· Clinical Research ·

Utility of 3D-display surgical videos for better educational effects in pediatric persistent fetal vasculature for trainees

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Abstract

● **AIM:** To compare the educational benefits of three-dimensional (3D) surgical videos compared with two-dimensional (2D) surgical videos as a training tool for trainees in pediatric persistent fetal vasculature (PFV).

● **METHODS:** Trainees were stratified into three tiers by retinal surgery exposure and independent operating experience: Level 1 (≤5y, no independent cases), Level 2 (5–10y, ≤5 independent years), Level 3 (>10y, >5 independent years). Trainees viewed 3D and 2D surgical videos of pediatric PFV in a randomized order and immediately completed a questionnaire to provide educational assessments.

● **RESULTS:** Twelve trainees viewed 9 paired 3D and 2D surgical videos from 9 pediatric PFV patients (9 3D videos and 9 2D videos), resulting in 216 completed questionnaires. For pediatric PFV cases, trainees demonstrated a higher accuracy rate when watching 3D surgical videos compared to 2D surgical videos in discerning the depth of the anterior chamber (85.2% *vs* 70.4%, χ^2=6.857, P=0.009), the location of lens opacity (86.1% *vs* 69.4%, χ^2=8.679, P=0.003), and vitreous strips (89.8% *vs* 78.7%, χ^2=5.027, P=0.025). Trainees believed that, compared to 2D surgical videos, 3D surgical videos significantly improved their ability to discriminate shallow anterior chambers (5.70±1.58 *vs* 3.92±1.14, P<0.001), the location of lens opacity (6.80±1.60 *vs* 4.36±1.35, P<0.001), vitreous strips (9.06±2.02 *vs* 7.16±2.42, P<0.001), complicated tractional retinal detachment (9.31±2.13 *vs* 7.99±2.63, P<0.001), and macular involvement (8.47±2.62 *vs* 6.91±2.84, P<0.001) in pediatric PFV cases. Trainees found 3D surgical videos to be significantly more satisfactory than 2D surgical videos in terms of image magnification (8.90±1.61 *vs* 7.17±1.65, P<0.001), clarity (9.21±2.11 *vs* 7.42±2.27, P<0.001), and depth of field (8.31±2.38 *vs* 6.78±2.79, P<0.001). Trainees regarded 3D surgical videos as significantly more suitable for ophthalmic surgical teaching (9.23±0.83 *vs* 5.75±0.93, P<0.001) and implementation (8.83±2.69 *vs* 6.15±2.83, P<0.001) compared to 2D surgical videos.

● **CONCLUSION:** 3D-display surgical videos offer superior educational benefits for trainees earning pediatric PFV vitrectomy surgery compared to 2D videos.

● **KEYWORDS:** 3D-display; education; pediatric; vitrectomy; persistent fetal vasculature; medical education

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INTRODUCTION

Vitreoretinal surgery, particularly in pediatric cases, poses significant challenges due to limited access and the need for specialized techniques[1-2]. The increasing focus on pediatric fundus diseases globally underscores the need for effective training methods[3], the complexity of pediatric vitreoretinal surgery and the lengthy training required highlight the urgent need for advanced educational tools[4-6]. Lack of high-quality educational resources, including videos, further complicates training in this area[7].

Three-dimensional (3D) surgical video systems offer enhanced depth perception and visualization, potentially improving educational outcomes[8-10]. Studies suggest that 3D systems provide clearer imaging and better anatomical discrimination compared to traditional two-dimensional (2D) systems, show promise in improving surgical outcomes and training efficiency[11-13]. Despite their advantages, their use in teaching pediatric vitreoretinal surgery remains limited.

This study aims to evaluate the effectiveness of 3D surgical video systems in training trainees for pediatric vitreoretinal surgeries, especially for persistent fetal vasculature (PFV).

PARTICIPANTS AND METHODS

Ethical Approval This prospective trial was conducted at the department of pediatric retina of Beijing Tongren Hospital, China, after taking approval from the Ethic Committee Board (Approval No. TRECKY2024-KY044). The study adheres with the tenets of the Declaration of Helsinki. Written informed consent was obtained from the legal guardians of all enrolled participants prior to study enrollment.

