Original Article

Digitally assisted three-dimensional surgery – Beyond vitreous

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Purpose: The aim of this study was to evaluate the application and safety of three-dimensional (3D) visualization system in varied anterior segment procedures and Scleral Buckle. **Methods:** This was a prospective observational study of 313 eyes. Patients undergoing phacoemulsification (PE) with intraocular lens (IOL), trabeculectomies, glaucoma triple procedure (GTP), scleral fixated (SF) IOL, and scleral buckle (SB) were included in the study. Cases were randomly distributed in 3D visualization system (learning and post-learning phase) and conventional microscope group. Parameters studied were complications (intraoperative and early postoperative), surgical outcomes, and surgeon's perspective on various parameters (through a validated questionnaire) like surgical time, time lag, learning curve, ease of doing various steps and its value as an educational tool, for both groups [Questionnaires 1 and 2]. **Results:** Complications rates were not different in two groups. Surgical outcomes (anatomical and physiological) were similar in both the groups. Mean duration of surgery in PE+IOL, Trabeculectomy, GTP in learning stage by 3D was significantly higher than Microscope, which became insignificant in postlearning stage. For, SB and SFIOL, duration between two groups were insignificantly different. There was significant learning struggle in PE+IOL, SB, and Trabeculectomy. Image resolution, depth perception, illumination and postural comfort was graded higher for 3D surgery across the stages. Time lag, poor color contrast, and field of view were appreciated during the learning stage. Educational relevance of 3D was higher, as appreciated by resident and nurses. **Conclusion:** 3D surgery is as safe, faster, and predictable after initial learning struggle. Even in anterior segment procedure, no apparent lag was appreciated after learning curve.

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3D visualization system is a decade-old system, especially exploited in various vitreo-retinal (VR) surgeries with definitive advantages over conventional Microscope. Few reports have shown the use of this system in phacoemulsification (PE) with IOL implantation.[1] This study aimed to exploit the use of this system in various anterior segment procedures and SB, and analyses its advantages over conventional surgery. Improved field of view, depth, magnification, reduced need of illumination, better levels of contrast, sharpness, color & digital imaging, to enhance visualization are definitive advantages with this system in VR procedures.[2,3] Basic inhibition of its use in anterior segment is the Time Lag. Human brain can perceive the lag equivalent to or more than 50 ms. Current system had a lag of <70 ms. This lag is more appreciated in less time-consuming anterior segment surgeries, especially PE, because surgical manipulations in the anterior chamber are usually faster as compared to the ones in the posterior chamber.[4] This has been the concern & a major inhibiting factor for anterior segment surgeons to adopt this technique. The purpose of this study is to assess the surgical efficacy of 3D system in varied anterior segment surgeries and its direct comparison with conventional Microscopes.

Methods

This was a prospective observational study, which was conducted on 313 eyes of 278 patients from September 2018 to December 2019. Eyes were randomly assigned to two group viz., Group I: Surgery on analog Microscope, Group II: Surgery on 3D visualization system (Ngenuity by Alcon). To negate the influence of learning curve, Group II was further subdivided into Group II A: initial 15–30% cases (depending upon type of surgery) for learning phase and Group II B: 70–85% cases as postlearning phase. Learning phase was defined as the total number of surgeries performed by a surgeon on 3D system before he/she became proficient/comfortable enough to perform the various surgical steps with equal ease as he/she with analog microscope. The learning phase varies with type of surgery done. So, depending upon the type of surgery, number of cases in learning phase varied from 15-30%. More complicated the surgery is…more the number of cases included in learning phase. Distribution of patients in various groups

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were : PEIOL (Total n = 213, in group I n = 112, in II A group n = 15 & in II B group n = 86), GTP (Total n = 19, in group I n = 10, in II A group n = 02 & in II B group n = 07), SB (Total n = 34, in group I n = 17, in II A group n = 05 & in II B group n = 12), SFIOL (Total n = 23, in group I n = 11, in II A group n = 04 & in II B group n = 08), Trab (Total n = 26, in group I n = 13, in II A group n = 03 & in II B group n = 10). Surgeries were performed by 4 surgeons from the institute with at least 5 years of surgical experience. Patient's demographics, diagnosis, surgical procedure and time, intra-operative and early post-operative complications were noted. Ease of surgical step, comfort of surgeon and its educational value for resident and scrubbed nurse were noted for every surgery through a structured questionnaire. Study was performed according to ethical standards of the Declaration of Helsinki and approval from the ethics committee.

Statistical methods

Since 3D visualization system had two phases i.e., learning and post-learning, with different patient enrolments, these two phases were considered as two independent groups, in addition to Microscope group. All study variables were evaluated across these three study groups and for each surgical method. Continuous variables like age, visual acuity (VA) on logMAR scale, intra-ocular pressure (IOP) and duration of surgery were expressed in terms of mean and standard deviation, and compared between these groups using one-way ANOVA. Paired comparison between groups was performed using Tukey's *post hoc* test. Categorical variables like gender, time lag (present or absent) were expressed in terms of frequency and percentages and compared using Pearson's Chi-square test and Fisher's exact test respectively. Comparison between Microscope and 3D visualization system at post-learning phase for VA and IOP parameters after surgery for PE+IOL, GTP, Trabeculectomy, Scleral buckle, SFIOL was done using two-sample independent t-test. Moreover, perception of surgeons on different attributes related to viewing platform were captured in terms of scores (5-point scale), and were further compared between groups using the Kruskal–Wallis test, while the paired comparison between groups was performed using Wilcoxon rank-sum test. Further, surgeon's response was sought on ease of steps (5-point scale) and time taken (2-point scale) for each surgical method. These two parameters were considered simultaneously resulting into 10 combinations. Number of cases corresponding to each combination was obtained for each group and the comparison of distribution of cases between groups was performed using Fisher's exact test. Spearman rank correlation was used to evaluate the correlation between postural comfort (1: No discomfort – 5: Discomfort) and OT hours (<3 h, ≥3 h). Regarding educational value, resident and scrubbed nurses graded 3D versus Microscope on 1–5 scale, (1: No value – 5: High value). Comparison of responses across three groups was performed using Kruskal–Wallis test. All analyses were performed using SPSS ver 20.0 (IBM Corp., USA) and the statistical significance was tested at 5% level.

