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Effects of a multistage virtual reality intervention on perioperative anxiety and recovery in patients undergoing elective gynecological surgery: a prospective single-blind randomized controlled trial

Guanghui Zhang[1†], Jingxing Hu[1†], Muchun Zhang[1], Wenhui Tao[1] and Xianwen Hu[1*]

Abstract

Backgrounds Preoperative anxiety is a common concern among adult patients undergoing elective surgery and is associated with poor outcomes.Virtual reality (VR)-based interventions have emerged as simpler, safer, and more effective alternatives than traditional care in reducing anxiety in patients undergoing gynecological surgery.

Methods A prospective, single-blind, randomized controlled trial design was conducted, involving 109 American Society of Anesthesiologists physical status I-II patients scheduled for gynecological laparoscopic surgery, who were randomly divided into a control group, a preoperative visit Virtual Reality group, and a preoperative visit combined with surgical waiting area Virtual Reality group .The primary outcome, preoperative anxiety, was assessed using the Amsterdam Preoperative Anxiety and Information Needs Scale, and secondary outcomes included sleep quality stress and pain and postoperative satisfaction. Interventions and measurements were performed at 4 time points: the start of the clinical session (T0), after the ward visit intervention (T1), in the surgical waiting area (T2), before anesthesia induction (T3), and after surgery (T4).

Results The results showed that intervention group 2 exhibited significantly lower anxiety scores than the control group at T2 and T3 (β=-4.15, $p < 0.001$; β=-5.88, $p < 0.001$), and postoperative acute pain scores ($H = 14.574$, $p < 0.001$) and satisfaction ($H = 38.027$, $p < 0.001$) also improved significantly. However, anxiety and stress levels were transiently elevated after the initial intervention (T1).

Conclusions Our study suggests that multiple VR interventions can effectively reduce preoperative anxiety and improve the perioperative experience through exposure and distraction mechanisms.However, it is important to note the possible short-term transient elevation in anxiety and stress levels after the initial intervention.

[†]Guanghui Zhang and Jingxing Hu contributed equally to this work.

*Correspondence:
Xianwen Hu
huxianwen001@163.com

Full list of author information is available at the end of the article

Trial registration This study was retrospectively registered on February 21, 2025, at the Chinese Clinical Trial Registry (which is part of the World Health Organization International Clinical Trials Registry Platform, registration number ChiCTR2500097598). All patients included in the statistics were enrolled after this date, and each patient signed a written informed consent form.

Keywords Virtual reality, VR, Preoperative anxiety, Female anxiety

Introduction

Anxiety is a common emotional state [1], and preoperative anxiety refers to the anxiety and fear experienced before undergoing surgery or other medical procedures. Younger female patients and individuals with high information needs tend to exhibit higher levels of preoperative anxiety, while prior exposure to anesthesia or surgery is associated with lower anxiety levels [2–4]. Prolonged anxiety may trigger physiological responses such as increased heart rate, elevated blood pressure, rapid breathing, insomnia, and excessive sweating [5, 6]. These physiological responses may negatively impact patients' physical condition and even increase surgical risks. Second, high levels of anxiety may lower patients' pain thresholds, thereby exacerbating postoperative pain [7]. Finally, preoperative anxiety may hinder effective communication between patients and healthcare providers, this situation may compromise the quality of the patient-provider relationship and negatively impact treatment outcomes and recovery progress [8].

Implementing effective strategies to alleviate preoperative anxiety is crucial. While pharmacological interventions (e.g., benzodiazepines or dexmedetomidine) have been commonly used in this patient population, they also have drawbacks, such as mucosal irritation, postoperative nausea and vomiting, delirium, and prolonged hospital stays [9, 10]. Currently, the role of Virtual Reality (VR) technology in reducing preoperative anxiety is being further explored [11, 12]. VR is a computer simulation system that creates virtual environments for user interaction. It uses a body-tracking motion sensor system based on built-in gyroscopes and an eye-tracking system to continuously capture the patient's state, then generates corresponding simulated environments in real-time via a computer, thereby immersing the user in that environment [13]. Its primary mechanisms for alleviating preoperative anxiety are distraction and exposure [14].

Previous research comprising 6 randomized controlled trials (RCTs) has indicated that VR-based interventions significantly reduce preoperative anxiety in adults [15–18] and children [19, 20] through pre-exposure and distraction, with pre-exposure interventions being more effective in adult populations. However, some studies have indicated that VR-based interventions have no significant effect on reducing preoperative anxiety [21–23]. Besides, the current VR therapeutic research landscape remains predominantly confined to single-phase applications, whereas this study pioneers a multi-phase protocol incorporating both preoperative consultation and perioperative holding area implementation, establishing an evidence-based framework for phased VR intervention in surgical settings.