Machine Information The surgical videos in this study were recorded using the OPMI Lumera T surgical microscope and the RESIGHT 500 wide-angle viewing system (ZEISS, Oberkochen, Germany). The 3D visualization system utilized was the NGENUITY 3D Visualization System, marketed by Alcon (Fort Worth, Texas, USA) in collaboration with True Vision Visualization System (Santa Barbara, California, USA).

Selection of Surgical Videos The surgical videos selected for analysis in this study included both 3D and 2D recordings of pediatric PFV surgeries. Pediatric PFV cases were defined as patients aged ≤14y, presenting with a definitive retrolental vitreous stalk extending to the optic disc, with or without retinal detachment. These cases can be further categorized based on pathological location into anterior, posterior, and combined types. Anterior PFV is characterized by a fibrovascular membrane surrounding the lens or attached to the posterior capsule within the pupillary zone, accompanied by a retrolental vitreous membrane and stalk extending to the optic disc, without retinal detachment. Posterior PFV is defined by the presence of a retrolental vitreous membrane and stalk reaching the optic disc, with retinal detachment but without posterior lens opacification or fibrovascular membrane. Combined PFV exhibits features of both anterior and posterior PFV.

These cases were managed with pars plana vitrectomy, with or without lens surgery, using a 3D system, and had both 3D and 2D surgical video recordings. The PFV cases exhibited a range of clinical signs, including shallow anterior chamber, varying levels of lens opacity (involving the anterior capsule, central cortex, or posterior capsule), and different degrees of vitreous cord thickness and traction retinal detachment in the posterior pole. These clinical signs were differentiated during surgery and were evaluated by the doctors in this study through prospective viewing of the surgical videos. All surgeries were performed by a single senior experienced surgeon, Professor Lu H. Following our hospital's standard protocol, both 3D and traditional 2D video-recording systems were available in the same operating room, ensuring that each PFV case had simultaneous 3D and 2D video recordings.

Assessment of Educational Impact of 3D and 2D Surgical Videos

Participants This study selected trainees at three different experience levels as research subjects. The participants, divided into three subgroups based on their clinical experience, viewed 3D and 2D surgical videos of pediatric PFV in a randomized order and immediately completed a questionnaire to provide educational assessments. The inclusion criteria were as follows: all participating doctors had never participated in or observed pediatric PFV surgeries using a 3D head-up display but had experience with other 3D surgeries. The subgroups were categorized as follows: Level 1: trainees with a master's degree or higher, with at least 3y of professional knowledge in ophthalmology, who have participated in retinal surgeries for 5y or less, but have no experience as an independent surgeon in retinal surgeries; Level 2: trainees with a master's degree or higher, who have participated in retinal surgeries for 5 to 10y, and have experience as an independent surgeon in retinal surgeries for 5y or less; Level 3: trainees with a master's degree or higher, who have participated in retinal surgeries for over 10y, and have experience as an independent surgeon in retinal surgeries for over 5y.

Questionnaire The questionnaire was developed with the assistance of a highly experienced surgeon with over 15y of experience in performing vitreo-retinal surgeries. To prevent bias, the questionnaires were anonymized and compiled by the hospital's statistics department. The questionnaire was also pre-tested among a pilot group of 5 trainees not included in the main study to ensure clarity and comprehensibility of the questions and the internal consistency of the questionnaire was assessed using Cronbach's alpha coefficient, which yielded a value of 0.87, indicating good reliability. The questionnaire, featuring multiple-choice questions, was designed to assess surgeons' experience and insights while observing surgical videos depicting various clinical scenarios involving pediatric patients with PFV. Furthermore, the questionnaire design primarily addresses three factors: the accuracy of discrimination, the difficulty of discrimination, and assessment of visualization effectiveness. Detailed questions and answer options included in the questionnaire are presented in Table 1.