Results

The mean age of patients across three groups was insignificantly different ($P > 0.05$) in each surgical method [Table 1]. Proportion of male and female patients included in the study across three groups in each method was insignificantly different, except for Trabeculectomy. Similarly, difference of mean VA and mean IOP at preoperative stage was insignificantly different between groups for each surgical method ($P > 0.05$), except for Scleral buckle, where mean IOP was lower in Group I as compared to Group IIA and Group IIB.

Further, duration of surgery was compared between groups for each method [Table 2]. In PE+IOL, mean duration was significantly more in 3D visualization system during learning phase (13.11 ± 3.7 min) as compared to Microscope (9.74 ± 2.97 min) and post-learning phase of 3D visualization system (9.74 ± 2.79 min) with a P value of 0.0002. However, the difference of mean duration between Microscope and 3D visualization system (post-learning phase) was statistically insignificant. In GTP, learning phase of 3D system required significantly more time (48.83 ± 1.89 min) as compared to other two groups ($P = 0.048$). Observations for SFIOL and Trabeculectomy surgical methods were on similar lines. Mean duration was insignificantly different across groups for Scleral buckle method. Mean measurements of VA and IOP variables at postoperative stage were obtained for all surgical methods. Comparison of these parameters revealed statistically insignificant difference in post-stage measurements between Microscope and 3D visualization system (post-learning) for each method.

Surgeon's perception on different attributes related to viewing platform has been summarized as per group in Table 3 for each surgical method. Proportion of cases with time lag differed significantly between three groups, irrespective of the surgical method. Significance was mainly contributed by the learning phase (Group IIA). As regards learning struggle and field of view, median scores between groups differed significantly for all the surgical methods. For both the attributes, difference was contributed by 3D visualization system learning phase. Median scores for image resolution, depth of perception and illumination were significantly lower in Microscope as compared to 3D visualization system platform. Median scores for color contrast were also significantly different between groups, for all surgical methods. In Scleral buckle and Trabeculectomy methods, paired comparison revealed significant difference of median scores between three groups, with Microscope showing scores on a higher side as compared to 3D visualization system. For other surgical methods, overall significance was contributed by learning phase of 3D visualization system, while the difference between Microscope and post-learning phase of 3D visualization system were insignificant. Further, postural comfort of surgeons were observed, where median scores was significantly lower in post-learning phase of 3D visualization system (Group IIB) compared to other two groups for PE+IOL, Scleral buckle and SFIOL methods, revealing more comfort in post-learning phase. However, for GTP and Trabeculectomy methods, difference in median scores were insignificant between groups.

Table 4 shows comparison of surgeon's response on ease of step and time taken to complete the task between groups for each surgical method. Distribution of surgeons based on their response on ease of tasks and time taken for each task in three study groups has been given in Supplementary Table S1.

In PE+IOL, the response on easiness and routine time taken in surgery was significantly in favor of Microscope as compared to learning phase of 3D visualization system. For steps such as *Capsulorhexis and Phaco fragmentation*, Microscope continued to be easier as compared to 3D visualization system in

Table 1: Comparison of demographic and ocular parameters of patients between platforms for each surgical method

Surgical methods	Levels	Viewing Platform			P
		Microscope (Group I)	3D-Visulaization		
			Learning (Group IIA)	Post-Learning (Group IIB)	
Age in years [Mean±SD] (*n*)					
PE+IOL (213)		63.85±08.01 (112)	62.13±15.28 (15)	61.16±09.54 (86)	0.1306 (NS)*
GTP (19)		63.7±12.39 (10)	60.00±07.07 (2)	58.00±09.50 (7)	0.5845 (NS)*
Scleral buckle (34)		32.12±15.37 (17)	29.00±14.37 (5)	31.67±15.01 (12)	0.9203 (NS)*
SFIOL (23)		48.55±22.54 (11)	57.00±08.76 (4)	44.50±26.27 (8)	0.6685 (NS)*
Trabeculectomy (26)		40.54±20.96 (13)	55.00±10.00 (3)	52.00±18.26 (10)	0.2836 (NS)*
Gender [*n*. (%)]					
PE+IOL	Female (*n*=97)	51 (52.58)	6 (6.19)	40 (41.24)	0.8966 (NS)‡
	Male (*n*=116)	61 (52.59)	9 (7.76)	46 (39.66)	
GTP	Female (*n*=9)	6 (66.67)	1 (11.11)	2 (22.22)	0.4410 (NS)‡
	Male (*n*=10)	4 (40)	1 (10)	5 (50)	
Scleral buckle	Female (*n*=13)	7 (53.85)	2 (15.38)	4 (30.77)	0.9089 (NS)‡
	Male (*n*=21)	10 (47.62)	3 (14.29)	8 (38.1)	
SFIOL	Female (*n*=6)	2 (33.33)	1 (16.67)	3 (50)	0.6378 (NS)‡
	Male (*n*=17)	9 (52.94)	3 (17.65)	5 (29.41)	
Trabeculectomy	Female (*n*=10)	8 (80)	0 (0)	2 (20)	0.0442 (S)‡
	Male (*n*=16)	5 (31.25)	3 (18.75)	8 (50)	
Pre-operative visual acuity on LogMAR scale [Mean±SD]					
PE+IOL		0.65±0.83	0.84±0.81	0.62±0.62	0.5913 (NS)*
GTP		0.34±0.31	0.63±0.22	0.73±1.08	0.5362 (NS)*
Scleral buckle		1.18±0.73	0.71±0.77	0.80±0.52	0.2117 (NS)*
SFIOL		1.70±0.99	2.75±1.26	1.78±0.76	0.1833 (NS)*
Trabeculectomy		0.28±0.23	1.00±1.73	0.32±0.44	0.1851 (NS)*
Pre-operative intraocular pressure in mmHg [Mean±SD]					
PE+IOL		14.72±02.86	15.27±02.71	14.97±03.02	0.7227 (NS)*
GTP		18.70±06.38	23.50±02.12	22.00±14.80	0.7352 (NS)*
Scleral buckle		12.24±3.56[a]	14.60±3.44[b]	15.67±3.11[b]	0.0345 (S)*
SFIOL		20.27±08.71	28.75±12.09	18.13±08.03	0.1764 (NS)*
Trabeculectomy		24.92±13.57	30.33±10.12	22.10±07.91	0.5437 (NS)*