Given this background, the objective of this study was to evaluate the effectiveness of VR-based interventions implemented at different time points in alleviating preoperative anxiety in patients undergoing elective gynecological surgery, and conduct an in-depth analysis of their impact on perioperative sleep quality, stress levels, satisfaction, and postoperative acute pain.

Methods

Setting and population

This prospective, single-blind, randomized controlled trial was conducted between January to March 2025. The experiment adhered to the ethical principles of the WMA Declaration of Helsinki (2013). All subjects gave their written informed consent before each experiment and were paid for their participation.This manuscript adheres to the applicable CONSORT guidelines.

Inclusion and exclusion criteria

The main types of elective surgery included laparoscopic hysterectomy with bilateral adnexectomy, laparoscopic hysterectomy, and laparoscopic resection of ovarian lesions. Patients attending the preanesthesia assessment clinic were invited to participate in the study if they met the following inclusion criteria: (1) Age 18–45; (2) Scheduled for their first elective surgery under general anesthesia within the subsequent week; (3) Voluntary enrolled and provision of informed consent after the content of the clinical trial was fully explained; (4) Fluency in Mandarin; (5) Classification as American Society of Anesthesiologists (ASA) physical status I or II. The exclusion criteria were as follows: (1) Undergoing emergency surgery without pre-operative assessment; (2) Cognitive impairment or inability to consent; (3) History of any psychological disorders; (4) History of vestibular dysfunction or motion sickness or audio-visual impairment; (5) History of alcohol or drug abuse; (6) A diagnosis of Parkinson's disease, multiple sclerosis or muscular dystrophy.

Sample size

The sample size calculation was based on the effect size (Cohen's d = 0.64) reported by Chiu et al. (2023) [13], a randomized clinical trial that also investigated a single-session VR intervention aimed at reducing preoperative anxiety in adults undergoing elective surgery under general anesthesia. This study was deemed highly comparable to ours in terms of population (adults), intervention type (preoperative VR exposure), primary outcome (preoperative anxiety), and measurement tool (APAIS).

Recruitment procedure

Potential participants were identified through chart review, and patients who met the enrolment criteria and were scheduled to undergo surgery in the near future were recruited into the cohort and contacted by an independent research assistant. A list of interested participants was recorded and sent to the researchers for further contact. Some of the study details and procedures were explained to potential participants by the researchers on the ward. After obtaining written consent from potential participants, an independent outcome assessor, blinded to group allocation, collected baseline data (T0).

Randomization and blinding

The randomization procedure was performed by a researcher independent of the recruitment, enrolment. Participants were randomized into three groups (A, B, and C) in a 1:1:1 ratio using block randomization with a fixed block size of 6. Opaque, sealed, sequentially numbered envelopes containing group assignment cards were prepared and opened sequentially by the researcher to assign each participant to their group.

Due to the nature of the intervention in this study, full double-blinding was not achievable, with the exception that the outcome assessor was blinded to the group allocation. However, participants were instructed not to disclose their group assignment to the scale assessor at the time of the scale assessment and were asked not to share specific details of the intervention with others.

Control and intervention groups

This study divided the participants into three groups: A, B, and C. Group A served as the control group, while groups B and C were the intervention groups.No preoperative sedative premedication (e.g., midazolam) was administered.

Participants in group A received routine preoperative visits and care measures before anesthesia, and the ward nurses provided them with routine preoperative information.In addition to standard care, participants in both Group B and Group C received a VR-based intervention using a PICO 4PRO.aParticipants in the VR group received no additional explanatory materials or instructions pertaining to the virtual reality intervention other than the use of the headset. The PICO 4 Pro is a VR headset featuring Pancake optics, wit*h a binocular resolution of 2160 × 2160 per eye, a pixel density (PPI) of 1200, a field* of view (FOV) of 105°, and a pixels per degree (PPD) of 20.6. It supports intelligent continuous IPD adjustment from 62 to 72 mm and can memorize IPD settings for multiple users. The device offers high-quality color passthrough, is compatible with glasses, and features an integrated audio system. Participants will watch a customized 9-minute immersive VR tour of the operating room. Based on previous studies [13, 15, 19], a 360° VR video has been produced to provide an immersive experience through which subjects will receive information regarding surgical and anesthesia procedures. The video is divided into four narrated segments that explain the perioperative process, emphasizing that all participants will undergo similar experiences. Further details are provided in Appendix 1 (pp. 5–7), including screenshots of the presentation (Figures S1–1 to S1-5). Moreover, participants in Group C received an additional virtual reality intervention during the preoperative waiting period, consisting of a 5 to 6-minute immersive panoramic VR video. The video featured either novel scenic environments or guided relaxation sequences, as illustrated in the representative screenshots provided in Figures S1–6 and S1-7 (Appendix 1).