Statistical analysis was conducted using SPSS version 23.0. Measurement data are presented as mean±standard deviation, while categorical data are expressed as frequencies and percentages. The independent sample *t*-test was employed to compare measurement data between groups, and Chi-square

Table 1 Summary of questionnaire contents

Questions	Answer options				
1) What do you think of the depth of the patient's anterior chamber	□ Normal	□ Shallow	□ Absent		
2) What do you think of the level of difficulty to distinguish the depth of the patient's anterior chamber	1: Almost unrecognizable	3: Difficult	5: Neither	7: Easy	10: Very easy
3) Does the patient have lens opacity	□ Yes	□ No	□ Unclear		
4) If there is lens opacity, the location of lens opacity is:	□ Anterior capsular	□ Anterior cortex	□ Posterior cortex	□ Posterior capsular	
5) From the video, does the patient have vitreous strips	□ Yes	□ No	□ Unclear		
6) From the video, does the patient have tractional retinal detachment	□ Yes	□ No	□ Unclear		
7) From the video, does the patient have macular detachment	□ Yes	□ No	□ Unclear		
8) What do you think of the level of difficulty to distinguish the location of lens opacity	1: Almost unrecognizable	3: Difficult	5: Neither	7: Easy	10: Very easy
9) Are you satisfied with the stereoscopic effect on visualizing the vitreous strips	1: Strongly dissatisfied	3: Dissatisfied	5: Neither	7: Satisfied	10: Very much satisfied
10) Are you satisfied with the stereoscopic effect on visualizing tractional retinal detachment	1: Strongly dissatisfied	3: Dissatisfied	5: Neither	7: Satisfied	10: Very much satisfied
11) Are you satisfied with the stereoscopic effect on visualizing the conditions of macular involved by pathological changes	1: Strongly dissatisfied	3: Dissatisfied	5: Neither	7: Satisfied	10: Very much satisfied
12) In terms of surgery training on PFV patients, your satisfaction with the magnification of the video is:	1: Strongly dissatisfied	3: Dissatisfied	5: Neither	7: Satisfied	10: Very much satisfied
13) In terms of surgery training on PFV patients, your satisfaction with the image clarity of this video is:	1: Strongly dissatisfied	3: Dissatisfied	5: Neither	7: Satisfied	10: Very much satisfied
14) In terms of surgery training on PFV patients, your satisfaction with visualizing the depth of field and stereopsis of this video is:	1: Strongly dissatisfied	3: Dissatisfied	5: Neither	7: Satisfied	10: Very much satisfied
15) Which field of vision do you think is more favorable for ophthalmic surgery training, 2D or 3D	1: 2D perfectly better	3: 2D better	5: No difference	7: 3D better	10: 3D perfectly better
16) Which field of vision do you think is more favorable for ophthalmic surgery implementation, 2D or 3D	1: 2D perfectly better	3: 2D better	5: No difference	7: 3D better	10: 3D perfectly better

3D: Three-dimension; 2D: Two-dimension; PFV: Persistent fetal vasculature.

tests were used for categorical data comparisons. A *P*-value of less than 0.05 was deemed statistically significant.

RESULTS

This study involved 12 trainees with 4 in each group. A total of 18 surgical videos, depicting 9 pediatric PFV patients, were selected for review. Each patient had both 3D and 2D surgical videos available. The 12 trainees from three different groups completed a total of 216 questionnaires after viewing the 18 surgical videos in a randomized sequence. All 9 pediatric PFV patients exhibited vitreous cords, with the clinical types distributed as follows: 3 cases of anterior segment type, 2 cases of posterior segment type, and 4 cases of combined type. The additional clinical findings included 7 cases of complicated cataract and pupil opacity, 6 cases of traction retinal detachment, 2 cases of shallow anterior chamber, and 1 case of absent anterior chamber. Totally 7 patients underwent vitrectomy combined with lensectomy, while 2 patients underwent vitrectomy combined with cataract phacoemulsification and intraocular lens implantation. Among them, 2 patients performed through the limbus approach with either a shallow anterior chamber or absent anterior chamber.