*Obtained using one-way ANOVA; ‡Obtained using Pearson's Chi-square test; Similar superscripts indicate statistical insignificance. S: Significant; NS: Non-Significant

post-learning phase; but *Irrigation & aspiration* and *IOL insertion* steps were much comfortable in 3D system post-learning phase as compared to Microscope. For anterior chamber entry, difference was insignificant between Microscope and 3D visualization system post-learning phase.

For GTP method, easiness along with routine time consumption was typical in Microscope as compared to learning stage of 3D visualization system for all relevant steps ($P < 0.05$); except for *Irrigation + Aspiration* and *IOL insertion*. However, these two steps showed improved easiness and less time consumption in postlearning phase of 3D system as compared to Microscope.

In Scleral buckle method, comparison between Microscope and 3D system learning phase was statistically significant for all the relevant steps, due to ease of steps and routine time consumption with Microscope. However, surgeon's response on these two parameters was similar for Microscope and 3D system post-learning phase, except for *Conjunctival suturing* and *SRF drainage steps*, wherein 3D post-learning phase was superior to Microscope.

For SFIOL method, ease of steps and time consumption was in favor of Microscope as compared to learning phase of 3D system for different steps, thereby resulting into statistical significance, except for *scleral tunnel* and *placing infusion cannula*. However, response on parameters for Microscope and 3D system post-learning phase were similar for all the steps except *scleral tunnel*.

Similarly, in Trabeculectomy, response on ease and time was in favor of Microscope than learning phase of 3D visualization system, resulting into statistical significance. However, response on parameters for Microscope and post-learning phase, for all the relevant steps, were similar resulting in statistical insignificance.

The educational value of 3D system was significantly more than Microscope irrespective of surgical method, as expressed by resident and nurses.

Table 5 shows a strong, positive and significant correlation between postural comfort and OT hours using Microscope in each surgical method. For 3D visualization system at learning phase, correlation was moderately positive between two

Table 2: Comparison of parameters between viewing platforms (groups) for each surgical method

Surgical methods	Viewing Platform			P[†]
	Microscope (Group I)	3D-Visualization		
		Learning (Group IIA)	Post-Learning (Group IIB)	
Duration of surgery in min [Mean±SD]				
PE+IOL	09.74±2.97[a]	13.11±3.70[b]	09.74±2.79[a]	0.0002 (S)
GTP	38.19±2.41[a]	48.83±1.89[b]	43.71±9.01[c]	0.0480 (S)
Scleral buckle	32.75±5.35	36.27±5.02	32.21±4.96	0.3285 (NS)
SFIOL	43.13±2.79[a]	51.37±5.62[b]	39.23±4.51[a]	0.0003 (S)
Trabeculectomy	26.06±2.51[a]	33.87±1.10[b]	27.55±3.29[a]	0.0009 (S)
	Post-op	Post-op	Post-op	P[¥]
Visual Acuity on LogMAR scale [Mean±SD]				
PE+IOL	0.03±0.07	0.02±0.06	0.03±0.07	0.9871 (NS)
GTP	0.10±0.17	0.63±0.22	0.60±1.50	0.4118 (NS)
Scleral buckle	0.77±0.73	0.35±0.40	0.53±0.39	0.2674 (NS)
SFIOL	0.18±0.10	0.21±0.06	0.25±0.18	0.3277 (NS)
Trabeculectomy	0.71±1.27	3.00±0.00	0.32±0.43	0.3646 (NS)
	Post-op	Post-op	Post-op	P[¥]
Intraocular pressure in mmHg [Mean±SD]				
PE+IOL	13.92±3.11	14.60±3.46	13.52±3.12	0.7335 (NS)
GTP	15.60±3.72	15.50±0.71	14.86±5.15	0.1783 (NS)
Scleral buckle	15.65±7.39	14.60±3.84	14.08±3.47	0.7665 (NS)
SFIOL	15.55±2.87	13.50±1.29	17.63±7.81	0.4924 (NS)
Trabeculectomy	18.62±9.60	17.33±6.11	25.00±12.41	0.1783 (NS)

[†]Comparison of duration of surgery between techniques using one-way ANOVA; Similar superscripts indicate statistical insignificance. [¥]Comparison of post-op VA, IOP between Microscope and 3D-Visualization (Post-learning) using two-sample independent *t*-test; S: Significant; NS: Non-Significant

parameter, but insignificant. At post-learning phase, correlation between parameters in PE+IOL method was moderately positive, which was statistically significant ($P < 0.0001$), while in other surgical methods, the correlation, although moderately positive, were statistically insignificant.

