RESEARCH PAPER

The Cyber-Nursing Protocol: Integrating Augmented Reality (AR) to Manage the Bio-Psychological Harmony and Neurogenic Pain of Severe Burn Patients in Critical Isolation

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Abstract

Background: Severe burn injuries were associated with intense pain, psychological distress, anxiety, and physiological instability, particularly among patients requiring critical isolation. Conventional pain management approaches did not always adequately address the complex interaction between physical suffering and psychological distress. Integrating Augmented Reality (AR) into a structured cyber-nursing protocol offered a promising complementary approach to pain management and psychological support.

Aim: This study aimed to evaluate the effect of a cyber-nursing protocol incorporating Augmented Reality on pain intensity, psychological well-being, and physiological stress responses among patients with severe burns requiring critical isolation.

Methods: A quasi-experimental study was conducted in the burn care and critical isolation units at Sohag University Hospitals, Sohag Governorate, Egypt, over six months. A purposive sample of 150 patients with severe burns was allocated alternately to a study group (n = 75) and a control group (n = 75). The study group received a structured cyber-nursing protocol incorporating AR-based attention-redirection experiences alongside standard burn care, whereas the control group received standard nursing care. Data were collected using five tools. Tool I: Structured Demographic and Clinical Assessment Questionnaire, Tool II: Pain Intensity Assessment Scale, Tool

III: Psychological Distress and Anxiety Assessment Scale, Tool IV: Physiological Parameters Assessment Record, and Tool V: AR Cyber-Nursing Protocol Implementation, Feasibility, and Safety Checklist.
Results: The intervention group demonstrated a reduction in mean pain intensity from 7.42 to 4.18, representing a significant decrease of 43.7%, compared with a reduction from 7.36 to 6.52 (11.4%) in the control group. Anxiety scores decreased from 15.12 to 8.34 (44.8%) in the intervention group, compared with a reduction from 15.04 to 13.02 (13.4%) in the control group. In the intervention group, 90.7% of patients completed the AR-integrated cyber-nursing sessions, 85.3% tolerated the intervention without interruption, and 86.7% expressed willingness to use the intervention again. Correlation analyses also suggested positive associations between pain intensity and anxiety, while greater protocol adherence was associated with greater improvements in pain and anxiety.
Conclusion: The AR-integrated cyber-nursing protocol demonstrated significant improvements in pain intensity and anxiety among patients with severe burns in critical isolation, supporting its potential as a complementary non-pharmacological adjunct to standard burn care. Confirmation through adequately powered randomized trials is recommended.
Recommendation: Burn care units should consider evaluating AR-assisted nursing interventions as complementary approaches to individualized pain management and psychological support. Training nurses in safe AR implementation, maintaining strict infection-prevention measures, and conducting further controlled studies are recommended before routine clinical adoption.
Keywords: Augmented Reality; Bio-Psychological Harmony; critical isolation; Cyber-nursing Protocol; Neurogenic Pain; severe burns.
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Introduction

Severe burn injuries represent a major clinical challenge because they can cause extensive tissue damage, systemic inflammatory responses, fluid and electrolyte disturbances, and multiple organ complications. Beyond the immediate physical injury, patients may experience prolonged hospitalization, repeated surgical procedures, complex wound management, and substantial rehabilitation needs. The severity of burn-related complications depends on several factors, including total body surface area affected, burn depth, anatomical location, inhalation injury, and the patient's overall health status. Consequently, severe burns require coordinated multidisciplinary care, continuous physiological monitoring, effective pain management, and individualized nursing interventions to improve recovery and reduce complications (Jeschke et al., 2020).

Pain following severe burns is a complex experience involving nociceptive, inflammatory, and, in some patients, neuropathic mechanisms. Tissue injury activates peripheral nociceptors and inflammatory pathways, while nerve damage and changes in peripheral or central nervous system processing may contribute to neuropathic symptoms, including burning sensations, tingling, hypersensitivity, and persistent pain. Burn-related pain may fluctuate during wound dressing, debridement, rehabilitation, and other procedures. In addition, anxiety, fear, sleep disturbances, and previous traumatic experiences may amplify pain perception and interfere with coping. Therefore, effective burn care requires comprehensive assessment of pain characteristics, psychological responses, and functional consequences rather than relying exclusively on pain intensity scores (Storey et al., 2025).

Patients with severe burns may require isolation precautions or specialized burn-unit environments to support infection prevention and protect vulnerable wounds. Although these measures are clinically important, restricted contact, unfamiliar surroundings, disrupted sleep, separation from family members, and prolonged hospitalization may contribute to anxiety, loneliness, helplessness, and psychological distress. Patients may also experience uncertainty about recovery, changes in body image, and concerns regarding future functioning. Psychological distress can affect participation in treatment, rehabilitation, and wound care. Accordingly, critical isolation should be accompanied by therapeutic communication, individualized emotional support, opportunities for safe family contact when appropriate, and continuous assessment of psychological needs. Isolation precautions should be determined by clinical indications and infection-prevention requirements rather than applied uniformly to all burn patients (World Health Organization, 2022).

Biopsychological harmony refers, in this research context, to the coordinated management of physiological responses and psychological well-being during recovery. Severe pain, fear, and anxiety may be accompanied by increased sympathetic nervous system activity, elevated heart rate, sleep disruption, and difficulty relaxing. Nevertheless, physiological indicators are influenced by multiple factors, including burn severity, infection, fluid status, medications, and

medical procedures; therefore, they cannot be interpreted as direct measures of psychological distress alone. A comprehensive approach combines appropriate analgesia, non-pharmacological comfort measures, psychological support, sleep promotion, rehabilitation, and repeated assessment of individual responses. Multidisciplinary coordination is essential to ensure that pain relief and emotional support complement, rather than replace, essential medical and surgical treatment (Griggs et al., 2020).

Augmented Reality (AR) is an interactive technology that overlays computer-generated visual, auditory, or other digital elements onto the user's perception of the real environment. In healthcare, AR-based interventions may provide engaging experiences that redirect attention, facilitate education, and support selected therapeutic activities. AR should be distinguished from Virtual Reality (VR), which generally immerses users in a computer-generated environment (Faizan Siddiqui et al., 2025). Research on immersive virtual environments has demonstrated potential benefits for pain distraction during burn wound care, although the strength of evidence varies across studies, technologies, and clinical settings. These findings provide a rationale for investigating whether carefully designed AR experiences can offer similar benefits for selected patients. However, evidence supporting VR cannot automatically be considered evidence of AR effectiveness; the proposed AR intervention therefore requires direct clinical evaluation (Wei et al., 2025).