Primary efficacy indicators and secondary efficacy indicators

The primary outcome was the amelioration of preoperative anxiety, assessed using the Amsterdam Preoperative Anxiety and Information Scale [24](range 6–30; higher scores indicate greater anxiety). The Chinese version of the translated and validated APAIS scale was used in the present study [25], with Cronbach's alpha for the anxiety and information needs subscales being 0.862 and 0.830, respectively).

Secondary outcomes, stress and pain, were assessed by a visual analogue scale(VSA) [26] at 4 time points: baseline at the start of the clinical session (T0), at the end of the clinical session after the ward visit intervention (T1), in the operating theatre waiting area for the operation (T2), and prior to induction of anesthesia (T3). Pain perception was assessed postoperatively (T4). Both VAS instruments consisted of a 100-mm horizontal line continuum anchored by verbal descriptors of two extreme symptom states. Participants marked their current level of pain or stress on the line, with scores ranging from 0 (no pain/no stress) to 100 (worst imaginable pain/highest possible stress). Participants were instructed to mark their current level of pain or stress on the line. The score was determined by measuring the distance from the left anchor to the participant's mark, recorded in millimeters. Additionally, improvement in sleep was assessed as

a secondary outcome using the Athens Insomnia Scale (AIS) [27]. A detailed description of each outcome metric is provided in Appendix 1.

Security indicators

Using the Simulator Sickness Questionnaire (SSQ) [28] to observe patients' adverse reactions to using the VR equipment (e.g., vertigo, nausea, and vomiting, etc.), those who were intolerant to severe motion sickness were withdrawn from the intervention trial immediately in order to ensure a positive experience during clinic visits.

Statistical analysis

Data were analyzed using SPSS statistical software version 26.0 (IBM). Demographic characteristics and baseline outcome measures were summarized by frequency, percentage, mean (SD), and range. Normality of continuous variables was assessed using normal Q-Q plots of skewness and kurtosis of the data. For continuous variables, depending on whether they met the assumptions of parametric tests, including normality and homogeneity of variances, either one-way analysis of variance (ANOVA) or the Kruskal–Wallis test was applied. Specifically, one-way ANOVA was used to compare continuous variables such as preoperative anxiety, pain, stress, and satisfaction, while the Kruskal–Wallis test was employed for the information needs scale due to its ordinal nature. If the one-way ANOVA results indicated significant differences between groups, post-hoc tests (e.g., Tukey's HSD) were conducted to identify the specific sources of these differences. For categorical variables, such as sleep outcomes, the chi-square test or Fisher's exact test was used to assess the homogeneity of characteristics among the intervention and control groups. Univariate with unstructured correlation structure was then validated with generalized estimating equation modelling (GEE), which maximized statistical power compared with separate analyses for each time point. A two-sided $p < 0.05$ was considered statistically significant.

Result

Characteristics of study population

A total of 149 people were identified as potential participants through case review. Of these, 111 female participants provided informed consent to participate in the study. Thirty-seven participants were randomly assigned to each group, and one patient in both intervention groups was lost to follow-up due to a change in their date of surgery (0% disengagement rate in the control group and 2.7% disengagement rate in the Intervention group). Accordingly, a total of 109 participants completed the study. The Fig. 1 shows the study flow. Detailed demographic and sociological characteristics of the participants are presented in Table 1.

Impact of VR-based interventions on primary outcomes

Table 4 presents the results of the GEE model comparing anxiety scores across different time points. Significant