Discussion

3D visualization system is rapidly challenging the role of Microscope in VR procedures because of advantages it offers, like better illumination, depth perception, color contrast and field of view. Previous studies have shown the use of system in various VR procedures.[5-14] Few reports on the use of this system in the anterior segment procedures are reported in literature with varying results. Few studies have compared standard Microscope with 3D system in cases undergoing PE.[1,15,16] Few other case reports/case series have been reported with implantation of the Argus II Retinal Prosthesis,[17] corneal surgeries including non-Descemet stripping automated endothelial keratoplasty for post-traumatic bullous keratopathy[18] and Descemet membrane endothelial keratoplasty[19] and extraocular muscle surgery.[20,21] In a study by Ohno,[22] Toric IOL implantation with PE and trabecular micro bypass stent implantation in patients with cataract and open-angle glaucoma were performed using the heads-up 3D visualization system combined with surgical navigation. But, most of these studies were case reports or case series. All the studies showed the safety of this system with equivocal or definitive advantage of 3D surgery like illumination, color contrast and field of view over the traditional Microscope.

Any new system needs to be assessed first and foremost on the safety parameter. Complication rate with 3D visualization system was observed to be similar to that of conventional Microscope across various surgical procedure, which is in unison with the previous studies.[1,3,22] Also there was no new specific complication which could be attributed to the system per se. Surgical outcomes (VA, IOP, retinal attachment, lens centration & stability) assessed were also similar to that of Microscope. Thereby, our study proves the non-inferiority and safety of 3D system in varied anterior segment procedures.

Getting adapted to any new system moves through a learning curve. Learning curve, in context to skills training, refers to the time taken and/or number of procedures a practitioner needs, to be able to perform with equal ease and acceptable outcome. Various factors are involved in learning curve. One most important factor is, individual characteristics of the surgeon, such as attitude, capacity for acquiring new skills and previous experience. Slope of curve depends on nature of procedure and frequency of procedures performed in a specific time period. Also, rapidity of learning is not significantly related to surgeon's age, size of practice or hospital setting.[23] Hence, initial difficulties of adapting a new procedure during a learning curve can bias the opinion of a surgeon (for/against) for a new technique or an instrument. None of the previous studies negate the bias of learning phase. In our study we divided 3D group into learning phase and post-learning phase. Each and every surgical procedure was assessed under these two subgroups for 3D group. As with any other new system, in learning

Table 3: Perception of surgeon/resident/scrubbed nurse on different attributes related to viewing platform according to surgical method

	Viewing platform			*P*
	Microscope (Group I)	3D-Visualization		
		Learning (Group IIA)	Post-Learning (Group IIB)	
Time lag [No. (%)]				
PE+IOL	0	11 (100)	0	<0.0001 (HS)[¥]
GTP	0	2 (100)	0	0.0001 (S)[¥]
Scleral buckle	0	3 (100)	0	0.0001 (S)[¥]
SFIOL	0	2 (100)	0	0.0055 (S)[¥]
Trabeculectomy	0	3 (75)	1 (25)	0.0001 (S)[¥]
Surgeon - Learning Struggle [Mean±SD (Median)]				
PE+IOL	1.00±0.00 (1.00)[a]	1.33±0.49 (1.00)[b]	1.00±0.00 (1.00)[c]	<0.0001 (HS)*
GTP	1.20±0.42 (1.00)[a]	2.00±0.00 (2.00)[b]	1.00±0.00 (1.00)[a]	0.0118 (S)*
Scleral buckle	0.00±0.00 (0.00)[a]	1.40±0.89 (2.00)[b]	0.00±0.00 (0.00)[a]	<0.0001 (HS)*
SFIOL	1.00±0.00 (1.00)[a]	1.50±0.58 (1.50)[b]	1.00±0.00 (1.00)[a]	0.0069 (S)*
Trabeculectomy	0.15±0.38 (0.00)[a]	2.00±0.00 (2.00)[b]	0.00±0.00 (0.00)[a]	0.0002 (S)*
Surgeon - Image Resolution [Mean±SD (Median)]				
PE+IOL	2.00±0.00 (2.00)[a]	5.00±0.00 (5.00)[b]	5.00±0.00 (5.00)[b]	<0.0001 (HS)*
GTP	2.00±0.00 (2.00)[a]	5.00±0.00 (5.00)[b]	5.00±0.00 (5.00)[b]	<0.0001 (HS)*
Scleral buckle	2.00±0.00 (2.00)[a]	5.00±0.00 (5.00)[b]	5.00±0.00 (5.00)[b]	<0.0001 (HS)*
SFIOL	2.00±0.00 (2.00)[a]	5.00±0.00 (5.00)[b]	5.00±0.00 (5.00)[b]	<0.0001 (HS)*
Trabeculectomy	2.00±0.00 (2.00)[a]	5.00±0.00 (5.00)[b]	5.00±0.00 (5.00)[b]	<0.0001 (HS)*
Surgeon - Field of View [Mean±SD (Median)]				
PE+IOL	4.95±0.23 (5.00)[a]	3.93±0.80 (4.00)[b]	4.97±0.18 (5.00)[a]	<0.0001 (HS)*
GTP	5.00±0.00 (5.00)[a]	2.50±0.71 (2.50)[b]	4.57±0.53 (5.00)[a]	0.0033 (S)*
Scleral buckle	5.00±0.00 (5.00)[a]	2.40±0.55 (2.00)[b]	4.67±0.49 (5.00)[a]	<0.0001 (HS)*
SFIOL	4.73±0.47 (5.00)[a]	3.50±0.58 (3.50)[b]	5.00±0.00 (5.00)[a]	0.0011 (S)*
Trabeculectomy	5.00±0.00 (5.00)[a]	2.33±0.58 (2.00)[b]	4.70±0.48 (5.00)[a]	0.0003 (S)*
Surgeon - Depth of perception [Mean±SD (Median)]				
PE+IOL	2.97±0.16 (3.00)[a]	4.80±0.41 (5.00)[b]	4.98±0.15 (5.00)[c]	<0.0001 (HS)*
GTP	3.00±0.00 (3.00)[a]	4.00±0.00 (4.00)[b]	5.00±0.00 (5.00)[c]	0.0001 (S)*
Scleral buckle	3.00±0.00 (3.00)[a]	4.00±0.00 (4.00)[b]	5.00±0.00 (5.00)[c]	<0.0001 (HS)*
SFIOL	3.00±0.00 (3.00)[a]	4.50±0.58 (4.50)[b]	5.00±0.00 (5.00)[c]	<0.0001 (HS)*
Trabeculectomy	3.00±0.00 (3.00)[a]	4.00±0.00 (4.00)[b]	4.80±0.42 (5.00)[c]	<0.0001 (HS)*
Surgeon - Color of Contrast [Mean±SD (Median)]				
PE+IOL	4.96±0.19 (5.00)[a]	4.60±0.63 (5.00)[b]	5.00±0.00 (5.00)[a]	<0.0001 (HS)*
GTP	4.70±0.48 (5.00)[a]	3.00±0.00 (3.00)[b]	4.71±0.49 (5.00)[a]	0.0305 (S)*
Scleral buckle	5.00±0.00 (5.00)[a]	2.20±0.45 (2.00)[b]	3.58±0.51 (4.00)[c]	<0.0001 (HS)*
SFIOL	4.82±0.40 (5.00)[a]	2.50±0.58 (2.50)[b]	4.75±0.46 (5.00)[a]	0.0013 (S)*
Trabeculectomy	5.00±0.00 (5.00)[a]	2.33±0.58 (2.00)[b]	3.90±0.57 (4.00)[c]	<0.0001 (HS)*
Surgeon - Illumination [Mean±SD (Median)]				
PE+IOL	3.00±0.00 (3.00)[a]	5.00±0.00 (5.00)[b]	5.00±0.00 (5.00)[b]	<0.0001 (HS)*
GTP	3.00±0.00 (3.00)[a]	5.00±0.00 (5.00)[b]	5.00±0.00 (5.00)[b]	<0.0001 (HS)*
Scleral buckle	3.00±0.00 (3.00)[a]	5.00±0.00 (5.00)[b]	5.00±0.00 (5.00)[b]	<0.0001 (HS)*
SFIOL	3.00±0.00 (3.00)[a]	5.00±0.00 (5.00)[b]	5.00±0.00 (5.00)[b]	<0.0001 (HS)*
Trabeculectomy	3.00±0.00 (3.00)[a]	5.00±0.00 (5.00)[b]	5.00±0.00 (5.00)[b]	<0.0001 (HS)*
Surgeon - Postural Comfort [Mean±SD (Median)]				
PE+IOL	0.63±0.80 (0.00)[a]	0.33±0.49 (0.00)[a]	0.23±0.42 (0.00)[c]	0.0021 (S)*
GTP	0.80±0.92 (0.50)	0.00±0.00 (0.00)	0.14±0.38 (0.00)	0.1598 (NS)*
Scleral buckle	1.00±0.94 (1.00)[a]	0.20±0.45 (0.00)[a]	0.08±0.29 (0.00)[c]	0.0090 (S)*
SFIOL	0.91±0.83 (1.00)[a]	0.25±0.50 (0.00)[a]	0.13±0.35 (0.00)[c]	0.0520 (S)*

