

Impact of Virtual Reality on Perioperative Stress, Hemodynamic Stability, and Patient Satisfaction During Spinal Anesthesia: A Randomized Controlled Study

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Abstract: Background: Spinal anesthesia maintains patient consciousness during surgery, potentially increasing intraoperative stress and anxiety. Traditional pharmacological anxiolytics carry risks, including respiratory depression and delayed recovery. **Objectives:** This study aims to evaluate the impact of immersive virtual reality (VR) on intraoperative stress markers, hemodynamic stability, and patient satisfaction in patients undergoing elective urological surgery under spinal anesthesia. **Methods:** A prospective, assessor-blinded randomized controlled trial was conducted from June to September 2024 at Rafidia Governmental Surgical Hospital in Palestine. A total of 145 patients were randomly assigned to the VR group (n=72) receiving immersive VR therapy or the control group (n=73) receiving standard care. Primary outcomes included anxiety assessed via State-Trait Anxiety Inventory (STAI), hemodynamic parameters, and patient satisfaction via Visual Analog Scale (VAS). Physiological stress markers, including salivary cortisol and heart rate variability (HRV), were measured at baseline, intraoperatively, and postoperatively. Statistical analysis utilized independent t-tests and repeated measures analysis. Missing data were handled using intention-to-treat principles with last observation carried forward for any incomplete assessments. **Results:** The VR group demonstrated significantly reduced salivary cortisol levels (15.2 ± 4.1 vs. 22.8 ± 5.3 nmol/L, $p < 0.001$) and improved HRV parameters (RMSSD: 42.1 ± 8.2 vs. 31.5 ± 7.6 ms, $p < 0.001$) compared to the controls. The VR group also demonstrated significantly reduced intraoperative anxiety scores and sustained postoperative anxiety reduction compared to controls. Patient satisfaction scores were substantially higher in the VR group. Hemodynamically, the VR group showed significantly lower heart rates intraoperatively, while other parameters remained stable. **Conclusions:** Immersive virtual reality is a safe and effective non-pharmacological intervention that reduces intraoperative stress and anxiety while improving patient satisfaction during spinal anesthesia. VR may be considered for integration into perioperative care protocols, particularly in resource-constrained settings. **Clinical Trial Registration:** AEA Registry (AEARCTR-0013093), registered February 23, 2024.

Keywords: Virtual Reality, Perioperative Anxiety, Heart Rate Variability, Spinal Anesthesia, Patient Satisfaction.

Introduction

Spinal anesthesia is a widely utilized regional anesthetic technique that offers numerous advantages, such as rapid onset, effective pain control, and avoidance of complication related to general anesthesia [1,2]. While spinal anesthesia provides clinical benefits, increased awareness may elevate intraoperative anxiety [3,4]. Patients under spinal anesthesia remain conscious, exposing them to operating room stimuli that may trigger stress responses and hemodynamic fluctuations [5,6]. This is particularly relevant in urological surgery within Palestinian healthcare settings, where limited resources may restrict pharmacological anxiety management options [7]. Intraoperative stress can activate the sympathetic nervous system, leading to adverse physiological responses, including tachycardia, hypertension, and arrhythmias [8,9].

Traditional pharmacological approaches to managing intraoperative anxiety carry inherent risks, including respiratory depression, prolonged recovery, and cognitive impairment [10,11]. Recent systematic reviews and meta-analyses have demonstrated the effectiveness of VR interventions across various medical procedures, with particular promise in perioperative settings [12,13]. However, limited research has

investigated the physiological stress markers and hemodynamic effects of VR under spinal anesthesia, especially in resource-constrained Middle Eastern populations [14,15].

Virtual reality (VR) has emerged as a promising non-pharmacological intervention by immersing patients in calming virtual environments that effectively distract from stressful operating room stimuli [16,17]. By engaging multiple sensory modalities simultaneously, VR creates a high cognitive load that redirects attention away from anxiety-inducing stimuli through distraction theory [18]. The immersive quality of VR stimulates parasympathetic nervous system activation, promoting a physiological state that counteracts the sympathetic stress response typically triggered by surgical anxiety [19,20]. The neurobiological mechanisms underlying VR's anxiolytic effects include engaging the prefrontal cortex to exert top-down inhibitory control over the amygdala, while nature-based VR content facilitates the release of mood-regulating neurotransmitters, including endorphins, serotonin, and dopamine [21,22].