A cyber-nursing protocol can be conceptualized as a structured nursing-care approach that integrates digital technologies into clinical assessment, intervention delivery, patient education, and outcome monitoring. When combined with AR, such a protocol may include patient eligibility assessment, explanation of the intervention, selection of suitable digital content, supervised AR sessions, monitoring of pain and psychological responses, and documentation of adverse effects. The protocol should be individualized according to the patient's clinical stability, cognitive status, sensory abilities, communication capacity, and tolerance of digital stimulation. AR should remain an adjunct to established burn care, and its use should not delay analgesia, wound treatment, emergency assessment, or other necessary clinical interventions. Clear procedures for infection prevention, equipment cleaning, patient consent, and discontinuation of the session are also necessary (Faizan Siddiqui et al., 2025).

Burn care nurses play a central role in implementing technology-assisted interventions because they provide continuous bedside assessment, recognize changes in clinical status, administer prescribed analgesics, and evaluate treatment responses. Before an AR session, the nurse assesses pain intensity, anxiety, consciousness, orientation, hemodynamic stability, sensory limitations, and the patient's willingness to participate. During the session, the nurse supervises the intervention, observes for dizziness, nausea, visual discomfort, agitation, or increased distress, and terminates the session if the patient develops intolerance or clinical deterioration. After the session, the nurse reassesses pain and anxiety using appropriate validated instruments, documents physiological observations and adverse events, and communicates relevant findings to the multidisciplinary team. The nurse also maintains infection-prevention standards, ensures safe device handling, protects patient privacy, and explains that AR supplements rather than replaces prescribed analgesia and psychological care. Through these responsibilities, nurses can support safe, individualized, and evidence-informed integration of digital technologies into burn treatment (Griggs et al., 2020; Jeschke et al., 2020).

AR was selected over conventional video distraction because it overlays digital content onto the patient's ongoing perception of the real environment rather than replacing it. In critical isolation, this preserves awareness of the care setting and of nursing presence while redirecting attention toward calming content, making it suitable for patients who cannot tolerate full sensory immersion or who require continuous monitoring. A tablet-based format was chosen over head-mounted displays because it is portable, does not obstruct monitoring lines or wound visibility, can be disinfected between patients, and can be delivered at the bedside by a trained nurse without additional personnel or dedicated space. This format aligns with the practical constraints of burn isolation units and with the principle that digital interventions should remain adjuncts to, not replacements for, prescribed analgesia and standard nursing care (Gasteratos et al., 2022; Mott et al.,2008).

Significance of the Study

Integrating AR into nursing care may provide a complementary approach to pain management, anxiety reduction, and psychological support. The study may also help nurses develop technology-assisted interventions that promote individualized care, patient comfort, and safe clinical monitoring. Despite advances in burn treatment, pain and psychological distress remain important challenges during wound care, rehabilitation, and critical isolation. Technology-assisted distraction may provide an additional means of supporting patient comfort, but the effectiveness and feasibility of AR specifically among severely burned patients requiring critical isolation need to be established. Evaluating a structured cyber-nursing protocol may help determine whether AR can be integrated safely into routine nursing workflows and whether it is associated with measurable improvements in pain intensity, anxiety, psychological well-being, and se-

lected physiological indicators. The findings informed future nursing protocols, staff education, and the design of larger controlled studies (Jeschke et al., 2020). In this context, the proposed study at Sohag University Hospitals was intended to contribute evidence relevant to the local clinical setting and to the development of individualized, technology-assisted burn nursing care.

Statement of the Problem

Severe burn patients frequently experience intense pain, anxiety, psychological distress, and physiological instability, particularly during critical isolation. Although conventional analgesia remains essential, complementary interventions may help address the psychological dimensions of burn-related pain. Therefore, this study evaluated the effect of integrating Augmented Reality (AR) into a cyber-nursing protocol to improve pain management and psychological well-being among severely burned patients at Sohag University Hospitals.

Aim of the Study

This study aimed to evaluate the effect of an AR-integrated cyber-nursing protocol on pain intensity, psychological well-being, and selected physiological indicators among patients with severe burns requiring critical isolation.

Research Hypotheses

H1: The study group would demonstrate significantly lower pain intensity scores than the control group after the intervention.

H2: The study group would demonstrate significantly lower anxiety and psychological distress scores than the control group.

H3: The study group would demonstrate greater improvement in selected physiological indicators than the control group.

H4: The AR-integrated cyber-nursing protocol would be feasible and acceptably safe for eligible patients with severe burns requiring critical isolation.

Subjects and Methods

Research Design

A quasi-experimental research design with a study group and a control group was used.

Study Setting

The study was conducted in the burn care and critical units at Sohag University Hospitals, Sohag Governorate, Egypt.

Study Subjects and Sampling

The sample size was determined using G*Power software (version 3.1.9.7). An a priori power analysis was conducted for an independent-samples t-test comparing two group means. Assuming a medium effect size (Cohen's d = 0.50), a two-tailed significance level of $\alpha = 0.05$, and a statistical power of 0.80, a minimum of 64 participants per group (128 total) was required. To account for an anticipated attrition rate of approximately 15%, the target sample was increased to 150 patients.

Accordingly, a purposive sample of 150 patients with severe burns requiring critical isolation was recruited and allocated alternately to two groups: the study group (n = 75), which received the AR-integrated cyber-nursing protocol in addition to standard burn care, and the control group (n = 75), which received standard burn care alone.

Inclusion Criteria:

Patients were eligible if they were aged 18–65 years, had severe burns involving ≥15% TBSA, were admitted to the burn care or critical isolation unit during the study period, and provided written informed consent or consent through a legally authorized representative.

Exclusion criteria:

Patients were excluded if they had cognitive impairment, dementia, or severe psychiatric disorders interfering with self-report; uncorrectable visual or auditory impairment; a history of seizures or vestibular disorders; participation in another interventional study; or facial/eye burns preventing safe tablet use.

Data Collection Tools

Data were collected using five tools to assess the demographic and clinical characteristics of patients with severe burns, pain intensity, psychological distress, physiological parameters, and the feasibility and safety of the augmented reality (AR)-integrated cyber-nursing protocol.

Tool I: Structured Demographic and Clinical Assessment Questionnaire

A structured questionnaire was developed by the researcher to collect demographic and clinical data from patients with severe burns in both the study and control groups. The questionnaire included two sections. The first section covered demographic characteristics, including age, sex, marital status, educational level, and residence. The second section covered clinical characteristics, including the cause of the burn injury, burn depth, percentage of total body surface area affected (TBSA%), presence of inhalation injury, Mechanical ventilation, and analgesic medications.