Accuracy of Discrimination Summary of clinical manifestations is in Figure 1. The overall accuracy rates of the 12 trainees in evaluating key ocular features, including anterior chamber depth, lens opacity, location of lens opacity, vitreous strands, tractional retinal detachment, and macular detachment, are presented in Table 2. Additionally, the table provides a breakdown of the accuracy rates across three distinct groups: 4 senior trainees (Level 3 group), 4 junior trainees (Level 2 group), and 4 fellows (Level 1 group), each assessed in their ability to evaluate the aforementioned ocular manifestations.

Comparative analysis revealed that trainees at all experience levels achieved higher accuracy in distinguishing various ocular manifestations using 3D surgical videos compared to 2D surgical videos. Specifically, for assessing the depth of the anterior chamber (85.2% *vs* 70.4%, χ^2=6.857, *P*=0.009), location of lens opacity (86.1% *vs* 69.4%, χ^2=8.679, *P*=0.003), and vitreous strips (89.8% *vs* 78.7%, χ^2=5.027, *P*=0.025), the accuracy with 3D surgical videos was significantly higher than with 2D surgical videos. For the location of lens opacity, both fellows (77.8% *vs* 55.6%, χ^2=4.000, *P*=0.046) and senior trainees (97.2% *vs* 83.3%, χ^2=3.956, *P*=0.047) demonstrated significantly higher accuracy when using 3D surgical videos compared to 2D surgical videos. Moreover, junior trainees showed significantly higher accuracy in identifying vitreous strips (88.9% *vs* 69.4%, χ^2=4.126, *P*=0.042) using 3D surgical videos compared to 2D surgical videos. For further details, please refer to Table 2.

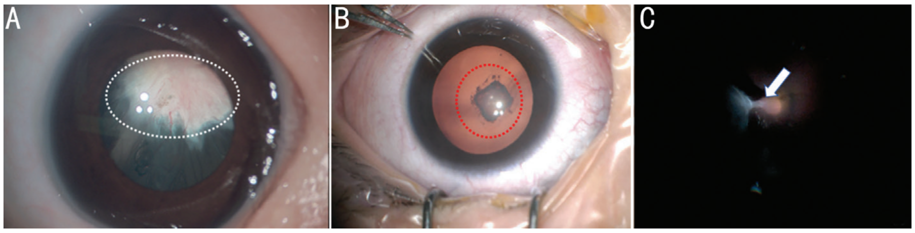

Figure 1 Various ocular manifestations in pediatric PFV A: 3-month old boy diagnosed with PFV (genetic testing results ruled out hereditary eye diseases) with shallow anterior chamber. White dotted circle indicates posterior neovascular membrane; B: PFV with posterior capsular lens opacification. Red dotted circle indicates posterior lens opacification; C: PFV with tractional retinal detachment. White arrow indicates tractional retinal detachment. PFV: Persistent fetal vasculature.

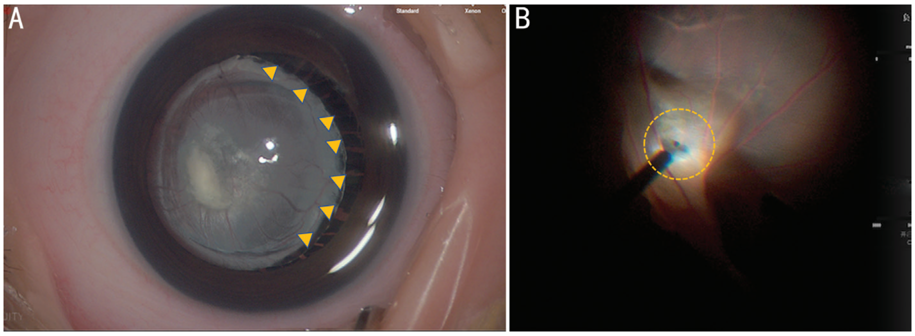

Figure 2 Images and videos illustrate two PFV subtypes with distinct lesions A: An anterior-type PFV, with extensive vascular membrane behind the posterior lens capsule and elongated nasal ciliary processes (marked by yellow triangles); B: Mixed-type PFV characterized by elevated tractional retinal detachment at the posterior pole, accompanied by retinal breaks within the detached area (enclosed by yellow dotted circles). Comparative analyses of synchronously recorded 2D (Figure 2A-video-2D, Figure 2B-video-2D) and 3D (Figure 2A-video-3D, Figure 2B-video-3D) intraoperative videos reveal prominent differences in image definition and stereopsis between the two imaging modalities. PFV: Persistent fetal vasculature; 2D: Two-dimensional; 3D: Three-dimensional.