Contd...

Table 3: Contd...

	Viewing platform			P
	Microscope (Group I)	3D-Visualization		
		Learning (Group IIA)	Post-Learning (Group IIB)	
Trabeculectomy	0.85±0.90 (1.00)	0.00±0.00 (0.00)	0.20±0.42 (0.00)	0.0744 (NS)*
Education value - Residents [Mean±SD (Median)]				
PE+IOL	2.00±0.00 (2.00)^{a}	5.00±0.00 (5.00)^{b}	5.00±0.00 (5.00)^{b}	<0.0001 (HS)*
GTP	2.00±0.00 (2.00)^{a}	5.00±0.00 (5.00)^{b}	5.00±0.00 (5.00)^{b}	<0.0001 (HS)*
Scleral buckle	1.82±0.39 (2.00)^{a}	5.00±0.00 (5.00)^{b}	5.00±0.00 (5.00)^{b}	<0.0001 (HS)*
SFIOL	2.00±0.00 (2.00)^{a}	5.00±0.00 (5.00)^{b}	5.00±0.00 (5.00)^{b}	<0.0001 (HS)*
Trabeculectomy	2.00±0.00 (2.00)^{a}	5.00±0.00 (5.00)^{b}	5.00±0.00 (5.00)^{b}	<0.0001 (HS)*
Education value - Scrubbed Nurse [Mean±SD (Median)]				
PE+IOL	1.00±0.00 (1.00)^{a}	5.00±0.00 (5.00)^{b}	5.00±0.00 (5.00)^{b}	<0.0001 (HS)*
GTP	1.00±0.00 (1.00)^{a}	5.00±0.00 (5.00)^{b}	5.00±0.00 (5.00)^{b}	<0.0001 (HS)*
Scleral buckle	1.00±0.00 (1.00)^{a}	5.00±0.00 (5.00)^{b}	5.00±0.00 (5.00)^{b}	<0.0001 (HS)*
SFIOL	1.00±0.00 (1.00)^{a}	5.00±0.00 (5.00)^{b}	5.00±0.00 (5.00)^{b}	<0.0001 (HS)*
Trabeculectomy	1.00±0.00 (1.00)^{a}	5.00±0.00 (5.00)^{b}	5.00±0.00 (5.00)^{b}	<0.0001 (HS)*

¥Obtained using Fisher's Exact test; *Obtained using Kruskal Wallis test; Similar superscripts indicate statistical insignificance; HS: Highly Significant; S: Significant; NS: Non-Significant

Table 4: Significance values for comparison of surgeon's response on ease of steps along with time taken

