Original Article

Optimization of surgeon ergonomics with three-dimensional heads-up display for ophthalmic surgeries

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Purpose: To describe the variables that may be utilized in the optimization of three-dimensional heads-up surgeries (3D-HUS) for achieving better ergonomics among ophthalmic surgeons. **Methods:** A cross-sectional study was conducted at the operating room of a tertiary eye care center, equipped with an ARTEVO 800 3D surgical microscope and display monitor. The parameters noted were monitor height (MH), surgeon eye-to-floor distance (ETFD), surgeon eye-to-monitor distance (ETMD) and viewing tilt (VT) angle. The neck and eye strain of the surgeon and assistant were scored as per Borg's CR-10 scale, before and after surgeries. **Results:** Thirty (13 right, 17 left) eye surgeries were analyzed. The minimum ETMD was 51 inches (in) and the eye strain reduced with shorter ETMD (within the range 51 inches to 83 inches). The VT and ETFD were higher for right eye surgeries. The optimum MH was between 50 and 55 in. Overall, the neck strain and eye strain were in the range of 0–3 and 0–1, respectively. **Conclusion:** The various parameters affecting the 3D image quality, neck and eye strain are chair height, VT angle, eye centration, monitor distance, laterality of the eye, and room illumination.

Key words: 3D surgery, ergonomics, heads-up surgery, ophthalmic surgery

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Three-dimensional heads-up surgery (3D-HUS) has revolutionized ophthalmic surgeries. They have improved surgical performance and deliver a better surgeon's experience with reduced back and neck strain to the surgeon for various anterior and posterior segment surgeries.[1-3] Conventional microscopes have been reported to cause neck and back pain and eye strain among surgeons due to a constant need to look into the microscope during ophthalmic microsurgeries.

The main advantages of 3D HUS are improved ergonomics, lower endoillumination intensity, and thus, reduced phototoxicity, better visualization, better peripheral visualization, magnification, and less asthenopia for vitreoretinal surgeries.[1,3] Various available 3D-HUS systems include ARTEVO 800 (Carl Zeiss Meditec AG, Jena, Germany) and NGENUITY 3D Visualization System (Alcon Laboratories Inc., Fort Worth, TX, USA). 3D-HUS microscopes and operating systems have improved surgeon ergonomics and help avoid the deleterious delayed effects on the musculoskeletal system observed in surgeons operating on conventional microscopes.

In 3D-HUS visualization systems, crosstalk refers to incomplete isolation of the left and right images. Crosstalk impairs the 3D image quality often leading to ghost images. Tsuboi *et al.* studied the relationship between display position and crosstalk for HUS systems in ophthalmology and reported that crosstalk decreased with increasing display distance when viewing a screen with polaroid glasses.[4] A viewing distance of 1.2 m (47.2 in) is suggested for NGENUITY 3D-HUS system,[5] and 3–4 ft (36–48 in) for the ARTEVO system.[6] No studies have yet been performed to study the optimum monitor distance that balances the amount of crosstalk and provides adequate magnification and comfort to the surgeon as well.

However, the authors believe that there can be further refinement and optimization of the performance of these 3D-HUS systems. The factors helping in the optimization of these systems have not been studied in detail. The current study was undertaken to study the modifiable factors, which help in the optimization of the 3D-HUS visualization systems for improving surgeon ergonomics while performing ophthalmic surgeries.

Methods

This cross-sectional study was conducted at an ophthalmology operating room (OR) of our tertiary care center, which is equipped with a 3D-HUS monitor and a 3-D compatible viewing microscope [Fig. 1]. Data collection was done from a single surgeon and assistants. This study was assessed as minimal risk and, as such, was exempt from the institutional review board review. For images, informed consent to publish the images was gathered from all patients undergoing surgery in the OR.