Difficulty of Discrimination We compared and analyzed the differences in satisfaction levels among trainees of varying expertise in identifying anterior and posterior segment anatomical structures and assessing the stereoscopic sense of lesions in 3D versus 2D surgical videos. These lesions included the depth of the anterior chamber, the location of lens opacity, vitreous strips, tractional retinal detachment, and macular detachment. Trainees believed that, compared to 2D surgical videos, 3D surgical videos significantly improved their ability to discriminate shallow anterior chambers (5.70±1.58 *vs* 3.92±1.14, P<0.001), the location of lens opacity (6.80±1.60 *vs* 4.36±1.35, P<0.001), vitreous strips (9.06±2.02 *vs* 7.16±2.42, P<0.001), complicated tractional retinal detachment (9.31±2.13 *vs* 7.99±2.63, P<0.001), and macular involvement (8.47±2.62 *vs* 6.91±2.84, P<0.001) in pediatric PFV cases.

The results also indicated that for both fellows (Level 1 group) and junior trainees (Level 2 group), 3D surgical videos significantly enhanced the trainees' ability to identify lesions and provided higher satisfaction with the stereoscopic sense compared to 2D surgical videos, enabling more accurate identification of the anterior and posterior segment anatomical structures.

Additionally, similar to the trainees in the Level 1 and Level 2 groups, those in the Level 3 group (senior trainees) were more effective at identifying anterior segment anatomical structures and lesions, such as the depth of the anterior chamber (6.77±1.54 *vs* 4.38±0.79, P<0.001) and the location of lens opacity (7.91±1.23 *vs* 5.33±0.90, P<0.001), when viewing 3D surgical videos compared to 2D surgical videos. However, unlike the first two groups, the Level 3 trainees did not show significantly higher satisfaction with using 3D surgical videos over 2D videos for identifying vitreoretinopathy, including vitreous strips (9.07±2.54 *vs* 8.08±2.69, P=0.113), tractional retinal detachment (9.56±2.79 *vs* 9.12±3.21, P=0.537), and macular detachment (9.05±2.89 *vs* 7.68±3.01, P=0.053).

Assessment of Visualization Effectiveness Trainees found 3D surgical videos to be significantly more satisfactory than 2D surgical videos in terms of image magnification (8.90±1.61 *vs* 7.17±1.65, P<0.001), clarity (9.21±2.11 *vs* 7.42±2.27, P<0.001), and depth of field (8.31±2.38 *vs* 6.78±2.79, P<0.001). Trainees regarded 3D surgical videos as significantly more suitable for ophthalmic surgical teaching (9.23±0.83 *vs* 5.75±0.93, P<0.001) and implementation (8.83±2.69 *vs* 6.15±2.83, P<0.001) compared to 2D surgical videos. A comparative analysis of satisfaction with video magnification, image clarity, depth of field, and the suitability for surgical teaching and implementation between 3D and 2D surgical videos indicate that, across all groups of trainees, 3D surgical

Table 2 Accuracy of discrimination in pathologies in 9 PFV patients using paired 3D and 2D surgical videos: questionnaire results *n* (%)