Steps	PE+IOL		GTP		Scleral buckle		SFIOL		Trabeculectomy	
	M vs. L	M vs. PL	M vs. L	M vs. PL	M vs. L	M vs. PL	M vs. L	M vs. PL	M vs. L	M vs. PL
Anterior Chamber Entry	<0.0001 (HS)^{M}	0.9999 (NS)	0.0303 (S)^{M}	0.9999 (NS)	-		0.0571 (NS)	0.9999 (NS)	0.025 (S)^{M}	0.9999 (NS)
Capsulorhexis	<0.0001 (HS)^{M}	0.0145 (S)^{M}	<0.0001 (HS)^{M}	0.8575 (NS)	-		-		-	
Phaco fragmentation	<0.0001 (HS)^{M}	0.0145 (S)^{M}	0.0152 (S)^{M}	0.6372 (NS)	-		-		-	
Irrigation & amp; aspiration	<0.0001 (HS)^{L}	<0.0001 (HS)^{PL}	0.3182 (NS)	0.0004 (S)^{PL}	-		-		-	
IOL insertion	<0.0001 (HS)^{L}	<0.0001 (HS)^{PL}	0.9999 (NS)	0.0001 (S)^{PL}	-		-		-	
Conjunctival peritomy	-		0.0303 (S)^{M}	0.3088 (NS)	<0.0001 (HS)^{M}	0.1626 (NS)	0.0088 (S)^{M}	0.9999 (NS)	0.0036 (S)^{M}	0.6175 (NS)
Scleral flap	-		0.0152 (S)^{M}	0.5656 (NS)	0.0001 (S)^{M}	0.6645 (NS)	0.0088 (S)^{M}	0.9999 (NS)	0.0250 (S)^{M}	0.6693 (NS)
Conjunctival suturing	-		0.0152 (S)^{M}	0.5656 (NS)	<0.0001 (HS)^{M}	0.0049 (S)^{PL}	0.0088 (S)^{M}	0.9999 (NS)	0.0089 (S)^{M}	0.3132 (NS)
Iridectomy	-		0.0152 (S)^{M}	0.9999 (NS)	-		-		0.025 (S)^{M}	0.9999 (NS)
Punching	-		0.0152 (S)^{M}	0.9999 (NS)	-		-		0.025 (S)^{M}	0.9999 (NS)
Flap suturing	-		0.0152 (S)^{M}	0.9999 (NS)	-		0.0088 (S)^{M}	0.9999 (NS)	0.0089 (S)^{M}	0.3132 (NS)
Scleral tunnel	-		-		0.0007 (S)^{M}	0.9999 (NS)	0.2344 (NS)	0.0004 (S)^{PL}	-	
Buckle placement	-		-		<0.0001 (HS)^{M}	0.9999 (NS)	-		-	
SRF drainage	-		-		<0.0001 (HS)^{L}	<0.0001 (HS)^{PL}	-		-	
Placing infusion cannula	-		-		-		0.0571 (NS)	0.9999 (NS)	-	

P-values obtained using Fisher's exact test; HS: Highly Significant; S: Significant; NS: Non-Significant; Superscript shows the better method in comparison; M: Microscope (Group I); L: 3D-Visualization (learning phase) (Group IIA) and PL: 3D-Visualization (post-learning phase) (Group IIB)

Table 5: Spearman rank correlation co-efficient between postural comfort and OT hours

Surgical Methods	Viewing Platform		
	Microscope (Group I) [Coefficient; *P*]	3D-Visualization	
		Learning (Group IIA) [Coefficient; *P*]	Post-Learning (Group IIB) [Coefficient; *P*]
PE+IOL	0.709; <0.0001 (HS)	0.500; 0.0576 (NS)	0.456; <0.0001 (HS)
GTP	0.945; <0.0001 (HS)	-	0.354; 0.4365 (NS)
Scleral buckle	0.711; 0.0013 (S)	0.250; 0.6850 (NS)	0.255; 0.4241 (NS)
SFIOL	0.718; 0.0128 (S)	0.333; 0.6667 (NS)	0.488; 0.2199 (NS)
Trabeculectomy	0.687; 0.0094 (S)	-	0.408; 0.2415 (NS)

HS: Highly Significant; S: Significant; NS: Non-Significant

phase, learning struggle was seen in all types of surgeries, which became insignificant in later phase. Similarly, duration of surgery was found to be higher in all types of surgeries i.e., PE+IOL, GTP, Trabeculectomy, SFIOL and SB, in learning phase. But, during post-learning phase, duration of surgery was similar to as that with the Microscope group.

Ease of performing and time consumed for each step was assessed on a scale using a questionnaire. Capsulorhexis and phaco-fragmentation was perceived to be more time-consuming and difficult when compared to Microscope even in postlearning phase. Though objectively, the actual overall surgical time in all these procedures remained same. For rest of the steps, 3D system was found to be superior in post-learning phase. In fact, either there was no difference between the systems used or 3D system was found to be better for performing these steps.

The main concern expressed in the literature is the latency seen with 3D system and is the most important factor preventing the introduction of 3D system in anterior segment procedures. Time lag means, a period of time between performing an action and its visibility on the screen. Current system has <70 ms time lag. Human brain does not recognize time lag </= 50 ms. So, we analyzed whether time lag with the system negatively impacted surgeon's perspective and visual outcomes. In our study, it is seen that this time lag is appreciated only during learning phase, while in postlearning phase, surgeon did not perceive time lag in performing any step evaluated. Time lag was highly significant ($P < 0.0001$) in PE+IOL group, while it was significant in rest of the surgeries in learning phase only and it neither impacted the surgeons comfort, nor the surgical outcome.