Despite the growing evidence for VR effectiveness in various medical settings, there remains a significant gap in understanding its specific impact on physiological stress markers

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and hemodynamic stability during spinal anesthesia. Furthermore, the cross-cultural validity of VR interventions in Middle Eastern populations requires investigation, as most existing studies have been conducted in Western populations [23,24].

This study aims to evaluate the impact of immersive virtual reality on intraoperative stress and hemodynamic stability in patients undergoing surgery under spinal anesthesia. We hypothesized that VR would significantly reduce physiological markers of stress, including heart rate variability and cortisol levels, and improve hemodynamic stability compared to standard care.

Methods

Study Design

This study was a prospective, assessor-blinded, parallel-group randomized controlled trial conducted from June to September 2024 at Rafidia Governmental Surgical Hospital in Nablus, Palestine. The study aimed to assess the effect of immersive VR on intraoperative stress, hemodynamic stability, and patient satisfaction in patients undergoing elective urological surgery under spinal anesthesia. The trial was approved by the Institutional Review Board and the protocol was registered in a clinical trial registry (AEA Registry: AEARCTR-0013093) on February 23, 2024.

Study Population and Participants

The study population consisted of adult patients scheduled for elective urological surgery under spinal anesthesia at a single tertiary care hospital in Palestine. Patients were recruited from the preoperative clinic during routine surgical consultations. Inclusion criteria included adults (≥ 18 years) undergoing elective urological surgery under spinal anesthesia, ASA physical status I or II [25], moderate to severe preoperative anxiety (STAI > 38) based on previous research demonstrating that patients with higher baseline anxiety levels show greater treatment responses to non-pharmacological interventions and that this threshold represents clinically significant anxiety requiring intervention [26,27], no previous surgical history to control for baseline anxiety levels related to surgical experience; the ability to read, write, and understand Arabic for questionnaire completion; and no contraindications to VR use such as epilepsy or visual/hearing impairment. Exclusion criteria included emergency surgery to ensure standardized perioperative conditions, a history of psychiatric illness, epilepsy, hypertension, or chronic pain to minimize confounding variables affecting stress and anxiety measurements; use of anxiolytic, sedative, or hypnotic medications pre/intraoperatively to avoid interference with study outcomes; cognitive, visual, or auditory impairments that would prevent VR use; implanted hearing aids or cardiac pacemakers due to potential electromagnetic interference; conversion to general anesthesia, which would alter the conscious state required for the intervention; and technical failure or intolerance of VR headset.

Randomization and Blinding

Patients were randomly assigned in a 1:1 ratio to the VR group or control group using block randomization (block size = 8), utilizing a computer-generated random number sequence. Allocation was concealed using opaque, sequentially numbered envelopes prepared by an independent researcher uninvolved in recruitment or assessment and opened immediately before surgery. Due to the nature of the intervention, patients and VR administrators could not be blinded; however, anesthesiologists and outcome assessors were blinded to group assignments and did not participate in VR intervention administration. Outcome assessors, who were blinded, did not

participate in the administration of the VR intervention and were oblivious to group assignments during data collection. The limitations of blinding were mitigated by employing objective physiological measures and utilizing blinded evaluators for all outcome assessments.

Ethical Approval

The study was approved by the Ethics Committee of the Faculty of Nursing, Cairo University (IRB: RHDIRB2019041701) under a collaborative protocol directed by the lead investigator affiliated with Cairo University. Additional permissions were obtained from the Palestinian Ministry of Health (Approval No. MOH-162/1512/2024, dated July 17, 2024). Written and signed consent forms were obtained from all participants in a confidential environment during the preoperative assessment clinic following a comprehensive explanation of the study. The research was conducted in accordance with the Declaration of Helsinki and relevant local regulations [28]. Data were anonymized with unique codes and stored in password-protected digital files accessible only to the research team.