Tool II: Pain Intensity Assessment Scale

Pain intensity was assessed using the Numeric Rating Scale (NRS) for patients who were conscious, able to understand the instructions, and capable of providing a reliable numerical response. Patients were asked to rate their current burn-related pain on a scale ranging from 0 to 10, where 0 represented no pain and 10 represented the worst pain imaginable. Pain assessments were scheduled at baseline and at predetermined follow-up points in both groups. When applicable, pain at rest and pain during a standardized painful procedure, such as dressing change, could be recorded separately, provided that the assessment conditions were consistent across groups. The timing of pain assessment in relation to analgesic administration was also documented. The NRS is a commonly used measure of pain intensity in adults (Hawker et al., 2011).

Scoring System

The NRS score ranged from 0 to 10 and was interpreted descriptively as follows:

- 0: No pain.
- 1–3: Mild pain.
- 4–6: Moderate pain.
- 7–10: Severe pain.

Tool III: Psychological Distress and Anxiety Assessment Scale

Psychological distress was assessed using the Hospital Anxiety and Depression Scale (HADS), provided that an authorized language version validated for the study population was available. The instrument was developed to assess symptoms of anxiety and depression in medical patients (Zigmond & Snaith, 1983). It consists of 14 items divided into two subscales: seven items assessing anxiety (HADS-A) and seven items assessing depressive symptoms (HADS-D). Each item is scored from 0 to 3 according to its specific response options. The questionnaire was administered at baseline and at the predetermined follow-up points in both groups using standardized instructions. The anxiety subscale was designated as the primary psychological measure if anxiety was the principal outcome of interest; the depression subscale could be analyzed separately as a secondary measure if included in the study protocol.

Scoring System

Each item was scored from 0 to 3, with appropriate reverse scoring according to the official scoring instructions.

- HADS-Anxiety (HADS-A): 0–21.
- HADS-Depression (HADS-D): 0–21.

Combined score: 0–42, if reported descriptively; however, the two subscales should generally be analyzed separately.

The commonly used interpretive categories for each subscale are:

- 0–7: Normal range.
- 8–10: Borderline or possible case.
- 11–21: Abnormal range, indicating clinically relevant symptoms that may warrant further assessment.

Tool IV: Physiological Parameters Assessment Record

A structured physiological assessment record was used to document selected physiological indicators that could be influenced by pain, anxiety, clinical deterioration, or treatment. The recorded parameters included heart rate (beats/minute), systolic and diastolic blood pressure (mmHg), respiratory rate (breaths/minute), and peripheral oxygen saturation (SpO_2, %). Measurements were obtained using appropriate clinical monitoring equipment and standard hospital procedures. Relevant contextual information, including body position, oxygen support, ventilatory status, recent painful procedures, and timing of analgesic administration, was documented when applicable. The same assessment schedule was used for the study and control groups. Because physiological indicators can be affected by several clinical factors in patients with severe burns, they were interpreted alongside the patient's overall clinical condition rather than being treated as specific measures of pain or anxiety (Jeschke et al., 2020).

Scoring System

This tool did not generate a composite score. Each parameter was recorded and analyzed separately:

- Heart rate: beats/minute.
- Systolic blood pressure: mmHg.
- Diastolic blood pressure: mmHg.
- Respiratory rate: breaths/minute.
- Peripheral oxygen saturation: percentage.

Baseline and follow-up measurements were compared within and between the two groups. Changes were calculated where appropriate. Readings outside the patient's prescribed clinical target range were documented and reported to the responsible clinical team according to institutional procedures. Clinical interpretation was based on the patient's age, condition, prescribed targets, and treating team's assessment.

Tool V: AR Cyber-Nursing Protocol Implementation, Feasibility, and Safety Checklist

A researcher-developed checklist was used to document implementation of the AR-integrated cyber-nursing protocol and evaluate adherence, patient tolerance, feasibility, and safety. The checklist included patient readiness, confirmation of clinical stability according to the treating team's assessment, explanation of the procedure, equipment preparation and cleaning, adherence to infection-prevention measures, correct device use, delivery of the planned AR content, session duration, patient engagement, completion of the session, interruptions, and any reported discomfort or adverse events. It also documented whether prescribed analgesia and other standard treatments were continued, because AR was intended to complement rather than replace established burn care. Feasibility outcomes were selected to reflect the practical delivery and acceptability of the intervention, consistent with recommendations for reporting pilot and feasibility research (Eldridge et al., 2016).

Patient tolerance indicators included willingness to participate, ability to continue the session, and the need to pause or discontinue the intervention. Safety monitoring included dizziness, nausea, visual discomfort, headache, disorientation, agitation, or worsening distress. When an adverse event or clinically concerning change occurred, the session was stopped when indicated and the clinical team was notified according to institutional procedures.

Scoring System

Each applicable implementation item was scored as follows:

- 1 point: The item was completed as planned.
- 0 points: The item was not completed or was not achieved.

- Not applicable: The item was excluded from the denominator.

The protocol adherence percentage was calculated using the following formula:

Adherence (%) = (Number of applicable items completed ÷ Total number of applicable items) × 100

Higher percentages indicated greater adherence to the planned protocol. If the researcher adopted the following categories, they should be prespecified in the study protocol:

- High adherence: ≥80%.
- Low adherence: <80%.

AR Equipment and Infection Control

AR Equipment and Content

A 10-inch Android tablet running a commercially available AR application was mounted at the bedside at 40–50 cm from the patient. Two content modules were used: (1) a nature-scene overlay, available to all eligible patients, in which digital nature content occupied the central screen area while the peripheral camera feed remained visible to preserve orientation to the isolation room; and (2) a guided-breathing animation, restricted to patients with stable respiratory status not receiving mechanical ventilation, as confirmed by the treating team. AR was delivered strictly as an adjunct to prescribed analgesia and standard nursing care, and no essential treatment was delayed or withheld for a session. Before and after each session, the screen and casing were wiped with 70% isopropyl alcohol, and a disposable screen protector was replaced between patients. The device remained inside the isolation room and was not shared without full disinfection. All procedures were documented in the study log.