Optical benefits of a 3D system are field of view, depth perception, color contrast and illumination. These benefits have been independently analyzed in our study. Field of view is the maximum area visible at any given moment and is inversely proportional to magnification. 3D system offers 30-40%[3] higher magnification than that of a Microscope. 3D system maintains a wide, high-resolution field of view even under high magnification, which means resolution is maintained across the entirety of the display. In this study, during learning phase, surgeons perceived difficulty in performing extra ocular steps like suturing and placement of buckle, as surgeon had to repeatedly adjust the field of interest. This problem was overcome in later phase, by learning to zoom out, specially while doing suturing and buckle placement. None of the intra-ocular steps posed challenge in context to field of view.

Depth perception is the ability to see things in 3 dimensions and image resolution is the details an image hold. For performing any step, better depth perception is the one factor which reduces complication rates even in complicated surgeries. Better the depth perception, least are the chances of complications. 3D system maintains depth of field even under high magnification, meaning that regardless of the area focused, each layer of that area is clear. As reported in other studies,[19,22] in our study also, depth perception and image resolution was appreciated superior to that of Microscope, in both phases of 3D visualization group.

Previous studies[5] have reported that, illumination needed to perform surgery is much less in 3D visualization system, thus minimizing the chances of photo toxicity. Digital modulation of 3D system facilitates better imaging, thus helping surgeon to operate at lower illumination levels.[3] In 3D system, illumination needed was 1/10th of the illumination used in Microscope. Though in less time-consuming anterior segment procedures, photo-toxicity is usually not reported and this factor is not of much importance.

According to surgeon's perspective, color contrast is the only optical parameter that was inferior to conventional Microscope in SB and Trabeculectomy group. In other surgeries, color contrast of 3D system scored over conventional Microscope. Red color in external surgeries, specially, when there is a bleed, hampers the quality interpretation of the structures. Color balance needs to be specifically adjusted on 3D system (red free filter to be used) while performing steps in a blood-filled field.

3D system (Ngenuity) offers 3 types of filters. Reduced red, Yellow & Blue filter. The beneficial effects of these filters are already established in vitreo-retinal procedures like improve visualization of epi-retinal membranes, vitreous or ILM. Even in anterior segment procedures these beneficial effects are seen in our study. For example, during phaco-emulsification, capsulorhexis becomes easy even with lesser amount of trypan blue, as the stained anterior lens capsule stands out prominent under red-free filter, hence reducing the toxicity of the dye. Also, in cases posterior capsular tear or while doing SFIOL, identification of vitreous in anterior chamber/ sectional wound was possible with blue filter without the use of triamcinolone acetate. Also, it is said that contrast is improved & glare is reduced by using yellow filter specially in cases with corneal scars. In our study, we shifted to yellow filter when encountering excess/disturbing glare specially in cases with corneal scars or high myopic patients & experienced the benefit of same. In our study, though we did not quantify the benefits of color filters during various steps, but, use of filters definitely over scores over conventional microscope.

Several studies have documented the deleterious effects of posture on the surgeon's spine.[24,25] 85% of retina surgeons complain of neck and back pain. By age 55, over 70% of ophthalmologists have neck, back or shoulder injuries.[26] Anterior segment surgeries are short-duration surgery and therefore this factor becomes irrelevant in shorter working hours. But, for high-volume surgeon where cumulative OT duration is more, ergonomics can be a factor of significance. In this study, we found 3D visualization system to be better in terms of postural comfort, especially noted in group >3 hours (maximum had discomfort after 4 hours).

Educational advantage of 3D has been quoted in various studies.[27] We also assessed the educational benefits of the system for residents as well as scrubbed nurses, based on a questionnaire. For every surgical method, value for 3D system (median score: 5) was significantly higher than Microscope (median score: 2), implying relevance of 3D over Microscope.

Limitations of the study

1. Except for Phacoemulsification + IOL group, rest groups have small sample size.
   RCT's with larger sample size are needed to establish the equivalence or superiority of 3D surgery over conventional microscope in anterior segment procedures.
2. Segments involving surgeries of Cornea & Oculoplasty are not included in the study.

Conclusion

This is the largest case series done on 3D visualizing system, for various anterior segment procedures and where 3D system is directly compared with conventional Microscope using objective and subjective parameters to assess and compare the two systems. Equivalent complications rate and no need to convert back to Microscope proves the safety and non-inferiority of 3D visualization system. This system opens up a plethoras of opportunities also for anterior segment. In summary, it's a complete system for any operation theater with all the benefits of viewing, ergonomics and teaching platform.

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Conflicts of interest

There are no conflicts of interest.

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Questionnaire 1: For Heads-Up Surgery and Traditional Binocular Microscope

MRD No:

Surgery Done:

Surgeon name, Age, Refractive power :

Assistant`s Name:

	Time lag	Learning curve	Image resolution	Field of view	Depth perception	Contrast	Illumination	Body comfort	
								Duration of surgery	OT hours before this case
Surgeon									

	Educational value
Resident	
Scrubbed nurse	

Scale:

1. Time lag : Yes/No
2. Learning Struggle : 1-5
   1- No struggle
   5- Maximum struggle
3. Image resolution: 1-5
   1- Less resolution
   5- Best resolution
4. Field of view : 1-5
   1- Poor
   5- Comfortable
5. Depth perception : 1-5
   1- Less
   5- Best
6. Colour contrast : 1-5
   1- Poor
   5- Comfortable
7. Illumination : 1-5
   1- Lowest
   5- Best
8. Postural comfort : 1-5
   1-2 : No discomfort
   3. : Mild Discomfort
   4-5 : Discomfort
9. OT hours : to calculate postural comfort :
   <3h
   >/= 3 h
10. Education value : Resident/Scrubbed staff : 1-5
   1- Least educational
   5- Best

Questionnaire 2: Regarding Ease of Tasks and Time taken for Various Steps of Surgery

Steps	Ease of step	Time taken	Others
Anterior Chamber Entry			
Capsulorhexis			
Phaco fragmentation			
Irrigation & aspiration			
IOL insertion			
Conjunctival peritomy			
Scleral flap			
Conjunctival suturing			
Iridectomy			
Punching			
Flap suturing			
Scleral tunnel			
Buckle placement			
SRF drainage			
Placing infusion cannula			