Anesthesia Protocol

All patients received standard monitoring, including electrocardiogram (ECG), non-invasive blood pressure monitoring (NIBP), pulse oximetry, and heart rate monitoring (HR). Spinal anesthesia was administered at L3-L4 or L4-L5 using 15-20 mg of heavy bupivacaine (dose determined according to patient weight and surgeon discretion) combined with 12.5-25 μ g of fentanyl using a 25-gauge Quincke spinal needle via the midline approach. The adequacy of sensory block (T8-T10) was verified using cold sensation assessment prior to the surgical incision. No anxiolytics or sedatives were administered preoperatively or intraoperatively to either group. Intravenous fluids (normal saline, 10-15 mL/kg) were administered according to hospital protocol as preloading to maintain hemodynamic stability.

VR Intervention

Patients in the VR group received immersive therapy using Meta Quest 2 headsets after verification of adequate sensory and motor blockade (sensory level T8-T10, Bromage score ≥ 2) [29] to ensure patient immobility and comfort prior to VR exposure. The standardized VR intervention consisted of four pre-validated calming natural environments: (1) a peaceful forest with gentle streams and bird sounds, (2) a serene snowy mountain landscape with soft instrumental music, (3) a tropical beach with ocean waves, and (4) an underwater coral reef exploration. Each environment was specifically designed and culturally adapted for the Palestinian population, incorporating Arabic language narration and culturally appropriate Islamic calming elements, including nature-based Quranic recitations. The VR content was pre-tested with a pilot group of 20 Palestinian patients to ensure cultural acceptability and therapeutic equivalence across all environments. Given that Arabic is the primary language in Palestine and Islamic cultural elements are familiar to the majority of the population, these adaptations likely enhance the intervention's effectiveness compared to Western-developed content. However, the generalizability of these culturally-adapted VR interventions to non-Arabic-speaking populations or those from different cultural backgrounds may be limited and would require separate validation studies.

Control Group

The control group received standard perioperative care per hospital protocol, without VR. Standard care included maintaining patients in the operating room under comparable environmental conditions and for the same duration as the VR

group, with consistent lighting, noise levels, and staff interaction patterns. No additional distractions, non-pharmacological interventions, ambient music, or patient engagement beyond routine care were provided.

Sample Size Calculation

Using G*Power 3.1.9.7 [31], based on an independent samples t-test for two groups and assuming a medium effect size ($d = 0.5$) derived from previous VR studies in perioperative settings that demonstrated similar effect sizes for anxiety reduction [30,32], with $\alpha = 0.05$ and power = 0.80, a minimum sample of 128 participants (64 per group) was required. To account for a 15% attrition rate based on institutional experience with similar intervention studies and previous VR research reporting dropout rates of 10-20% due to technical issues or patient intolerance [33], 150 participants were enrolled (75 per group). Five patients were excluded due to conversion to general anesthesia ($n=3$) and VR intolerance ($n=2$), yielding a final sample of 145 participants (VR = 72, control = 73). Statistical analysis was conducted on an intention-to-treat basis, with all randomized participants included in the final analysis according to their original group assignment.

Data Collection and Variables

Primary Outcomes

1. **Intraoperative Stress:** Assessed via heart rate variability using a portable HRV monitor (Polar H10 chest strap) connected to Kubios HRV Premium software [34] during 5-minute recording periods, and salivary cortisol was collected using Salivette tubes (Sarstedt) and analyzed using an enzyme-linked immunosorbent assay (ELISA) [35] with an intra-assay coefficient of variation <5% at baseline, 30 minutes intraoperatively, and at the end of surgery.
2. **Hemodynamic Stability:** Monitored using systolic blood pressure (SBP), diastolic blood pressure (DBP), mean arterial pressure (MAP), and heart rate (HR) at 5-minute intervals using Philips IntelliVue MX40 patient monitors. Incidences of hypotension (MAP <65 mmHg or >20% drop from baseline) and bradycardia (HR <50 bpm) were recorded.