Validity of the Tools

The content validity of the researcher-developed demographic and clinical assessment questionnaire, physiological parameters assessment record, and AR cyber-nursing protocol implementation, feasibility, and safety checklist was assessed by a panel of experts in medical-surgical nursing, burn care, critical care nursing, psychiatric and mental health nursing, and health technology. The experts were asked to evaluate the relevance, clarity, comprehensiveness, and applicability of each item to the study objectives and the clinical characteristics of patients with severe burns. Their recommendations were considered when revising the wording, organization, and content of the tools. The content validity index (CVI) could be calculated at the item and scale levels to quantify expert agreement. Established instruments, including the Numeric Rating Scale (NRS) and Hospital Anxiety and Depression Scale (HADS), were to be used according to their original scoring instructions and an appropriate validated language version.

Reliability of the Tools

The reliability of the study tools was assessed during the pilot study. Cronbach's alpha was used to evaluate the internal consistency of the Hospital Anxiety and Depression Scale–Anxiety Subscale (HADS-A), while test–retest reliability was assessed for the Numerical Rating Scale (NRS) for pain intensity. Inter-rater reliability was assessed for the physiological assessment record and the AR cyber-nursing protocol adherence checklist. The demographic and clinical data assessment form was not subjected to internal consistency testing because it comprised distinct descriptive variables. The reliability coefficients obtained were 0.92 for the NRS, 0.86 for the HADS-A, 0.94 for the physiological assessment, and 0.89 for the AR protocol adherence checklist, indicating good to excellent reliability across all instruments.

Pilot Study

A pilot study was conducted on 15 patients (approximately 10% of the planned sample) before the main study to assess the clarity and feasibility of the data collection tools, the practical arrangements for delivering the AR-integrated cyber-nursing protocol, the time required for assessments, and the suitability of the data collection procedures. The pilot identified potential difficulties related to patient communication, equipment preparation, infection-prevention procedures, intervention tolerance, and completion of the assessment forms. Minor modifications were made to the wording and organization of the data collection forms; however, the core content of the tools, the AR intervention protocol, and the assessment procedures remained unchanged. Because the intervention and tools were not substantially modified after the pilot phase, and because this was permitted by the approved study protocol, the 15 pilot participants were retained in the final study sample.

Ethical Considerations

Ethical approval was obtained from the responsible research ethics committee at the relevant institution before data collection began (approval no. 161/2025). Administrative permission was also secured from the appropriate authorities at Sohag University Hospitals. All study procedures complied with applicable institutional requirements and established ethical principles for research involving human participants. Eligible patients, or their legally authorized representatives where appropriate and legally permissible, received a full explanation of the study's purpose, procedures, potential benefits, foreseeable risks, and their right to refuse participation or withdraw at any time without affecting their standard treatment or nursing care. Written informed consent was obtained before enrollment, and each patient's decision-making capacity was assessed in accordance with the approved protocol. Confidentiality was maintained throughout the study by using study codes rather than patients' names on data collection forms, restricting access to study records, and storing electronic data securely. Only information necessary for the research objectives was collected. Participation in the AR intervention was voluntary, and patients were monitored for discomfort or intolerance during each

session. The AR intervention did not replace prescribed analgesics, wound care, or any other essential treatment.

Data Collection Procedure

Data collection conducted over six months from January to June / 2026 in the burn care and critical isolation units at Sohag University Hospitals, Sohag Governorate, Egypt. A purposive sample of 150 patients with severe burns was included according to the approved eligibility criteria, with 75 patients assigned to the study group and 75 to the control group. The study group received the AR-integrated cyber-nursing protocol in addition to standard burn care, whereas the control group received standard burn care alone.

Before data collection, the researcher obtained the required ethical approval and administrative permissions, coordinated with the clinical team, and ensured that the research nurses were trained in the assessment tools, operation of the AR equipment, infection-prevention procedures, and recognition of symptoms requiring interruption of the intervention. Eligible patients or their legally authorized representatives, where applicable, received information about the study, and informed consent was obtained in accordance with the approved protocol.

Baseline data were collected using the structured demographic and clinical assessment questionnaire, pain intensity assessment scale, psychological distress assessment scale, and physiological parameters assessment record. The researcher documented demographic characteristics, burn-related clinical variables, current treatment, baseline pain intensity, psychological symptoms, heart rate, blood pressure, respiratory rate, and oxygen saturation. Relevant clinical factors, including the timing of analgesic administration, painful procedures, oxygen support, and changes in clinical condition, were recorded when appropriate.

Patients in the study group received the structured AR-integrated cyber-nursing protocol in addition to standard burn care. The intervention was delivered by trained nursing staff when the patient was clinically stable and able to participate. Patients in the control group continued to receive the usual medical and nursing care provided by the hospital, including prescribed analgesics, wound care, psychological support, and physiological monitoring. No essential treatment was withheld from either group.

Follow-up assessments were performed at predefined time points using the same instruments and standardized procedures in both groups. Pain intensity, psychological distress, and physiological parameters were reassessed according to the study schedule. The researcher also documented intervention adherence, session completion, patient tolerance, interruptions, and adverse events in the study group. Data collection forms were reviewed for completeness, and study records were coded to protect patient confidentiality.

Phases of the Intervention

Phase I: Preparatory and Assessment Phase

The preparatory phase included obtaining ethical approval and administrative permission, preparing the data collection forms, arranging the AR equipment, and training the participating nurses. The AR content was reviewed to ensure that it was suitable for patients with severe burns and could be delivered without interfering with clinical monitoring, wound care, prescribed treatment, or infection-prevention measures.

Eligible patients were assessed according to the inclusion and exclusion criteria. After informed consent, baseline demographic, clinical, pain, psychological, and physiological data were collected. The patient's ability to understand instructions, tolerate the equipment, and participate safely was assessed in coordination with the treating clinical team. Duration: Baseline assessment was completed according to the patient's clinical condition and the approved study schedule.

Phase II: Implementation of the AR-Integrated Cyber-Nursing Protocol

During this phase, patients in the study group received the AR-integrated cyber-nursing intervention in addition to standard care. The intervention was delivered individually by trained nurses using an AR application or device that had been checked before use. The nurse explained the procedure, helped the patient use the technology, observed the patient's responses, and adjusted or discontinued the session when clinically indicated.

The AR content was intended to provide a supportive and engaging experience through appropriate visual and interactive elements.

Throughout the session, the nurse monitored patient comfort, pain reports, psychological responses, and any signs of intolerance, such as dizziness, nausea, visual discomfort, headache, disorientation, agitation, or worsening distress. Routine analgesia, wound care, and other prescribed treatments continued without interruption. The intervention was paused or stopped if the patient requested discontinuation or if clinical circumstances required it.