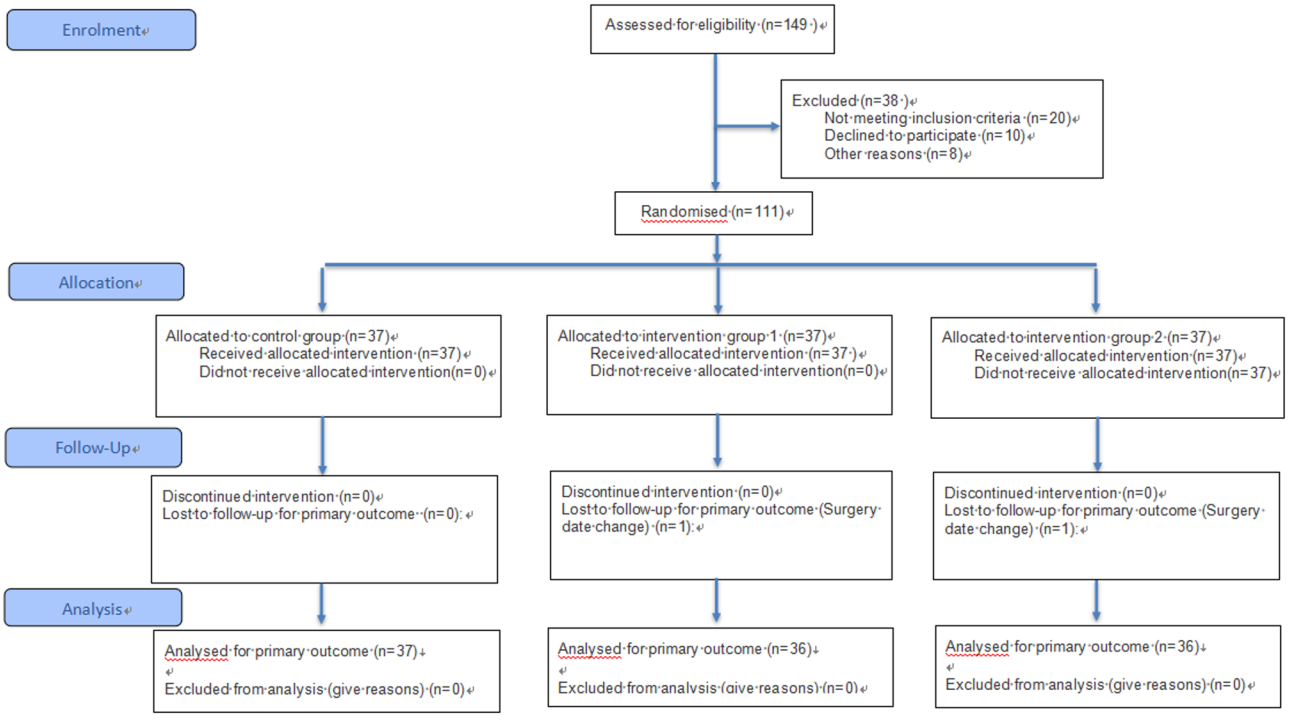

Fig. 1 Consolidated Standards of Reporting Trials (CONSORT) flow diagram defining patient assessment and enrollment numbers in present study

Table 1 Participant demographic sociological statistics

Participants, No. (%) (N = 109)			
diagnostic property	**control subjects**	**Intervention group I**	**Intervention group II**
	(n = 37)	**(n = 36)**	**(n = 36)**
Age, mean (SD) [range] y	32.86(19–43))	31.72(19–45))	33.03(19–44)
Marital status			
Unmarried or Divorced	9 (0.243)	10 (0.278)	7 (0.194)
Married	28 (0.757)	26 (0.722)	29 (0.806)
Level of education			
Junior high school and below	5 (0.135)	5 (0.139)	1 (0.028)
High school and secondary school	7 (0.189)	4 (0.111)	11 (0.306)
Universities and colleges	25 (0.676)	27 (0.750)	24 (0.667)
Living conditions			
live alone	2 (0.054)	2 (0.056)	2 (0.056)
Parental cohabitation	7 (0.189)	7 (0.194)	1 (0.028)
Cohabitation of spouses	28 (0.757)	27 (0.75)	33 (0.917)
Employment			
schoolchildren	2 (0.054)	5 (0.139)	2 (0.056)
domestic work	8 (0.216)	8 (0.222)	7 (0.194)
individually	5 (0.135)	3 (0.083)	6 (0.167)
staff member	22 (0.595)	20 (0.556)	21 (0.583)
Hospitalization experience			
No	24 (0.649)	26 (0.722)	18 (0.5)
Yes	13 (0.351)	10 (0.278)	18 (0.5)
Type of surgery			
Laparoscopic resection of ovarian lesions	21 (0.568)	23 (0.639)	22 (0.611)
Laparoscopic resection of uterine lesions	16 (0.432)	13 (0.361)	14 (0.389)

differences were observed at T1 (β=−2.32; 95% CI, −2.92 to −1.73; $p < 0.001$), T2 (β = 2.49; 95% CI, 0.63 to 2.29; $p < 0.001$) and T3 (β = 3.24; 95% CI, 2.30 to 4.18; $p < 0.001$) when each intervention group was compared to baseline (T0). Similar trends were found for the subscores of anxiety and information needs at T1, T2, and T3 (see Figure S2–1 in Appendix 2). Table 2 also summarizes the multiple comparison results for these subscores across the three time points.