Secondary Outcomes

1. **Anxiety:** Measured using the State-Trait Anxiety Inventory (STAI) Arabic version [36], validated for use in Palestinian populations, and administered by trained, blinded assessors at baseline, intraoperative (30 minutes post-spinal block administration), and postoperative approximately 30 minutes after arrival in recovery.
2. **Satisfaction:** Evaluated using a 100 mm Visual Analog Scale (VAS) [37] administered by blinded assessors in the post-anesthesia care unit (PACU).
3. **Time Perception:** Assessed by comparing perceived surgical duration to actual duration, calculated as $(\text{perceived duration}/\text{actual duration}) \times 100$, where lower values indicate compressed time perception and enhanced distraction efficacy.
4. **Adverse Events:** Monitored using standardized checklists for nausea, vomiting, dizziness, motion sickness, and other VR-related or anesthesia-related side effects, which were assessed through continuous clinical observation and patient reporting.

Data Collection Time Points

- Baseline (Pre-anesthesia): Prior to spinal anesthesia administration

- Intraoperative (30 minutes post-spinal block): During surgical procedure and VR exposure
- End of Surgery: Immediately after skin closure
- PACU: Thirty minutes after arrival in recovery room

Motion Sickness Assessment: VR-related discomfort was assessed using a modified Simulator Sickness Questionnaire (SSQ) [38], adapted for intraoperative use with continuous monitoring during VR exposure. Inter-rater reliability was established with Cohen's $\kappa = 0.85$.

Statistical Analysis

Data were analyzed using SPSS version 27 on an intention-to-treat basis. Missing data were minimal ($n=0$ for primary outcomes) due to the controlled intraoperative environment and continuous monitoring. For any secondary outcome measures with missing values, last observation carried forward (LOCF) imputation was used to maintain the intention-to-treat principle. Continuous variables were reported as mean $\pm$ SD and categorical variables as frequencies and percentages. Between-group comparisons used independent t-tests; and chi-square tests were used for categorical data. Repeated measures ANOVA evaluated within-group and between-group differences over time. Effect sizes (Cohen's d) were calculated [39] and interpreted as small (0.2), medium (0.5), and large (0.8) effects. A p-value of <0.05 was considered statistically significant.

Results

Patient Flow and Characteristics

A total of 150 patients were enrolled and randomized. The flow of participants through each stage of the trial is detailed in Figure 1. Five patients were excluded due to conversion to general anesthesia ($n=3$) and VR intolerance ($n=2$), yielding a final sample of 145 participants who completed the study (VR group: $n=72$, control group: $n=73$). No patients in the VR group requested early discontinuation, and no rescue sedative medications were required in either group (Table 1).

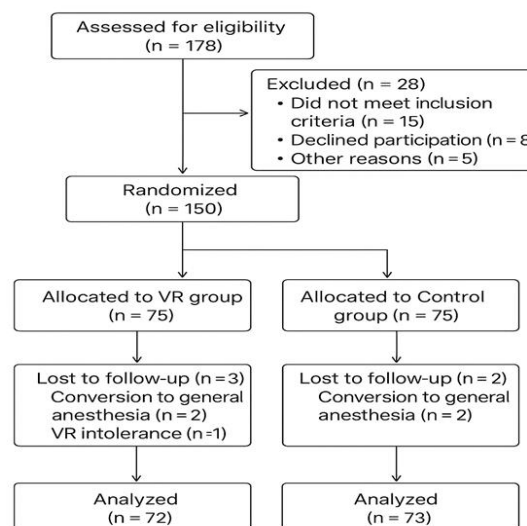


Table (1): Baseline demographic and clinical characteristics of the study participants.