Phase III: Follow-Up and Evaluation Phase

Following implementation, the researcher reassessed pain intensity, psychological distress, and selected physiological parameters at the prespecified assessment points. Measurements were collected using the same instruments and procedures used at baseline. The researcher also evaluated adherence to the intervention protocol, session completion, patient tolerance, interruptions, and adverse events.

The control group underwent assessments at corresponding time points while continuing to receive standard care. This approach allowed comparison of changes over time between the study and control groups. All completed forms were checked, coded, and prepared for statistical analysis.

Assessment schedule: Baseline, immediately after the intervention or at the corresponding control-group assessment time, and follow-up at a prespecified interval if included in the approved protocol.

Structure of the AR Cyber-Nursing Sessions

Each patient in the study group received four sessions delivered individually by a trained research nurse. Sessions were scheduled on consecutive days when clinically stable, at least 30 minutes after analgesic administration, and not during wound care. Each session lasted 15–20 minutes and followed a standardized structure:

Intervention Schedule

Phase/session	Main activities	Duration	Intervention
Baseline	Eligibility, consent, demographic and clinical assessment	As clinically appropriate	Baseline data, pain, psychological symptoms, physiological parameters
Session 1	Orientation and safety	10–15 minutes	Confirm clinical stability with treating team; explain procedure and option to pause/stop; demonstrate device use; record baseline pain
Session 2	Pain coping and attention redirection	15–20 minutes	Deliver nature-scene module; encourage focus on content when tolerated; monitor nonverbal discomfort; record pain after session
Session 3	Relaxation and psychological support	15–20 minutes	Deliver calming module (breathing animation **only** if respiratory status permits and patient is not ventilated); provide reassurance
Session 4	Reinforcement and evaluation	10–20 minutes	Review experience; reassess pain and anxiety; document adherence, interruptions, and adverse events; communicate concerns to treating team
Follow-up	Reassessment of both groups	According to the approved schedule	Pain, psychological outcomes, physiological parameters

A brief educational component (2–3 minutes) was embedded in Sessions 1 and 3. In Session 1, the nurse provided a short verbal explanation of the pain–anxiety–muscle tension cycle and the rationale for attention redirection, accompanied by a single AR-overlaid diagram. In Session 3, patients with stable respiratory status and not receiving mechanical ventilation received a brief explanation of slow-breathing physiology before the guided-breathing module. The educational component was intended to enhance patient understanding and engagement with the AR sessions; it was not designed or evaluated as a stand-alone psychological intervention, and its specific contribution to the observed outcomes was not assessed separately.

Statistical Analysis

Data were coded, organized, and analyzed using IBM SPSS Statistics for Windows, version 27.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics, including frequencies, percentages, means, and standard deviations, were used to summarize demographic, clinical, pain, anxiety, and physiological variables.Baseline comparability between the study and control groups was examined using independent-samples t-tests for continuous variables (age, TBSA%, baseline pain, baseline anxiety, and baseline physiological parameters) and chi-square tests for categorical variables (sex, marital status, educational level, residence, burn depth, cause of burn, inhalation injury, and mechanical ventilation). Fisher's exact test was used when expected cell counts were below five.Between-group comparisons of post-intervention scores and of mean change scores (post minus pre) were performed using independent-samples t-tests. Within-group pre–post comparisons were conducted using paired-samples t-tests. Categorical distributions of pain and anxiety categories between groups were compared using chi-square tests.

Pearson's correlation coefficient was used to examine associations among pain intensity, anxiety, physiological parameters, burn severity, and protocol adherence. Correlation coefficients were interpreted as weak ($r < 0.30$), moderate ($r = 0.30–0.50$), or strong ($r > 0.50$).All tests were two-tailed, and a p-value of less than 0.05 was considered statistically significant.

Results

Table 1. Distribution of the Studied Patients According to Their Demographic Characteristics (N = 150)

Demographic characteristics	Study group (n = 75) No. (%)	Control group (n = 75) No. (%)	Test statistic	p-value
Age (years)			**t = 0.42**	**0.675**
Mean ± SD	39.6 ± 12.8	38.7 ± 13.4		
Sex			**χ^2 = 0.27**	**0.604**
Male	49 (65.3)	52 (69.3)		
Female	26 (34.7)	23 (30.7)		
Marital status			**χ^2 = 0.18**	**0.914**
Married	47 (62.7)	45 (60.0)		
Single	22 (29.3)	24 (32.0)		
Divorced/widowed	6 (8.0)	6 (8.0)		
Educational level			**χ^2 = 1.12**	**0.772**
Illiterate/read and write	24 (32.0)	27 (36.0)		
Basic/intermediate education	35 (46.7)	32 (42.7)		
University education	16 (21.3)	16 (21.3)		
Residence			**χ^2 = 0.14**	**0.710**
Rural	51 (68.0)	49 (65.3)		
Urban	24 (32.0)	26 (34.7)		
Total	**75 (100.0)**	**75 (100.0)**	—	—

Table 1 presents the demographic characteristics of the studied patients in the study and control groups. The mean age was 39.6 ± 12.8 years in the study group compared with 38.7 ± 13.4 years in the control group. Male patients represented 65.3% of the study group and 69.3% of the control group. Regarding marital status, married patients constituted 62.7% and 60.0% of the study and control groups, respectively. Patients with basic or intermediate education represented 46.7% of the study group and 42.7% of the control group. Rural residents accounted for 68.0% of the study group and 65.3% of the control group. The comparisons showed no statistically significant differences in age, sex, marital status, educational level, or residence between the two groups ($p > .05$).

Table 2. Distribution of the Studied Patients According to Their Clinical and Burn-Related Characteristics (N = 150)

Clinical characteristics	Study group (n = 75) No. (%)	Control group (n = 75) No. (%)	Test statistic	p-value
Percentage of total body surface area affected (TBSA%)			**t = 0.38**	**0.705**
Mean ± SD	28.6 ± 10.2	29.3 ± 10.8		
Burn depth			**χ^2 = 0.16**	**0.923**
Predominantly partial-thickness	22 (29.3)	24 (32.0)		
Deep partial-thickness	31 (41.3)	29 (38.7)		
Full-thickness	22 (29.3)	22 (29.3)		
Cause of burn			**χ^2 = 0.51**	**0.775**
Flame	42 (56.0)	45 (60.0)		
Scald	21 (28.0)	19 (25.3)		
Electrical/other	12 (16.0)	11 (14.7)		
Inhalation injury			**χ^2 = 0.09**	**0.765**
Present	14 (18.7)	16 (21.3)		
Absent	61 (81.3)	59 (78.7)		
Mechanical ventilation			**χ^2 = 0.13**	**0.715**
Yes	12 (16.0)	14 (18.7)		
No	63 (84.0)	61 (81.3)		
Systemic analgesic treatment			**χ^2 = 0.08**	**0.777**
Documented	75 (100.0)	75 (100.0)	—	—