The findings indicate a significant reduction in anxiety among participants in the operating theatre following the intervention, with repeated interventions showing greater efficacy. However, a transient increase in anxiety was noted immediately after the initial intervention.

Impact of VR-based interventions on secondary outcomes Additional analysis comparing participant stress levels between the intervention and control groups at T1 (Table 3) showed significantly higher stress scores in Intervention Group I (β= 8.52; 95% CI,3.47 to 13.57; p<0.001) and Intervention Group II (β= 8.52; 95% CI,2.68 to 14.36; p=0.004), indicating that participants experienced a transient increase in stress immediately after the intervention. In contrast, at T2 (β= 15.00; 95%CI,10.54 to 19.46; p<0.001) and T3 (β= 27.43; 95%CI,23.23 to 31.63; p<0.001) stress scores were significantly lower in the intervention groups, suggesting that participants felt less stressed in the operating theatre after the intervention (Figure S2-2 in Appendix 2).

Results from multiple between-group comparisons further indicated a significant difference in postoperative satisfaction among the groups (H=38.027, p<0.001)(Table 4 and Figure S2-3 in Appendix 2). Post-hoc pairwise comparisons revealed that Intervention Group 2 had significantly higher satisfaction scores than the other two groups. Additionally, a significant reduction in postoperative pain scores was observed in the intervention group compared to the control group (H=14.574, p<0.001) (Figure S2-4 in Appendix 2). No significant difference was found in the amount of sufentanil used among the groups (H=0.136, p=0.934) (Figure S2-5 in Appendix 2), indicating that the reduction in self-reported pain among VR intervention patients occurred under equivalent analgesic conditions.

The sleep quality results presented in Table 5 revealed that treating the intervention groups on the ward as a single group yielded a significant difference at T2 ($\chi 2$ = 8.434, p = 0.004), suggesting that increased information improved participant sleep in the pre-operative period.

Discussion

Main findings

This randomized controlled trial adds to the evidence on virtual reality (VR) interventions for perioperative

Table 2 Comparison of Outcomes Scores Between Study Groups at 4 Time Points

Result		Score, mean (SD)/Quartiles					
	Timeline[a]	control subjects	Intervention group I	Intervention group II	F/H value	*P*-value	HSD
Patient preoperative anxiety[b]							
	Baseline (T0)	17.46 (2.734)	17.28 (2.173)	17.44 (2.006)	0.429	0.934	NA
	T1	15.14 (2.299)	17.44 (2.699)	16.92 (1.381)	11.105	<0.001	1,2>0d
	T2	18.92 (2.203)	14.97 (1.341)	14.75 (1.251)	73.085	<0.001	1,2>0d
	T3	20.7 (3.036)	16.33 (2.111)	14.81 (1.925)	58.894	<0.001	2>1>0d
Anxiety scale[b]							
	Baseline (T0)	11.62 (2.126)	11.39 (1.745)	11.61 (1.745)	0.176	0.934	NA
	T1	10.86 (2.263)	12.92 (2.579)	12.31 (1.564)	8.566	<0.001	1,2>d
	T2	12.54 (2.076)	10.28 (1.542)	9.86 (1.496)	25.497	<0.001	1,2>0d
	T3	14.05 (2.738)	11.42 (2.234)	9.81 (2.054)	30.106	<0.001	2>1>0d
Information needs[c]							
	Baseline (T0)	5.84 6(4,6)	5.89 6(6,6)	5.83 6(6,6)	0.068	0.966	NA
	T1	4.27 4(4,5)	4.53 4(4,6)	4.61 4(4,6)	2.151	0.341	NA
	T2	6.38 6(6,8)	4.69 4(4,6)	4.89 6(4,6)	24.39	<0.001	1,2>0d
	T3	6.65 6 (6, 8)	4.92 5.5 (4,6)	5 4(4,6)	26.269	<0.001	1,2>0d
Self-perceived stress[b]							
	Baseline (T0)	54.46 (14.181)	53.33 (14.88)	52.92 (12.385)	0.121	0.886	NA
	T1	51.22 (15.157)	58.61 (9.828)	58.19 (11.961)	4.026	0.021	1,2>0d
	T2	69.46 (12.681)	57.22 (10.586)	57.92 (9.44)	14.309	<0.001	1,2>0d
	T3	81.89 (10.888)	68.61 (10.929)	63.75 (7.404)	33.018	<0.001	1,2>0d