Characteristic	VR Group (n=72)	Control Group (n=73)	p-value
Age (years), mean $\pm$ SD	36.1 $\pm$ 11.3	37.1 $\pm$ 12.5	0.62
Gender, n (%)			0.65
Male	44 (61.1%)	42 (57.5%)	
Female	28 (38.9%)	31 (42.5%)	
Education level, n (%)			0.72
Primary	15 (20.8%)	18 (24.7%)	
Secondary	35 (48.6%)	33 (45.2%)	
University	22 (30.6%)	22 (30.1%)	

Characteristic	VR Group (n=72)	Control Group (n=73)	p-value
ASA Physical Status, n (%)			
I	45 (62.5%)	47 (64.4%)	0.84
II	27 (37.5%)	26 (35.6%)	
Surgery duration (min), mean $\pm$ SD	68.4 $\pm$ 15.2	71.1 $\pm$ 16.8	0.31
Baseline STAI score, mean $\pm$ SD	54.2 $\pm$ 8.1	55.1 $\pm$ 7.7	0.49
Baseline cortisol (nmol/L), mean $\pm$ SD	18.3 $\pm$ 4.2	19.1 $\pm$ 4.8	0.31

SD = standard deviation; ASA = American Society of Anesthesiologists; STAI = State-Trait Anxiety Inventory.

Demographic and clinical characteristics were comparable between groups, with no statistically significant differences (all $p > 0.05$), ensuring adequate randomization and baseline equivalence (Table 1). The mean age was 36.1 $\pm$ 11.3 years in the VR group and 37.1 $\pm$ 12.5 years in the control group ($P = 0.62$). The gender distribution, education level, ASA physical status, and surgery duration were similar between groups. Baseline anxiety scores (STAI) and stress markers were also equivalent, confirming that subsequent changes could be attributed to the intervention.

The impact of the VR intervention on primary outcomes is summarized in Figure 2 (Supplemental file 1).

Physiological Stress Markers

Salivary cortisol levels demonstrated significant between-group differences at all measurement time points (Figure 2A). At baseline, cortisol levels were comparable between groups (VR: 18.3 $\pm$ 4.2 vs. Control: 19.1 $\pm$ 4.8 nmol/L, $p=0.31$). However, during the intraoperative period, the VR group showed significantly lower cortisol levels (15.2 $\pm$ 4.1 vs. 22.8 $\pm$ 5.3 nmol/L, $p<0.001$; Cohen's $d = 1.62$), indicating substantial stress hormone suppression. This difference persisted postoperatively (VR: 16.8 $\pm$ 3.9 vs. Control: 21.4 $\pm$ 5.1 nmol/L, $p<0.001$; Cohen's $d = 1.01$).

Heart rate variability analysis revealed significant improvements in the VR group across multiple parameters (Figure 2B). The root mean square of successive differences (RMSSD), a key indicator of parasympathetic activity, was significantly higher in the VR group during the intraoperative period (42.1 $\pm$ 8.2 vs. 31.5 $\pm$ 7.6 ms, $p < 0.001$; Cohen's $d = 1.34$). Similarly, the standard deviation of normal-to-normal intervals (SDNN) showed superior values in the VR group (38.7 $\pm$ 7.3 vs. 29.2 $\pm$ 6.8 ms, $p < 0.001$; Cohen's $d = 1.36$), confirming enhanced autonomic balance and reduced physiological stress response (Table 2).

Table (2): Anxiety scores (STAI) across study time points.

Time point	VR Group (n=72)	Control Group (n=73)	p-value	Cohen's d
Baseline	54.2 $\pm$ 8.1	55.1 $\pm$ 7.7	0.49	0.11
Intraoperative	37.2 $\pm$ 15.3	52.9 $\pm$ 15.7	<0.001	1.01
Postoperative	40.1 $\pm$ 13.5	53.3 $\pm$ 15.0	<0.001	0.94

Data presented as mean $\pm$ SD. STAI = State-Trait Anxiety Inventory.

Anxiety Assessment

The VR group had significantly lower intraoperative anxiety scores (Figure 2C) (37.2 $\pm$ 15.3 vs. 52.9 $\pm$ 15.7, $p<0.001$; Cohen's $d = 1.01$) and postoperative anxiety scores (40.1 $\pm$ 13.5 vs. 53.3 $\pm$ 15.0, $p<0.001$; Cohen's $d = 0.94$) than the controls. This represents a clinically meaningful anxiety reduction exceeding the minimal clinically important difference of 10 points for STAI scores in surgical settings (Table 2).