Scale :

Time (Subjective time for surgeon) :
- M - More
- R - Routine

Ease of step : 1-5
1. - Easy
5. - Most difficult

Table S1: Distribution of as per ease of task and time taken in three groups as per surgery				
Categories		Viewing platform		
		Microscope (Group I) (Frequency)	3D-Visualization	
			Learning (Group IIA) (Frequency)	Post-Learning (Group IIB) (Frequency)
Anterior Chamber Entry (Ease of step -Time)				
PE+IOL	1-R	112	5	84
	2-M	0	1	0
	2-R	0	5	2
	3-M	0	3	0
	3-R	0	1	0
GTP	1-R	8	0	5
	2-R	2	0	2
	3-M	0	2	0
SFIOL	1-R	11	2	8
	2-M	0	2	0
Trabeculectomy	1-R	13	1	10
	2-M	0	2	0
Capsulorhexis (Ease of step -Time)				
PE+IOL	1-R	112	5	81
	2-M	0	1	0
	2-R	0	4	5
	3-M	0	3	0
	3-R	0	2	0
GTP	1-R	7	0	4
	2-M	1	0	0
	2-R	2	0	2
	3-M	0	2	0
	3-R	0	0	1
Phacofragmentation (Ease-Time)				
PE+IOL	1-R	112	5	81
	2-M	0	1	0
	2-R	0	4	5
	3-M	0	3	0
	3-R	0	2	0
GTP	1-R	6	0	3
	2-R	4	0	4
	3-M	0	2	0
Irrigation & amp; aspiration (Ease of step -Time)				
PE+IOL	1-R	0	9	83
	2-M	0	3	0
	2-R	112	1	3
	5-M	0	1	0
	5-R	0	1	0
GTP	1-R	1	0	7
	2-M	0	1	0
	2-R	9	1	0
IOL insertion (Ease of step -Time)				
PE+IOL	1-R	0	9	83
	2-M	0	3	0
	2-R	112	1	3
	5-R	0	2	0

Contd...

Table S1: Contd...

Categories		Viewing platform		
		Microscope (Group I) (Frequency)	3D-Visualization	
			Learning (Group IIA) (Frequency)	Post-Learning (Group IIB) (Frequency)
GTP	1-R	0	0	7
	2-R	10	2	0
Conjunctival peritomy (Ease of step -Time)				
GTP	1-M	0	0	1
	1-R	8	0	6
	2-M	0	1	0
	2-R	2	0	0
	3-M	0	1	0
Scleral buckle	1-R	17	0	10
	2-M	0	2	0
	2-R	0	0	2
	3-M	0	3	0
SFIOL	1-R	11	1	8
	2-M	0	1	0
	3-M	0	2	0
Trabeculectomy	1-M	2	0	3
	1-R	11	0	7
	2-M	0	1	0
	3-M	0	2	0
Scleral flap (Ease of step -Time)				
GTP	1-R	7	0	5
	2-M	0	0	1
	2-R	3	0	1
	3-M	0	2	0
Scleral buckle	1-R	12	0	10
	2-M	0	1	0
	2-R	5	0	2
	3-M	0	4	0
SFIOL	1-R	11	1	8
	2-M	0	1	0
	3-M	0	2	0
Trabeculectomy	1-R	7	0	7
	2-R	6	1	3
	3-M	0	2	0
Conjunctival suturing (Ease of step -Time)				
GTP	1-R	7	0	5
	2-M	0	0	1
	2-R	3	0	1
	3-M	0	2	0
Scleral buckle	1-R	9	0	5
	2-M	0	0	4
	2-R	8	0	1
	3-M	0	2	2
	3-R	0	3	0
SFIOL	1-R	6	0	5
	2-R	5	1	3
	3-M	0	3	0

Contd...

Table S1: Contd...

Categories		Viewing platform		
		Microscope (Group I) (Frequency)	3D-Visualization	
			Learning (Group IIA) (Frequency)	Post-Learning (Group IIB) (Frequency)
Trabeculectomy	1-R	9	0	6
	2-R	4	1	2
	3-M	0	0	2
	4-M	0	2	0
Iridectomy (Ease of step -Time)				
GTP	1-R	10	0	7
	2-M	0	2	0
Trabeculectomy	1-R	13	1	10
	2-M	0	1	0
	2-R	0	1	0
Punching (Ease of step -Time)				
GTP	1-R	10	0	7
	2-M	0	2	0
Trabeculectomy	1-R	13	1	10
	2-M	0	1	0
	2-R	0	1	0
Flap suturing (Ease of step -Time)				
GTP	1-R	10	0	7
	2-M	0	2	0
SFIOL	1-R	11	1	8
	2-M	0	1	0
	3-M	0	2	0
Trabeculectomy	1-R	9	0	6
	2-R	4	1	2
	3-M	0	0	2
	4-M	0	2	0
Scleral tunnel (Ease of step -Time)				
Scleral buckle	1-R	17	1	12
	2-M	0	1	0
	2-R	0	1	0
	3-M	0	2	0
SFIOL	1-M	2	0	0
	1-R	1	2	8
	2-M	5	0	0
	2-R	3	2	0
Buckle placement (Ease of step -Time)				
Scleral buckle	1-R	13	0	10
	2-M	0	3	0
	2-R	4	0	2
	3-M	0	2	0
SRF drainage (Ease of step -Time)				
Scleral buckle	1-R	0	5	12
	2-R	17	0	0
Placing infusion cannula (Ease of step -Time)				
SFIOL	1-R	11	2	8
	2-R	0	2	0

Ease of steps:- Easy (1), Somewhat difficult (2), Difficult (3), Very difficult (4) and Most difficult (5). Time taken for surgery:-More, Routine