Abbreviations: *NA* Not applicable

[a]T1 is post-intervention. t2 is the time after entry into the operating theatre (reception area). t3 is prior to transfer to the operating theatre (ward).T4 is post-surgery

[b]One-way ANOVA was used to compare data between groups

[c]Data were compared between groups using the Kruskal-Wallis H test. Data are means (quartiles)

[d]0 represents the control group, 1 represents intervention group I, and 2 represents intervention group II

outcomes in elective gynecological surgery. We found that VR-based interventions effectively reduced preoperative anxiety and improved perioperative sleep quality, pain perception, and patient satisfaction, particularly when combined with other interventions in the surgical waiting area.It is important to note that the VR intervention was supplementary to standard preoperative care, not a replacement for it. The control group received the full standard of care, including preoperative visits.

The study also demonstrated that using VR preoperatively in the ward—as an alternative to traditional preoperative education—can significantly alleviate patients' anxiety, consistent to some extent with earlier findings. [13, 18, 21].

On the other hand, using VR equipment as an alternative to standard preoperative visits increased the interaction time between anesthetists and patients, thereby delivering more comprehensive preoperative information. According to previous studies, providing such information—including details about the surgical process—can effectively reduce preoperative anxiety[13, 17, 19, 20]. Improved sleep quality the night before surgery was also observed among patients who underwent VR-based preparation[6], likely resulting from enhanced informational clarity and reduced anxiety, which collectively contributed to better rest.

The results of the current study showed that participants who received the virtual reality intervention reported significantly lower levels of self-perceived stress compared to the control group. However, we found that anxiety and stress levels were significantly higher in patients immediately after receiving the virtual reality intervention in the ward compared to the control group, contrasting with the literature[13].The transient increase in anxiety and stress immediately after the initial VR intervention (T1) may be attributed to the novelty of the technology itself. For patients unfamiliar with VR, the initial exposure can be arousing or slightly disorienting, potentially leading to short-term discomfort [29]. Furthermore, while the immersive VR experience familiarizes patients with the surgical setting, the initial confrontation with the operating room environment might momentarily heighten awareness of the impending procedure. This suggests that the timing and delivery of VR interventions require careful consideration; a gentle introduction and clear explanation may help mitigate this initial reaction.

This study found that a virtual reality-based intervention had a significant impact on relieving patients' acute postoperative pain levels, consistent with previous literature[30, 31]. Preoperative elevated anxiety levels are positively associated with increased postoperative leukocyte

Table 3 Participant sleep

Participants, No. (%) (N = 109)													
	Control subjects				Intervention group I				Intervention group II				
Study endpoint	(n = 37)				(n = 36)				(n = 36)				
	No insomnia		suffer from insomnia		No insomnia		suffer from insomnia		No insomnia		suffer from insomnia		
Hospitalization	19	0.514	18	0.486	17	0.472	19	0.528	21	0.583	15	0.417	0.020	0.88
Night before surgery	20	0.541	17	0.459	29	0.806	7	0.194	29	0.806	7	0.194	8.434	0.004
Night after surgery	33	0.892	4	0.108	33	0.917	3	0.830	32	0.899	4	0.101	0.185	0.912

count and inflammatory cytokine levels in patients [32, 33]. Interventions aimed at reducing anxiety may alleviate postoperative pain by mitigating the inflammatory response. However, the precise mechanisms underlying this relationship remain incompletely understood based on the current study and require further investigation.. After accounting for the length of surgery and the amount of intraoperative analgesic medications administered, which were not statistically significant, it was observed that patients who underwent the virtual reality intervention reported lower self-assessment of acute postoperative pain and exhibited better pain tolerance.

Although the VR intervention significantly reduced anxiety scores before anesthesia induction, the clinical relevance of these reductions warrants consideration. Currently, there is no established minimal clinically important difference (MCID) for the APAIS scale in this specific population. However, the observed reductions in self-perceived stress (VAS) and postoperative pain, which were substantial (e.g., mean pain score reduction of approximately 12–14 points on a 100-mm VAS in intervention groups), suggest a clinically meaningful benefit. Future studies should aim to define the MCID for APAIS in surgical populations to better interpret the clinical impact of such interventions.To the best of our knowledge, this is one of the few studies to implement a virtual reality (VR) intervention across multiple time points and evaluate its effects, thereby supporting the expanded clinical adoption of VR technology. The findings provide a valuable foundation for future research into non-pharmacological strategies aimed at reducing preoperative anxiety and improving surgical outcomes in adults undergoing elective procedures.By enhancing patients' comprehensive understanding of the surgical process—before, during, and after the operation [17]—VR helps reduce uncertainties related to postoperative pain and preoperative anxiety. This contributes to a more satisfactory perioperative experience and higher postoperative satisfaction.