Heart Rate Variability, Hemodynamic Parameters, and Safety

Analysis of heart rate variability (HRV) revealed a significant increase in parasympathetic activity in the VR group, as

indicated by a higher root mean square of successive differences (RMSSD) intraoperatively (38.2 $\pm$ 12.1 ms vs. 28.5 $\pm$ 10.3 ms, $p < 0.001$; Cohen's $d = 0.87$) compared to controls. Hemodynamic parameters remained stable between groups, with no significant differences in systolic blood pressure, diastolic blood pressure, or oxygen saturation (all $p > 0.05$). The VR group showed significantly lower intraoperative heart rates (85.5 $\pm$ 7.6 vs. 90.0 $\pm$ 7.8 bpm, $p=0.028$; Cohen's $d = 0.58$), consistent with the HRV findings and suggesting enhanced autonomic regulation and stress response modulation (Table 3). The incidence of adverse events was comparable between groups, with VR-related side effects occurring in only 6.9% of patients, requiring no intervention (Table 4).

Table (3): Intraoperative hemodynamic parameters.

Parameter	VR Group (n=72)	Control Group (n=73)	p-value
Heart Rate (bpm), mean $\pm$ SD	85.5 $\pm$ 7.6	90.0 $\pm$ 7.8	0.028
Systolic BP (mmHg), mean $\pm$ SD	128.4 $\pm$ 10.3	125.7 $\pm$ 11.5	0.14
Diastolic BP (mmHg), mean $\pm$ SD	75.2 $\pm$ 6.8	76.9 $\pm$ 7.2	0.15
Mean Arterial Pressure (mmHg), mean $\pm$ SD	92.9 $\pm$ 7.2	93.1 $\pm$ 7.9	0.87
Oxygen Saturation (%), mean $\pm$ SD	98.5 $\pm$ 1.1	98.3 $\pm$ 1.3	0.31

SD = standard deviation; BP = blood pressure; bpm = beats per minute.

Table (4): Adverse events and safety profile.

Adverse Event	VR Group (n=72)	Control Group (n=73)	p-value
Any adverse event, n (%)	5 (6.9%)	4 (5.5%)	0.75
Nausea	2 (2.8%)	3 (4.1%)	0.68
Vomiting	1 (1.4%)	1 (1.4%)	>0.99
Dizziness	2 (2.8%)	0 (0%)	0.15
Motion Sickness	2 (2.8%)	N/A	N/A
Required intervention, n (%)	0 (0%)	0 (0%)	>0.99

Patient Satisfaction and Secondary Outcomes

Patient satisfaction scores were substantially higher in the VR group (Figure 2D) (82.4 $\pm$ 12.1 vs. 61.3 $\pm$ 15.7, $p < 0.001$; Cohen's $d = 1.49$). Perceived stress levels were significantly lower in the VR group (21.1 $\pm$ 5.3 vs. 25.9 $\pm$ 5.8, $p<0.001$; Cohen's $d = 0.87$). Time perception was significantly compressed in the VR group (26.1 $\pm$ 8.4 vs. 61.7 $\pm$ 19.8, $p < 0.001$), indicating effective distraction (Table 5).

Table (5): Patient-reported outcomes.

Outcome	VR Group (n=72)	Control Group (n=73)	p-value	Cohen's d
Satisfaction (VAS 0-100 mm), mean $\pm$ SD	82.4 $\pm$ 12.1	61.3 $\pm$ 15.7	<0.001	1.49
Perceived Stress, mean $\pm$ SD	21.1 $\pm$ 5.3	25.9 $\pm$ 5.8	<0.001	0.87
Time Perception Ratio, mean $\pm$ SD	26.1 $\pm$ 8.4	61.7 $\pm$ 19.8	<0.001	2.28

SD = standard deviation; VAS = Visual Analog Scale. Time Perception Ratio = (perceived duration/actual duration) $\times$ 100.

Discussion

Interpretation of Key Findings

This randomized controlled trial suggests that immersive VR may be an effective non-pharmacological intervention for reducing intraoperative anxiety and stress while enhancing patient satisfaction in Palestinian patients undergoing urological surgery under regional anesthesia. The intervention demonstrated significant reductions in objective physiological stress markers, including salivary cortisol, and improvements in heart rate variability parameters, supporting the stated hypothesis regarding VR's impact on measurable stress indicators.