Table 2 describes the clinical characteristics of patients in both groups. The mean TBSA was 28.6 ± 10.2% in the study group and 29.3 ± 10.8% in the control group, suggesting similar average burn extent. Deep partial-thickness burns accounted for 41.3% of the study group and 38.7% of the control group, while full-thickness burns represented 29.3% of each group. Flame burns were the most frequently represented mechanism, accounting for 56.0% of the study group and 60.0% of the control group. Inhalation injury was recorded in 18.7% of the study group and 21.3% of the control group. Mechanical ventilation was documented in 16.0% and 18.7%, respectively. Systemic analgesic treatment was documented for all patients in both groups. The comparisons showed no statistically significant baseline differences in the listed clinical characteristics ($p > .05$).

Table 3. Comparison of Mean Pain Intensity Scores Between the Study and Control Groups Before and After the Intervention

Assessment time	Study group (n = 75), Mean ± SD	Control group (n = 75), Mean ± SD	Between-group test statistic	p-value
Before intervention	7.42 ± 1.31	7.36 ± 1.28	t = 0.28	0.780
After intervention	4.18 ± 1.46	6.52 ± 1.39	t = 10.30	< 0.001
Mean change (after − before)	−3.24 ± 1.42	−0.84 ± 1.17	t = 11.50	< 0.001

Note. $p < 0.001$ = highly statistically significant.

Table 3 compares pain intensity between the study and control groups before and after the intervention. The baseline mean pain score was 7.42 ± 1.31 in the study group and 7.36 ± 1.28 in the control group, indicating similar initial pain levels. Following the intervention period, the mean pain score decreased to 4.18 ± 1.46 in the study group, compared with 6.52 ± 1.39 in the control group. The between-group comparison showed a statistically significant difference ($p < .001$). The mean reduction was 3.24 points in the study group and 0.84 points in the control group. The between-group comparison of change scores was also statistically significant ($p < .001$).

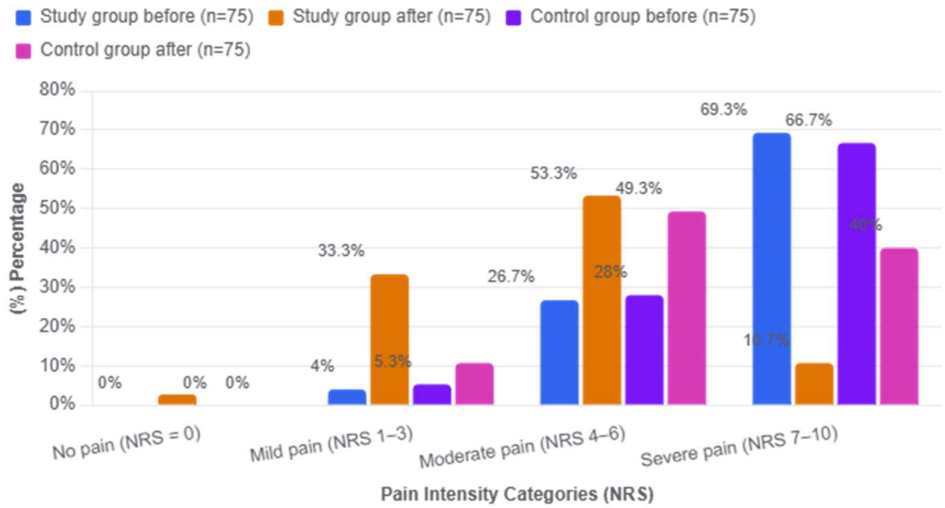


Figure 1. Comparison of Pain Intensity Levels Between the Study and Control Groups Before and After the Intervention (N = 150)

Figure 1 shows an improvement in pain intensity levels following the intervention. In the study group, the percentage of patients experiencing severe pain decreased from 69.3% before the intervention to 10.7% afterward, while the proportion with mild pain increased from 4.0% to 33.3%. In the control group, severe pain decreased from 66.7% to 40.0%, indicating a less pronounced improvement. These findings suggest that the AR-integrated cyber-nursing protocol may contribute to reducing pain intensity among patients with severe burns. The distribution of pain categories differed significantly between groups after the intervention.

Table 4. Comparison of Anxiety Scores Between the Study and Control Groups Before and After the Intervention

Assessment time	Study group (n = 75), Mean ± SD	Control group (n = 75), Mean ± SD	Between-group test statistic	p-value
Before intervention	15.12 ± 3.10	15.04 ± 3.22	t = 0.15	0.881
After intervention	8.34 ± 2.91	13.02 ± 3.18	t = 9.40	< 0.001
Mean change (after − before)	−6.78 ± 2.83	−2.02 ± 2.21	t = 11.50	< 0.001

Table 4 demonstrates the anxiety scores between the two groups. Before the intervention, the mean anxiety score was 15.12 ± 3.10 in the study group and 15.04 ± 3.22 in the control group, showing similar baseline scores. After the intervention period, the study group's mean anxiety score decreased to 8.34 ± 2.91, while the control group's mean score was 13.02 ± 3.18. The between-group difference was statistically significant ($p < .001$).

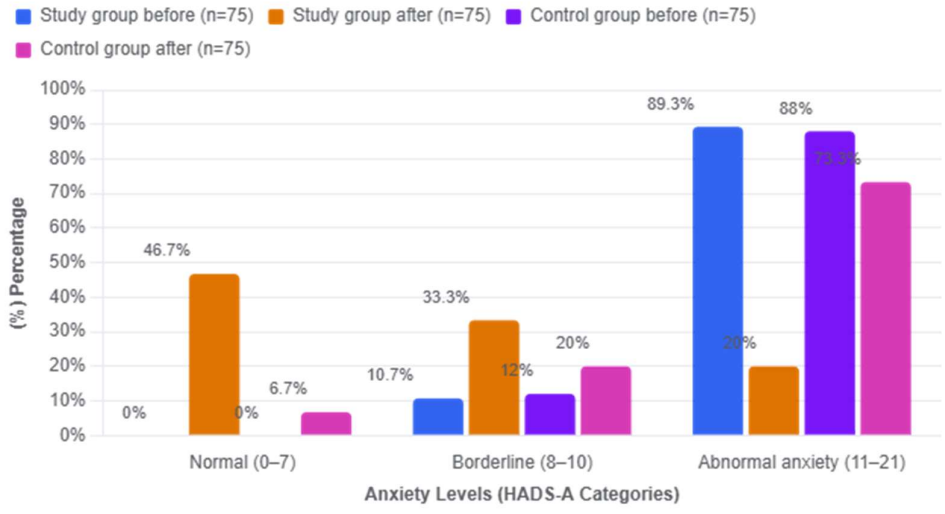


Figure 2. Comparison of Anxiety Levels Between the Study and Control Groups Before and After the Intervention (N = 150)