Currently, the clinical adoption of VR remains limited, mainly due to high economic and time costs[34]. Although some evidence suggests that VR interventions may save an average of $5.39 per child in hospitalization costs compared to conventional care[35], these savings do not yet offset the expenses associated with VR use. Nonetheless, as VR hardware costs continue to decline and patient expectations for higher-quality healthcare experiences grow, VR technology demonstrates considerable long-term cost-effectiveness and clinical value. Therefore, hospitals should increase investment in VR development and adaptation, and conduct rigorous scientific evaluations of its costs and benefits to facilitate broader integration and application in clinical practice.

Table 4 Participant postoperative indicators

	Score; quartiles					
Results(T4[a])	**control subjects**	**Intervention group I**	**Intervention group II**	**H-value**	**P-value**	**paired comparison**
Satisfaction [b]						
	79.86 80 (70,87.5)	87.64 90 (85,90)	93.06 90 (90,98.5)	38.027	< 0.001	2 > 1 > 0[c]
Pain[b]						
	46.22 45 (32.5,60)	34.86 32.5 (26.25, 43.75)	32.36 30 (25,38.75)	14.574	< 0.001	1,2 > 0[c]
Length of surgery (minutes)[b]						
	124.73 120 (70,140)	106.81 100 (62.5,140)	119.17 120 (90,150)	2.645	0.267	NA
Sufentanil[b]						
	29.73 30 (25,35)	28.89 30 (25,35)	29.31 30 (25,35)	0.136	0.934	NA

Abbreviations: NA, not applicable

a T4 is post-surgery

b The Kruskal-Wallis H test was used to compare data between groups. Data are expressed as means (quartiles)

c represents the control group, 1 represents intervention group I, and 2 represents intervention group II

Table 5 Results of analyses of generalized estimating equations

Variable	APAIS		Anxiety Scale		Information needs		Self-perceived stress	
	β (95 per cent CI)[b]	*P*-value	β (95 per cent CI)[b]	*P*-value	β (95 per cent CI)[b]	*P*-value	β (95 per cent CI)[b]	*P*-value
Group 1 [a]	−0.18 (−1.30 to 0.93)	0.750	−0.23 (−1.11 to 0.65)	0.604	0.05 (−0.50 to 0.60)	0.856	−1.13 (−7.71 to 5.45)	0.737
Group 2 [a]	−0.02 (−1.10 to 1.07)	0.978	−0.01 (−0.89 to 0.87)	0.981	−0.01 (−0.55 to 0.54)	0.987	−1.54 (−7.56 to 4.48)	0.615
T1[a]	−2.32 (−2.92 to −1.73)	< 0.001	−0.76 (−1.36 to −0.16)	0.014	−1.57 (−2.12 to −1.02)	< 0.001	−3.24 (−6.51 to 0.03)	0.052
Group1*T1[a]	2.49 (1.47 to 3.51)	< 0.001	2.29 (1.22 to 3.35)	< 0.001	0.21 (−0.46 to 0.87)	0.541	8.52 (3.47 to 13.57)	< 0.001
Group2*T1[a]	1.80 (0.96 to 2.63)	< 0.001	1.45 (0.61 to 2.30)	< 0.001	0.35 (−0.31 to 1.00)	0.300	8.52 (2.68 to 14.36)	0.004
T2[a]	1.46 (0.63 to 2.29)	< 0.001	0.92 (0.12 to 1.72)	0.024	0.54 (0.15 to 0.93)	0.006	15.00 (10.54 to 19.46)	< 0.001
Group1*T2[a]	−3.77 (−4.90 to −2.63)	< 0.001	−2.03 (−3.21 to −0.85)	< 0.001	−1.74 (−2.36 to −1.11)	< 0.001	−11.11 (−17.77 to −4.45)	0.001
Group2*T2[a]	−4.15 (−5.24 to −3.07)	< 0.001	−2.67 (−3.76 to −1.58)	< 0.001	−1.49 (−2.06 to −0.91)	< 0.001	−10.00 (−16.09 to −3.91)	0.001
T3[a]	3.24 (2.30 to 4.18)	< 0.001	2.43 (1.53 to 3.33)	< 0.001	0.81 (0.43 to 1.19)	< 0.001	27.43 (23.23 to 31.63)	< 0.001
Group1*T3[a]	−4.19 (−5.51 to −2.87)	< 0.001	−2.41 (−3.71 to −1.10)	< 0.001	−1.78 (−2.37 to −1.20)	< 0.001	−12.16 (−18.53 to −5.78)	< 0.001
Group2*T3[a]	−5.88 (−7.14 to −4.62)	< 0.001	−4.24 (−5.50 to −2.98)	< 0.001	−1.64 (−2.25 to −1.04)	< 0.001	−16.60 (−22.74 to −10.46)	< 0.001