The magnitude of anxiety reduction observed (Cohen's $d = 1.01$ intraoperatively) is comparable to previous VR studies in Western populations [40,41], supporting the cross-cultural validity of nature-based VR interventions. However, the single-center design and specific cultural context may limit generalizability to other populations and settings.

Neurobiological Mechanisms and Theoretical Framework

The observed physiological and psychological changes align with established neurobiological mechanisms underlying VR's therapeutic effects. The significant reduction in cortisol levels and improvement in HRV parameters, specifically the increased RMSSD observed in our results, suggest that VR effectively modulates the hypothalamic-pituitary-adrenal axis while enhancing parasympathetic nervous system activity [35,42,43]. According to Roy's Adaptation Model [44], which provides the theoretical foundation for this study, VR serves as an adaptive coping mechanism that enabled patients to maintain this physiological and psychological equilibrium during surgical stress. The distraction theory mechanisms are evidenced by compressed time perception and reduced anxiety scores, indicating successful cognitive redirection away from anxiety-provoking stimuli. The multisensory nature of VR creates a high cognitive load that likely engaged prefrontal cortex resources, exerting top-down inhibitory control over the amygdala and reducing subsequent stress hormone release [42,43]. This aligns with our findings of reduced sympathetic activation (lower heart rate) and increased parasympathetic tone (higher HRV).

Clinical Implications and Safety Profile

The intervention's safety profile was excellent, with minimal VR-related adverse events (6.9%) and no interference with standard anesthetic management. This supports VR's feasibility for integration into perioperative care protocols, particularly where pharmacological alternatives may be limited or contraindicated.

The substantial satisfaction improvements (21.1-point increase on VAS) exceed minimal clinically important differences for satisfaction scales [45], confirming clinical relevance. These findings may support VR implementation in resource-constrained healthcare settings seeking to enhance patient-centered care.

Cost-Effectiveness Considerations

While formal cost-effectiveness analysis was beyond the scope of this study, the use of readily available VR technology (Meta Quest 2 headsets, approximately \$300 USD per unit) presents a favorable economic profile compared to traditional pharmacological anxiety management. In resource-constrained settings like Palestine, where imported anxiolytic medications can be costly and sometimes unavailable, VR represents a one-time investment with potential for repeated use across multiple patients. Conservative estimates suggest that a single VR headset could be used for 200-300 procedures annually after accounting for cleaning protocols and maintenance [46].

The economic benefits extend beyond direct medication cost savings. Traditional anxiolytics may prolong recovery time, increase postoperative monitoring requirements, and potentially increase adverse events, all of which carry indirect costs [46]. Our study showed no VR-related complications requiring intervention, suggesting reduced downstream healthcare resource utilization. Additionally, the significant improvement in patient satisfaction scores may translate to better hospital reputation and patient retention, providing intangible economic benefits.

In the Palestinian healthcare context specifically, where resources are often constrained due to political and economic

factors, VR technology offers a sustainable solution that does not depend on pharmaceutical supply chains. The cultural adaptation of VR content to include Arabic narration and Islamic elements may provide additional value by creating a more culturally competent care experience. Future health economic studies should quantify these potential cost savings, including reduced medication costs, shortened recovery times, and improved operational efficiency [46]. A comprehensive cost-effectiveness analysis comparing VR implementation costs against traditional pharmacological anxiety management is warranted to support policy decisions in similar resource-limited healthcare settings.

Comparison with Existing Literature

Recent systematic reviews and meta-analyses have consistently demonstrated VR's effectiveness in reducing perioperative anxiety across diverse surgical populations [12,13,47]. Our findings align with these broader evidence syntheses while extending the evidence base to Middle Eastern populations and resource-constrained settings. The anxiety reduction observed (Cohen's $d = 1.01$) aligns with previous studies by Alaterre et al. [1] and Arifin et al. [2], which reported similar effect sizes (0.85-1.20) using VR during regional anesthesia.