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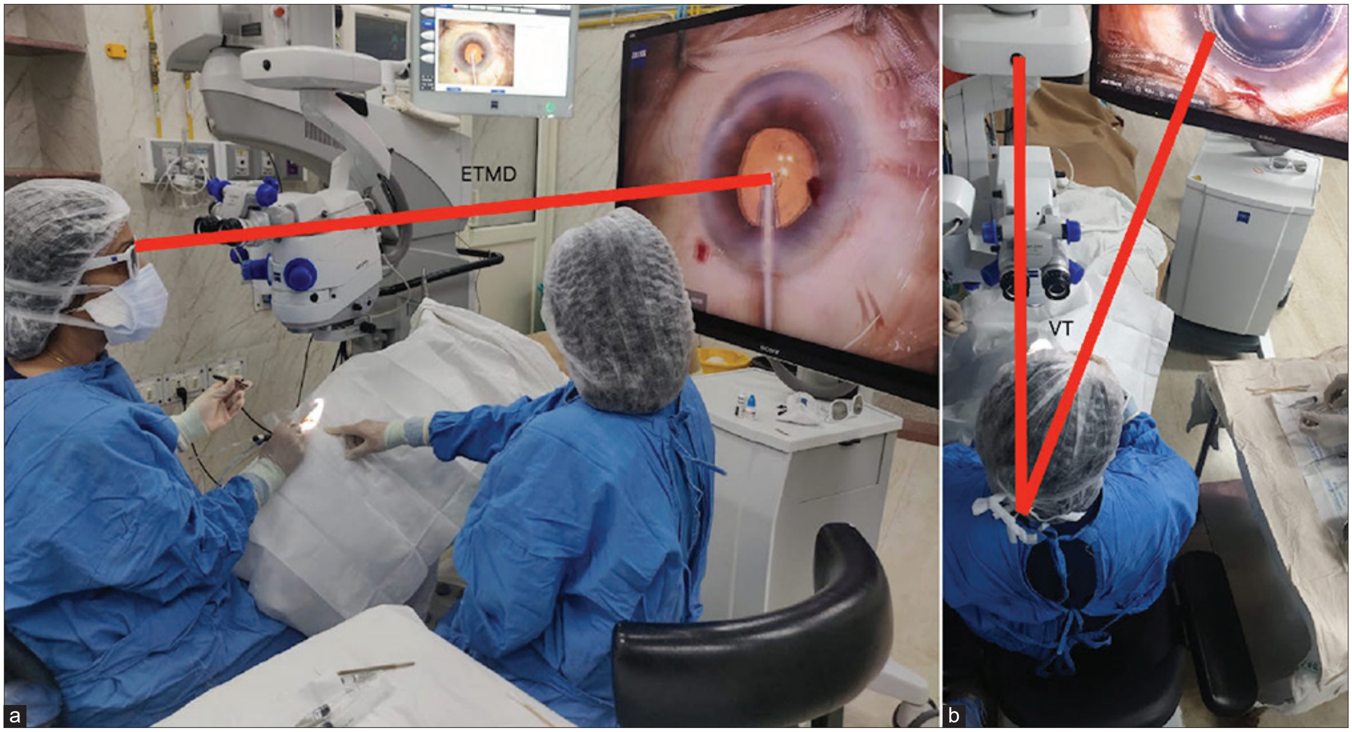

Figure 1: Measurement of (a) eye-to-monitor distance (ETMD) (b) viewing tilt (VT) angle measured from a picture taken with a bird's eye view

Technical specifications of 3D-HUS

ARTEVO 800 (Carl Zeiss Meditec) surgical microscope and visualization systems were used. Zeiss intraoperative Optical Coherence Tomography (OCT) (Rescan 700, Carl Zeiss Meditec) was used wherever intraoperative scanning was required. A 3D video monitor measuring 55″ mounted on a movable cart, allowing adjustments in the total height of the monitor (floor to the topmost point of the display) in the range of 67–72 in, was used.

Measurements taken in OR

A single surgeon was observed for a surgical position (adjusted as per the convenient ergonomics) during consecutive cataract surgeries performed on the ARTEVO system under peribulbar anesthesia. The surgeon's sitting position was superior (90°) in all cases. The measurements taken were monitor height (MH, i.e., the vertical distance of the center of the monitor from the floor), surgeon eye-to-floor distance (ETFD, i.e., the vertical distance of the surgeon eye level from the floor), surgeon eye-to-monitor distance (ETMD, i.e., the horizontal distance between the surgeon's eyes and the monitor) [Fig. 1a], viewing tilt (VT, i.e., the angle subtended between the ETMD and an imaginary line connecting the eyepiece of the microscope and the surgeon's back of the head) [Fig. 1b], and surgeon gaze height. The laterality of the operated eye was also recorded.

Eye and neck strain

Before and after each surgery, the surgeon and assistant rated their eye and neck strain as per Borg's CR-10 scale.[7,8] Three questions asked were "To what extent do your eyes ache or feel strained?" "To what extent do you have a burning or smarting sensation in your eyes?" and "To what extent do you feel pain or discomfort in your neck and/or shoulders" to rate the internal symptoms (related to accommodation or vergence stress), external symptoms (related to dry eye disorders), and neck strain, respectively.[9] The surgeon ensured a zero screen time (mobile devices, television screen, etc.) at least 2 h before surgeries, to reduce digital eye strain due to device use.

