of the bench testing survey. With the nearly-collimated beam illumination, an undiminished red reflex in a model eye was maintained with significantly greater displacement distances along the x - and y -axes relative to the focused beam illumination; a usable red reflex was also maintained over significantly greater distances with the nearly-collimated beam illumination versus the focused beam illumination. Displacement of the model eye was intended to simulate patient eye movement in a surgical setting. Maintaining an adequate red reflex despite movement of the microscope illumination relative to pupillary

Figure 4. Red reflex limits determined in bench testing. (A) Mean $\pm$ SD displacement distances relative to pupillary center along the x- and y-axes are shown. Data indicate the offset distance at which the red reflex became diminished or unusable. $*P < 0.0001$ ($n = 13$). (B) Schematic of red reflex zone limits. Limits represent the average diameter of x- and y-axis displacement before the red reflex became diminished or unusable.

center is beneficial in that it minimizes the need for patient repositioning and may have the potential to decrease surgical times.¹ The more intense red reflex and larger reflex area observed with the microscope with nearly-collimated beam illumination may improve visualization of ophthalmic structures (e.g., fibrillar strands of cortical material) and allow greater surgical precision.^{5,6}

Surgeon preference for ophthalmic surgical microscope systems can be influenced by several factors. Systems that are easy to use, produce a natural view of the eye, and minimize the need to stop surgery to

refocus or readjust the microscope or reposition the patient may be preferred over other systems. No published studies to date have evaluated clinically relevant design characteristics of surgical microscopes, and reports regarding different microscopes have typically been limited to descriptions of the overall preference of one or two individual surgeons.^{1,5–7} In the microscope preference survey, a majority of the participating surgeons reported a preference for the microscope with nearly-collimated beam illumination with regard to stability of the red reflex; all 13 participating surgeons reported a

Figure 5. Mean $\pm$ SD illumination intensity preferred by participating surgeons on each microscope tested. Data represent preferred luminance during bench testing ($n = 13$).

preference for the nearly-collimated illumination for the red reflex stability with movement along the x - and y -axes. The depth of focus, surgical working distance, and illumination intensity of the microscope with nearly-collimated beam illumination were also preferred by surgeons who reported a microscope preference. Differences in light transmission through a patient's or model eye's cornea may have the potential to contribute to differences in red reflex intensity and preferred illumination intensity observed in the surgical videos and bench testing survey.

However, the objective of the current efforts was to understand the performance of each surgical microscope as a complete system, coupled with either a patient eye (for surgical videos) or a model eye (for bench testing).

With equal illumination intensity, the microscope with focused beam illumination produced a qualitatively dimmer red reflex yet a washed-out view of the sclera in the surgical video capture assessments. Potential differences in image quality may have contributed to the lower mean luminance level with nearly-collimated beam illumination reported by surgeons to provide their preferred red reflex intensity. Most surgeons (77%) participating in the microscope use and preference survey reported greater patient comfort with the nearly-collimated beam illumination; the remaining surgeons (23%) reported no preference between microscope systems. Additional studies are needed to determine whether this preference could be related to differences in beam type (nearly-collimated versus focused) or illumination source (halogen versus xenon), source light intensity, or a combination of these factors.

As a first study we know of its kind to evaluate microscopes using subjective and quantitative criteria, there are opportunities where quantification of technological and performance differences can be explored and improved. First, it was both inconvenient and challenging to mask the microscope type in the surgeon survey. The lack of masking could have introduced bias into reported microscope preference data because familiarity with the oculars, adjustment levers, or knobs required to optimize preferred settings made it difficult to adequately disguise the device being tested. Furthermore, although the

Table 1. Surgeon-Reported Microscope Preference

Parameter, n^*	Surgeon Preference, n (%)		
	Nearly-Collimated Beam Microscope	Focused Beam Microscope	No Preference
Red reflex stability			
Coaxial, $n = 12$	9 (75)	0 (0)	3 (25)
X/Y axis, $n = 13$	13 (100)	0 (0)	0 (0)
Manual tilt, $n = 13$	12 (92)	0 (0)	1 (8)
Overall, $n = 12$	11 (92)	0 (0)	1 (8)
Depth of focus, $n = 13$	9 (69)	0 (0)	4 (31)
Surgical working distance, $n = 13$	10 (77)	0 (0)	3 (23)
Illumination intensity, $n = 11$	7 (64)	1 (9)	3 (27)
Patient comfort, $n = 13$	10 (77)	0 (0)	3 (23)

* n = total responses.

microscope use survey was intended to provide quantitative data regarding the limits of the red reflex (i.e., the diminished and unusable red reflex zones) and depth of focus, these measurements were based on observer-dependent quantification that introduced subjectivity (although data were still comparable from surgeon to surgeon). This was particularly challenging for the depth of focus evaluation because each surgeon would not necessarily accommodate equally nor identify “clear” lines on the target block with the same discretion. Comparative studies designed from this preliminary survey-based attempt to quantify surgically-relevant parameters should include a larger sample size as well as microscope system masking, if practical.

During surgery, the red reflex can be influenced by patient eye movements. We evaluated red reflex intensity and stability in surgical videos of patient eyes and in a model eye in bench testing. The stage-mounted model eye was displaced along the x - and y -axes relative to the surgical microscope to simulate patient eye movement in superior-inferior and temporal-nasal directions. However, the potential effects of eye tilt and other movements on the red reflex were not explored. Future studies may evaluate how a range of eye movements can affect the red reflex stability during surgery or in laboratory settings.

Because eye dilation was not performed in the simulated surgeon/patient experience portion of the survey, differences in perceived patient comfort may have been underestimated as individual responses to incident light intensity may have resulted in nonuniform pupil constriction. In an attempt to create an equivalent baseline illumination level as a controlled parameter (i.e., equivalent incident light) during the surgical video capture and analysis portion of this evaluation, the illumination level was first optimized for postsurgical observation with the nearly-collimated beam microscope; the same illumination was then used for assessment with the focused beam microscope. Future testing will provide an opportunity to evaluate red reflex intensity using the illumination levels optimized for each microscope system and at levels away from optimal to demonstrate how robust red reflex range and stability can be maintained. The surgeon-preferred luminance results of our bench testing survey suggests that considerably more incident light would be required with the focused beam microscope system to obtain a red reflex intensity equivalent to that achieved with the nearly-collimated microscope with lower levels of illumination.

In conclusion, using the test methods described here, the microscope system with nearly-collimated beam illumination produced a more intense and significantly more stable red reflex and greater depth of focus, and was preferred by more surgeons to a microscope system with focused beam illumination. Quantification of surgical ophthalmic microscopes is necessary for accurate comparisons among microscope designs. This is the first report of an attempt to quantify red reflex intensity and stability and to evaluate surgically relevant parameters such as depth of focus between microscope systems. Additional studies refining quantification methods and building on these initial findings are needed to identify potentially important technological and clinically-relevant differences among surgical microscopes.

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