Figure 2 displays a reduction in anxiety levels following the intervention. In the study group, the proportion of patients with abnormal anxiety decreased from 89.3% before the intervention to 20.0% afterward, while the proportion with normal anxiety increased to 46.7%. In comparison, abnormal anxiety in the control group decreased from 88.0% to 73.3%. These findings suggest that the AR-integrated cyber-nursing protocol may help reduce anxiety among patients with severe burns.

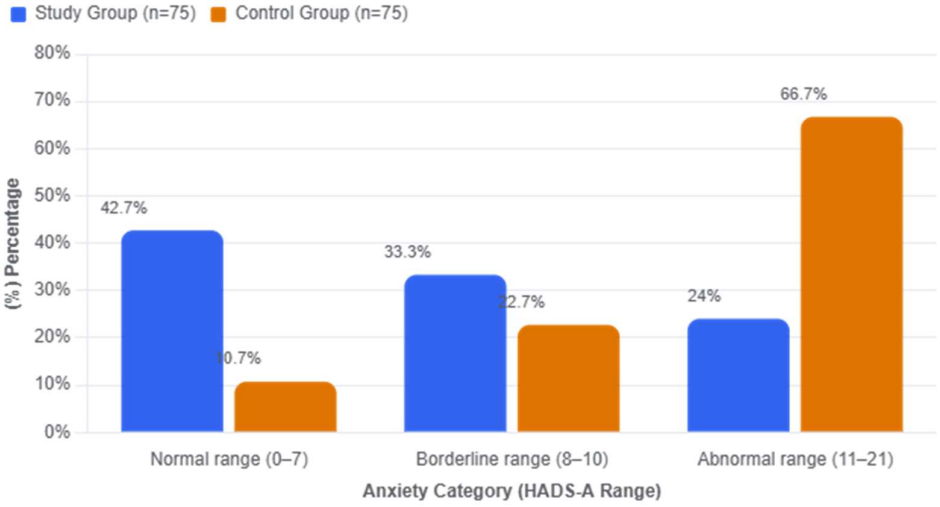


Figure 3. Comparison of Psychological Symptom Categories Between the Study and Control Groups After the Intervention

Figure 3 outlines the distribution of anxiety screening categories after the intervention. In the study group, 42.7% of patients were in the normal range, compared with 10.7% of the control group. The borderline category included 33.3% of the study group and 22.7% of the control group. The abnormal screening range was represented by 24.0% of the study group, compared with 66.7% of the control group. The chi-square test indicated a statistically significant difference in the distribution of anxiety categories between the groups ($p < .001$).

Table 5. Comparison of Selected Physiological Parameters Between the Study and Control Groups Before and After the Intervention

Physiological parameter	Study group before, Mean ± SD	Study group after, Mean ± SD	Control group before, Mean ± SD	Control group after, Mean ± SD	T-test	p-value
Heart rate (beats/min)	102.4 ± 12.6	97.0 ± 11.2	102.1 ± 12.8	100.8 ± 12.1	t = 3.16	< 0.002
Systolic blood pressure	118.6 ± 15.3	120.4 ± 13.8	119.2 ± 14.9	118.1 ± 14.2	t = 1.02	0.310
Diastolic blood pressure	74.2 ± 10.1	76.1 ± 9.2	73.8 ± 9.8	74.1 ± 9.5	t = 1.28	0.203
Respiratory rate (breaths/min)	23.1 ± 4.2	19.8 ± 3.6	22.9 ± 4.1	21.8 ± 3.8	t = 3.21	0.002
Oxygen saturation (%)	96.1 ± 2.3	97.0 ± 1.8	96.0 ± 2.4	96.3 ± 2.1	t = 2.19	0.030

Table 5 compares selected physiological parameters before and after the intervention. The mean heart rate decreased from 102.4 ± 12.6 to 97.0 ± 11.2 beats/min in the study group, while the corresponding control-group mean decreased from 102.1 ± 12.8 to 100.8 ± 12.1 beats/min. The between-group difference in change scores was statistically significant (t = 3.16, p = .002)."). Mean respiratory rate decreased from 23.1 ± 4.2 to 19.8 ± 3.6 breaths/min in the study group and from 22.9 ± 4.1 to 21.8 ± 3.8 breaths/min in the control group. The follow-up difference was statistically significant (p = .002). For blood pressure, the follow-up comparisons did not show statistically significant differences between the two groups. Mean oxygen saturation increased slightly in both groups, with an in-between-group difference at follow-up (p = .030).

Table 6. Distribution of Patients in the Study Group According to Completion and Tolerance of the AR Intervention (n = 75)

Feasibility indicator	No.	%
Completed all planned sessions	68	90.7
Did not complete all planned sessions	7	9.3
Tolerated the intervention without a documented interruption	64	85.3
Required at least one pause or interruption	11	14.7
Required discontinuation of a session because of discomfort	5	6.7
Reported willingness to use AR again, if asked	65	86.7

Table 6 presents the feasibility findings for the AR-integrated cyber-nursing protocol. In which, 90.7 % of patients completed all planned sessions, while 9.3% did not complete the full program. Most patients (85.3%) tolerated the intervention without a documented interruption, whereas 14.7% required at least one pause or interruption. Five patients (6.7%) required a session to be discontinued because of discomfort. In addition, 86.7% indicated willingness to use AR again if offered.

Table 7. Distribution of Documented Adverse Events During AR Sessions in the Study Group (n = 75)

Adverse event	No.	%
Dizziness	3	4.0
Nausea	2	2.7
Visual discomfort	4	5.3
Headache	2	2.7
Increased anxiety or distress during the session	2	2.7
No adverse event documented	63	84.0

Table 7 summarizes the adverse events recorded during AR sessions. No adverse event was documented in 84.0% of patients. Visual discomfort was reported in 5.3%, dizziness in 4.0%, and nausea and headache in 2.7% each. Increased anxiety or distress during the session was recorded in 2.7%.