[a] Group 1 refers to the group difference at baseline between intervention 1 and the control group. Group 2 refers to the group difference at baseline between intervention 2 and the control group

Group1*T1 refers to the change in additional scores for each variable at T1 for intervention group 1 compared to the control group

Group1*T2 refers to the change in additional scores for each variable at T2 for intervention group 1 compared to the control group

Group1*T3 refers to the change in additional scores for each variable at T3 for intervention group one compared to the control group

Group2*T1 refers to the change in additional scores for each variable at T1 for intervention group two compared to the control group

Group2*T2 refers to the change in additional scores for each variable at T2 for intervention group two compared to the control group

Group2*T3 refers to the change in additional scores for each variable at T3 for intervention group one compared to the control group. T1 is the change in additional scores after the VR intervention, T2 refers to changes in the surgical waiting area, and T3 denotes changes after entering the operating theatre

[b]β refers to the between-group and time interaction term, representing the difference in the mean change in an outcome (mean change in the intervention group minus mean change in the control group) between the intervention group (intervention 1, intervention 2) and the control group at a given time point compared with baseline (T0)

Limitations

However, this study has several limitations that should be considered. First, the sample was restricted to patients undergoing gynecological surgery, with a total of 109 participants, which may constrain the generalizability of the results. Hysterectomy, due to its distinct psychosocial significance related to fertility and femininity, may be associated with higher levels of preoperative anxiety compared to oophorectomy. Consequently, surgery type may represent an unmeasured confounder that could affect the estimated efficacy of the intervention (e.g., a new preoperative counseling method). Secondly, the participants were relatively young (18–45 years) and classified as ASA physical status I or II, undergoing relatively low-risk and less painful procedures. This homogeneous sample limits the extrapolation of results to older populations (e.g., over 60 years) or patients with higher ASA grades (III–IV), who may exhibit different responses to the VR intervention. Additionally, due to the nature of the VR intervention, full double-blinding was not feasible. The awareness of treatment allocation among both participants and unblinded investigators may have introduced performance bias, particularly affecting subjective outcome measures. These factors could collectively compromise the internal validity of the trial and reduce the reliability of the results.

Conclusion

This study demonstrates that a multistage virtual reality intervention can significantly reduce preoperative anxiety and improve perioperative recovery outcomes in patients undergoing elective gynecological surgery, with enhanced effectiveness observed when VR is also used in the surgical waiting area. However, an initial transient increase in anxiety highlights the need for careful implementation. Future research should focus on older patients, diverse surgical populations, and cost-effectiveness analyses to further validate and promote the integration of VR into routine perioperative care.

Supplementary Information

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Supplementary Material 1

Supplementary Material 2

Supplementary Material 3

Supplementary Material 4

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Authors' contributions

**Guanghui Zhang: ** Data curation, Methodology, Software, Formal analysis, Visualization, Writing-Original draft preparation. **Xianwen Hu: ** Conceptualization, Methodology, Writing-Review & Editing, Validation. **Muchun Zhang: ** Conceptualization, Methodology, Visualization, Review & Editing. **Jingxing Hu: ** Methodology, Review & Editing. **Wenhui Tao: ** Supervision, Review & Editing.

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CRediT authorship contribution statement.

Guanghui Zhang : Data curation, Methodology, Software, Formal analysis, Visualization, Writing-Original draft preparation.Xianwen Hu :Conceptualization, Methodology, Writing-Review & Editing, Validation. Muchun Zhang: Conceptualization, Methodology, Visualization, Review & Editing.Jingxing Hu: Methodology, Review & Editing.Wenhui Tao: Supervision, Review & Editing.

Data availability

The data are available via reasonable requests to the corresponding author.

Declarations

Competing interests

The authors declare no competing interests.

Author details

[1]Department of Anesthesiology, The Second Affiliated Hospital of Anhui Medical University, No. 678 of Furong Road, Jingkai District, Hefei 230000, Anhui, China

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