Eye centration

Different ophthalmology residents observed the eye centration on the 3D screen during the surgery, using 3D goggles. They judged the quality of the 3D display during the entire surgery while viewing the monitor sitting in the viewing plane of the surgeon.

Data analysis

All data were managed in a Microsoft Excel spreadsheet. Statistical analysis was performed using Statistical Package for the Social Sciences software (SPSS) version 17.0 (SPSS Inc. Chicago, IL, USA). Descriptive statistics were obtained for all parameters and data were expressed as mean ± standard deviation (SD). The mean values for ETFD, ETMD, and VT were evaluated for all surgeries by one-way repeated measures analysis of variance (ANOVA). *Post hoc* analysis was done to compare between different groups of data. A P value < 0.05 was considered to be statistically significant. All categorical data were analyzed using Pearson Chi-square test or Fisher's exact test.

Results

We conducted measurements for 30 surgeries (13 right, 17 left) on 8 OT days. On average, 2–4 (median: 4) cataract surgeries were evaluated from each OT day. The results are summarized in Table 1. The mean monitor distance after ergonomic adjustment for various surgeries was 67.4 ± 10.21 in.

Impact of monitor distance

We observed that the internal eye strain was more for surgeries done at a higher distance (ETMD) of monitor from the

Table 1: The various parameters noted during the surgeries performed using the ARTVEO 800 3-D HUS system

Parameter	Mean±SD	Range	Right Eye (*n*=13)	Left Eye (*n*=17)	*P*
Eye-to-monitor distance (in)	67.4±10.21	51-83	66.38±11.94	68.17±8.98	0.6
Eye-to-floor distance (in)	52±2.04	50-55	53.15±2.15	51.35±1.54	0.01
Viewing tilt (degrees)	29.69±7.06	10-34	29.69±2.56	17.82±4.54	<0.0001*
Neck strain	1.1±0.92	0-3	1.92±0.64	0.47±0.21	<0.0001*
Internal eye strain	0.46±0.51	0-1	0.46±0.51	0.47±0.51	0.9
External eye strain	0.23±0.43	0-1	0.38±0.51	0.11±0.33	0.06

*Significant *P*<0.5; SD=standard deviation

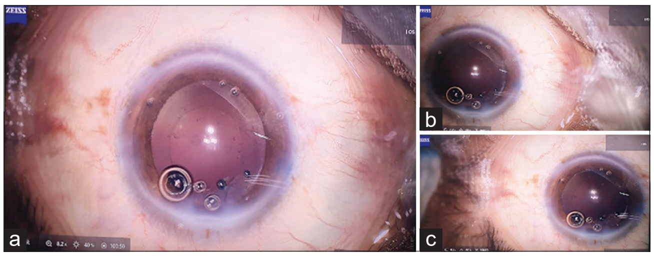

Figure 2: Images showing (a) better 3D visualization when the eye was well centered on the 3D monitor display screen and (b) impaired quality when the eye was at the corner of the monitor and (c) higher VT with right eye surgeries

surgeon ($r = 0.76$, $P < 0.0001$). The external eye strain and neck strain did not vary significantly, when ETMD varied ($r = -0.12$, $P = 0.51$ and $r = 0.13$, $P = 0.48$, respectively). ETMD did not depend on the laterality of the operated eye.

Viewing tilt or angle

The VT was higher for right eye surgeries than left eye surgeries (29.69 ± 2.56 vs. 17.82 ± 4.54 degrees, respectively; $P = <0.0001$). A higher neck strain score was associated with a higher VT ($r = 0.77$, $P < 0.0001$). The internal and external eye strain did not vary significantly with a change in VT.

Centration

The resident observing the surgeries noted better-quality 3D visualization and a good-quality 3D image when the eye was well centered on the 3D screen compared to the events when the eye was in the peripheral corners of the screen [Fig. 2].

Chair height

The mean chair height or ETFD was 52 ± 2.04 in. A higher neck strain was noted for lower ETFD ($r = 0.7$, $P < 0.001$), i.e., at lower chair heights, the surgeon experienced more neck strain [Fig. 3a]. The MH observed was in the range of 50–55 in. There was no significant effect on the eye strain scores with the adjustment of the ETFD. Also, the ETFD was higher for the right eye surgeries than the left eye surgeries.