Questions	Accuracy in Level 1 group				Accuracy in Level 2 group				Accuracy in Level 3 group				Accuracy in all 3 groups			
	Watching 2D videos	Watching 3D videos	χ^2	*P*	Watching 2D videos	Watching 3D videos	χ^2	*P*	Watching 2D videos	Watching 3D videos	χ^2	*P*	Watching 2D videos	Watching 3D videos	χ^2	*P*
Total number of questionnaires	36	36			36	36			36	36			108	108		
What do you think of the depth of the patients' anterior chamber: disappear/shallow/normal	23 (63.9)	29 (80.6)	2.492	0.114	24 (66.7)	31 (86.1)	3.773	0.052	29 (80.6)	32 (88.9)	0.966	0.326	76 (70.4)	92 (85.2)	6.857	0.009[a]
Does the patient have lens opacity: Yes/no/unclear	31 (86.1)	34 (94.4)	1.424	0.233	33 (91.7)	35 (97.2)	1.059	0.303	35 (97.2)	36 (100)	1.014	0.314	99 (91.7)	105 (97.2)	3.176	0.075
If there is lens opacity, the location of lens opacity is: anterior capsular/anterior cortex/posterior cortex/posterior capsular	20 (55.6)	28 (77.8)	4.000	0.046[a]	25 (69.4)	30 (83.3)	1.925	0.165	30 (83.3)	35 (97.2)	3.956	0.047[a]	75 (69.4)	93 (86.1)	8.679	0.003[a]
From the video, does the patient have vitreous strips: Yes/no/unclear	25 (69.4)	29 (80.6)	1.185	0.276	25 (69.4)	32 (88.9)	4.126	0.042[a]	35 (97.2)	36 (100)	1.014	0.314	85 (78.7)	97 (89.8)	5.027	0.025[a]
From the video, does the patient have tractional retinal detachment: Yes/no/unclear	29 (80.6)	32 (88.9)	0.966	0.326	30 (83.3)	33 (91.7)	1.143	0.285	36 (100)	36 (100)	-	-	95 (88.0)	101 (93.5)	1.984	0.159
From the video, does the patient have macular detachment: Yes/no/unclear	22 (61.1)	27 (75.0)	1.597	0.206	26 (72.2)	30 (83.3)	1.286	0.257	34 (94.4)	35 (97.2)	0.348	0.555	82 (75.9)	92 (85.2)	2.956	0.086

[a]Differences reached statistical significance. PFV: Persistent fetal vasculature; 3D: Three-dimension; 2D: Two-dimension.

videos were significantly more satisfactory than 2D surgical videos regarding image magnification, clarity, and depth of field. Additionally, all groups of trainees agreed that 3D surgical videos were significantly more suitable for ophthalmic surgical teaching and implementation compared to 2D surgical videos. These statistical analyses were all significant. Comparative analysis of 3D and 2D surgical video images is in Figure 2 with paired 2D and 3D videos.

DISCUSSION

This study provides compelling evidence that 3D surgical video systems offer significant educational advantages over traditional 2D systems for trainees specializing in pediatric vitreoretinal surgery, particularly in cases involving PFV. The results suggest that the use of 3D video technology enhances depth perception, enabling a more precise and efficient evaluation of critical ocular features such as anterior chamber depth, the location of lens opacities, and vitreous strands. Additionally, the study confirms the superiority of 3D video systems in facilitating the teaching and learning process for trainees undergoing training in pediatric vitreoretinal procedures.

This study selected trainees with varying years of experience as research subjects and utilized pediatric PFV surgical videos to compare the educational benefits of 3D versus 2D surgical videos as training tools for trainees in pediatric fundus diseases. The rationale for selecting trainees with different levels of experience lies in the distinct differences between pediatric and adult fundus diseases in terms of disease spectrum and pathogenesis, which necessitate unique vitreoretinal surgical techniques and principles[14-16]. Trainees at different stages of their careers have varying understandings of pediatric fundus diseases, leading to differences in the effectiveness of 3D surgical video teaching. Additionally, pediatric PFV surgical videos were chosen for analysis because PFV typically presents in three subtypes: anterior, posterior, and combined[17-18]. Moreover, PFV is associated with diverse anterior and posterior segment lesions, including those affecting the anterior chamber, lens, vitreous, and retina[2].