Limitations and Methodological Considerations

Several important limitations should be acknowledged. The single-center design limits generalizability beyond Palestinian healthcare contexts, though this also ensures consistency in clinical protocols and cultural relevance. The inability to blind patients to the VR intervention introduces potential expectation bias in self-reported outcomes, though objective physiological findings provide validation of treatment effects. The culturally-adapted VR content, while potentially enhancing effectiveness for Arabic-speaking Muslim populations, may limit the direct applicability of these results to non-Arabic-speaking populations or those from different cultural backgrounds. Future studies in diverse cultural settings would need to develop and validate culturally-appropriate VR content specific to their target populations. However, the underlying neurobiological mechanisms of VR's anxiolytic effects are likely universal, suggesting that culturally-adapted VR interventions could be effective across different populations with appropriate content modifications.

The use of patient-selected VR environments, while enhancing engagement and real-world applicability, introduced some variability in intervention delivery. Although all environments were pre-tested for equivalence, this represents a compromise between methodological rigor and clinical practicality. Future studies might benefit from either using a single standardized environment or conducting subgroup analyses based on environment type. The absence of long-term follow-up limits understanding of sustained VR effects on anxiety, pain outcomes, and surgical recovery. Additionally, the use of a single-item VAS for satisfaction assessment may not capture the multidimensional aspects of the patient experience [48].

Future Research Directions

Future studies should employ multicenter designs with diverse populations and surgical specialties to enhance generalizability. Specific research priorities should include validation studies of culturally-adapted VR interventions in different ethnic and cultural groups, with particular attention to content adaptation strategies and their impact on effectiveness. Long-term outcome studies evaluating VR's effects on chronic pain development, healthcare satisfaction, and functional

recovery would provide valuable insights. Comparative effectiveness research comparing VR to other non-pharmacological interventions (music therapy, guided imagery, meditation) would inform optimal anxiety management strategies. Comprehensive cost-effectiveness analyses incorporating equipment costs, staff training, pharmaceutical cost savings, and potential reductions in healthcare resource utilization should be prioritized for healthcare policy decision-making, particularly in resource-constrained settings.

Clinical Recommendations and Implementation

Based on these findings, healthcare institutions may consider VR implementation as part of comprehensive perioperative anxiety management strategies, particularly for conscious procedures where traditional sedation may be contraindicated. Successful implementation should include appropriate staff training in VR technology, cultural content adaptation when necessary, and integration with existing clinical workflows. Quality assurance protocols should ensure consistent technical standards and regular equipment maintenance [49].

Conclusion

This study provides preliminary evidence supporting immersive VR as a safe and effective non-pharmacological intervention that may significantly reduce intraoperative stress and anxiety while improving patient satisfaction during spinal anesthesia. The intervention demonstrated objective reductions in physiological stress markers, including salivary cortisol, and improved heart rate variability parameters, supporting its neurobiological mechanisms of action. The cultural adaptation of VR content for Arabic-speaking populations appeared effective, though generalizability to other cultural groups requires separate validation. From a health economics perspective, VR presents a promising cost-effective alternative to traditional pharmacological anxiety management, particularly in resource-constrained healthcare settings. VR may be considered as a valuable adjunct to perioperative care protocols, particularly in resource-constrained settings. Future multicenter studies with diverse populations and long-term outcomes are needed to validate these findings and further explore VR's potential in surgical care settings.

Disclosure Statements

- **Ethics approval and consent to participate:** Approved by Cairo University Faculty of Nursing Ethics Committee (IRB RHD/IRB2019041701, November 27, 2024) and Palestinian Ministry of Health (MOH-162/1512/2024, July 17, 2024). Written informed consent obtained from all participants.
- **Consent for publication:** The Author(s) declare(s) that there is no conflict of interest.
- **Availability of data and materials:** The corresponding author will furnish the data substantiating the study's conclusions upon a reasonable request.
- **Author's contribution:** K.M. conceptualized the study, coordinated data collection, and conducted the primary analysis. S.A.A. contributed to the study design, methodology, and manuscript drafting. N.A.M. provided supervision, critical revision, and expert guidance in psychiatric and mental health nursing. All authors reviewed, revised, and approved the final manuscript.
- **Competing interest:** The authors declare that they have no competing interests.
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