Ergonomics of the assistant in surgeries

The assistant had less neck strain when left eye surgery was performed. The neck strain was reported to be more when the assistant was on the same side as the monitor screen [Fig. 3b].

Use of hybrid mode of 3D-HUS

There was a seamless transition when switching from seeing a 3D screen to seeing into binoculars of the microscope for the assistant and the surgeon both [Fig. 3c].

Figure 3: Image showing (a) greater neck strain (yellow arrow) with a lower eye-to-floor height of the surgeon (b) greater neck strain (yellow arrow) for the assistant when sitting on the same side as the screen (c) seamless transition (white arrow) for the assistant between the 3D screen and the binoculars of the microscope in the hybrid mode of the ARTEVO 800 system. Also, note the dim illumination of the operating room for a better 3D image quality

Effect of laterality

It was observed that the tilt while viewing and neck strain were significantly more for the right eye surgeries than for the left eye surgeries. The mean VT for the right eye and left eye was 29.69 ± 2.56 and 17.82 ± 4.54, respectively ($P < 0.0001$). The mean neck strain scores for the right eye and left eye were 1.92 ± 0.64 and 0.47 ± 0.21, respectively ($P < 0.0001$).

Effect of room illumination

The room had to be only dim lit to provide better contrast on the 3D monitor [Fig. 3c]. Dim illumination provided better 3D image quality. However, the neck strain and eye strain scores were the same with variations in room illumination.

Discussion

The 3D-HUS systems have expanded frontiers, have simplified ophthalmic surgeries, and are increasingly popular due to better ergonomics than conventional microscopes.[10] They provide a better experience to the surgeon, assistant, and the residents in training, who can watch the surgical steps from a distance. They also enable social distancing in the OR, especially useful in this coronavirus (COVID-19) era.[6] However, there is a need to define the variable parameters that can help optimize the surgical experience with the 3D-HUS systems.

The monitor display position strongly affects the image quality in 3D systems.[4] In the current study, we report that the surgeon's neck and eye strain were found to reduce with the adjustment of the surgeon chair height and monitor distance, respectively. A closer kept monitor, i.e., a lesser monitor distance (~50–55 in) was found to cause less eye strain to the surgeon. Similar to our finding, Tsuboi and coworkers report an optimum distance of 1.26 m (~49 in) with the NGENUITY 3D-HUS system to minimize the crosstalk (a phenomenon occurring with stereoscopic images on 3D displays) and improve the 3D image quality. Tsuboi and coworkers[4] also reported that the amount of crosstalk decreased with increasing display distance from the observer and increased when the eye level of the observer was too high or too low.

Usually, because the microscope swivel arm is kept toward the right-hand side of the surgeon, the surgeon has to maintain a head tilt while operating with the 3D-HUS systems to look out of the eyepiece of the surgical microscope during the right eye surgeries. This is relatively easier for left eye surgeries. In our study, we confirmed this hypothesis as the VT angle was observed to be more for the right eye surgeries [Fig. 1c]. This also causes slightly more neck strain to the surgeon in the right eye surgeries.

The various parameters affecting the 3D image quality, neck and eye strain are chair height, VT angle, eye centration, monitor distance, laterality of the eye, and room illumination. But the impact of these parameters on depth perception was not analyzed and this is one limitation of our study. Another limitation is the small sample size. Various studies comparing conventional and 3D-HUS microscope systems prove the improved ergonomics with 3D-HUS. As a corollary, in the future, comparative studies may be carried out to determine the contrast differences in the two systems, utilizing the same surgical team in two arms. Though the current study involved a single surgeon to remove the surgeon factors, e.g., variations in age, physiological built, sex, pain threshold, fatigue factor, etc., as a recommendation, future studies may also evaluate the experiences of multiple surgeons. Also, cataract surgery is a less time-consuming surgery and the inferences of this study may be further verified by studying ergonomics in more time-consuming ophthalmic surgeries. Chronic neck strain during ophthalmic surgeries of long duration can cause musculoskeletal problems in the ophthalmic surgeon. Nevertheless, to the best of our knowledge, our study is the first to report the methods to optimize the 3D-HUS surgical experience.

Conclusion

The experiential use of the 3D surgical microscope for ophthalmic surgeries with respect to image quality, neck and eye strain as perceived by the surgeon can be affected by objective quantitative parameters namely chair height, viewing tilt angle, eye centration, monitor distance, laterality of the eye and room illumination.

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Conflicts of interest

There are no conflicts of interest.

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