In this study, trainees with varying levels of experience were selected as research participants to assess the educational efficacy of 3D versus 2D surgical videos as training tools for pediatric fundus diseases, particularly in the context of PFV surgery. The selection of trainees at different career stages was motivated by the significant distinctions between pediatric and adult fundus diseases in terms of their disease spectrum and pathophysiology, which demand specialized vitreoretinal surgical techniques and principles[14-16]. Trainees with different levels of experience possess varying degrees of understanding of pediatric fundus disorders, resulting in differential responses to the instructional value of 3D surgical videos. Pediatric

PFV surgical videos were specifically chosen for this analysis due to PFV's classification into three primary subtypes: anterior, posterior, and combined[17-18]. Furthermore, PFV is associated with a wide range of anterior and posterior segment pathologies, including abnormalities involving the anterior chamber, lens, vitreous, and retina[1].

This study further investigated the difficulty and satisfaction levels experienced by trainees at varying stages of their careers in distinguishing anterior and posterior segment lesions when using 3D versus 2D surgical videos, a topic of growing interest in recent years. The use of 3D surgical video technology was first introduced in anterior segment procedures, such as cataract surgery, in 2008. Subsequently, in 2016, Eckardt and Paulo[19] provided a seminal report detailing the characteristics of 3D surgical video systems in terms of digital image processing, ergonomics, image resolution, and depth of field. Their case series of 43 macular hole surgeries confirmed the feasibility of 3D systems in vitreoretinal surgery[8]. Our findings revealed that ophthalmology fellows (Level 1 group) and junior trainees (Level 2 group) demonstrated significant improvement in their ability to identify anterior and posterior segment lesions when using 3D surgical videos, reporting higher satisfaction with the stereoscopic depth perception compared to 2D videos. In contrast, while senior trainees found 3D videos more beneficial for distinguishing anterior segment lesions, no significant difference was observed between 3D and 2D videos in their ability to discern vitreous and retinal lesions. These results suggest that for fellows and junior trainees, 3D surgical videos enhance both their understanding and accuracy in identifying ocular lesions across the anterior and posterior segments. Additionally, the data support the notion that 3D video systems offer greater advantages in distinguishing anterior segment lesions and anatomical structures.

The final section of this study conducted a comparative analysis of trainees' satisfaction with 3D and 2D surgical videos in terms of video magnification, image clarity, depth of field, and their suitability for surgical teaching and application. Across all groups of trainees, 3D surgical videos were rated significantly higher than 2D videos. Additionally, all groups consistently agreed that 3D surgical videos were more appropriate for both teaching and performing ophthalmic surgeries compared to 2D videos, aligning with findings from previous studies[11,20-23]. These results underscore the superior visualization capabilities provided by 3D surgical video systems. Through advanced digital image processing and optimization, these systems deliver greater image magnification, enhanced depth of field, and improved image incidence, which are instrumental in the teaching of vitreoretinal surgery. Trainees reported that these enhanced features facilitate a more comprehensive understanding of the anatomy of the anterior chamber, lens, and vitreoretinal structures. Moreover, the enhanced stereoscopic perception offered by 3D systems helps to highlight pathological characteristics of lesions and enables more precise recognition of fine anatomical details, further improving the educational and practical aspects of surgical training.

This study has several limitations. First, it was not a randomized controlled trial, as switching observation systems for pediatric PFV cases is time-consuming. Second, the single-center sample limits the generalizability; multi-center enrollment of trainees with varied backgrounds across regions is needed. Third, only immediate educational outcomes were assessed, and long-term knowledge retention and surgical performance at 3 and 6mo post-training require further longitudinal investigation. Fourth, the findings need validation *via* larger cohorts and randomized designs. Despite the aforementioned limitations, this study demonstrates that 3D surgical video systems achieve superior training outcomes relative to 2D systems for learners of pediatric PFV vitrectomy. As the first investigation focusing on this technically demanding surgery that relies heavily on depth perception, our work differentiates from prior studies on adult cases or general ophthalmic training, and stratified analysis further reveals the varied advantages of 3D video training for trainees with different clinical experience.

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