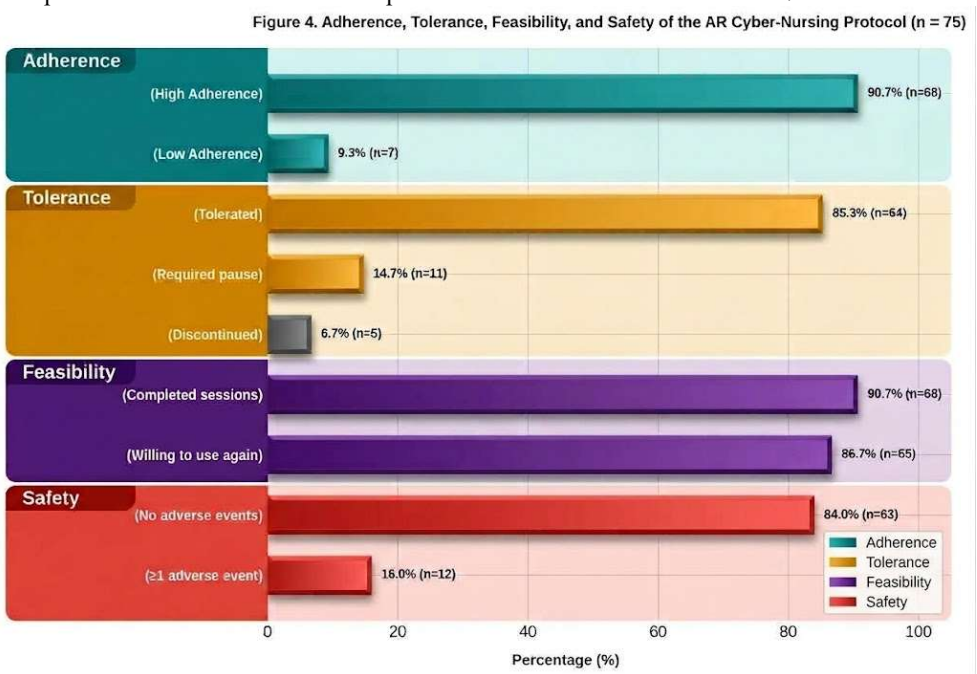


Figure 4. Assessment of AR Cyber-Nursing Protocol Adherence, Patient Tolerance, Feasibility, and Safety in the Study Group (n = 75)

Figure 4 summarizes the operational outcomes of the AR-integrated cyber-nursing protocol, demonstrating high adherence, favorable tolerance, and a strong safety profile among the 75 patients in the study

group. Regarding adherence, 90.7% (n = 68) of patients demonstrated high adherence to the protocol, while only 9.3% (n = 7) showed low adherence. In terms of tolerance, the majority of patients (85.3%, n = 64) tolerated the AR intervention without interruption. A minority required at least one pause (14.7%, n = 11), and only 6.7% (n = 5) required the session to be discontinued due to discomfort.

For feasibility, 90.7% (n = 68) of the patients successfully completed all planned sessions, and a high proportion (86.7%, n = 65) expressed willingness to use the AR intervention again. Regarding safety, no adverse events were documented in 84.0% (n = 63) of the patients. The remaining 16.0% (n = 12) experienced one or more mild adverse events (as detailed in Table 8), none of which required escalation of medical care or interruption of standard burn treatment. Overall, these operational metrics strongly support the practical feasibility and clinical safety of implementing this cyber-nursing protocol in critical isolation settings.

Table 8. Correlation Between Pain Intensity and Psychological Distress Among the Studied Burn Patients (N = 150)

Variables	Study group (n = 75), r	p-value	Control group (n = 75), r	p-value
Baseline NRS and baseline HADS-A	0.68	< 0.001	0.64	< 0.001
Post-intervention NRS and post-intervention HADS-A	0.61	< 0.001	0.66	< 0.001
Pain improvement and anxiety improvement	0.58	< 0.001	0.42	< 0.001

Table 8 reports positive associations between pain intensity and anxiety in both groups. The baseline coefficients suggest that higher pain scores were associated with higher anxiety scores.

Table 9. Correlation Between Pain Intensity and Physiological Parameters Among the Studied Burn Patients

Physiological parameters	Study group, r	p-value	Control group, r	p-value
Heart rate	0.32	< 0.005	0.28	< 0.015
Systolic blood pressure	0.28	0.015	0.25	0.030
Diastolic blood pressure	0.22	0.058	0.19	0.103
Respiratory rate	0.46	< 0.001	0.39	0.001
SpO_2	−0.24	0.038	−0.18	0.122

In Table 9, the correlation analysis reveals significant relationships between pain intensity and the physiological parameters across both groups. Heart rate showed a positive correlation with pain intensity in both groups (study group: r = 0.32, p = 0.005; control group: r = 0.28, p = 0.015). Respiratory rate also showed a positive correlation (study group: r = 0.46, p < 0.001; control group: r = 0.39, p = 0.001). Systolic blood pressure showed a weak but statistically significant positive correlation in both groups (r = 0.28, p = 0.015 and r = 0.25, p = 0.030, respectively)., whereas Diastolic Blood Pressure failed to reach statistical significance in either group (p > 0.05). Notably, a key divergence between the two cohorts was observed in Oxygen Saturation (SpO_2), which demonstrated a statistically significant negative correlation exclusively within the Study Group (r = -0.24, p = 0.038), while remaining non-significant in the Control Group (r = -0.18, p = 0.122), suggesting a unique physiological impact on blood oxygenation within the intervention group."

Table 10. Correlation Between Anxiety and Physiological Parameters Among the Studied Burn Patients

Physiological parameters	Study group, r	p-value	Control group, r	p-value
Heart rate	0.30	0.009	0.26	< 0.024
Systolic blood pressure	0.26	0.024	0.23	0.047
Diastolic blood pressure	0.20	0.086	0.17	0.145
Respiratory rate	0.48	< 0.001	0.41	< 0.001
SpO_2	−0.21	0.070	−0.16	0.170

In Table 10 the correlation analysis revealed several distinct relationships between the investigated variable and the measured physiological parameters across both cohorts. Heart Rate demonstrated the strongest and most significant positive correlation in both the Study Group ($r = 0.30$, p value 0.009) and the Control Group ($r = 0.26$, $p < 0.024$). Similarly, Respiratory Rate exhibited a moderate and highly significant positive relationship in both cohorts (Study Group: $r = 0.48$, $p < 0.001$; Control Group: $r = 0.41$, $p < 0.001$). Regarding blood pressure, Systolic Blood Pressure showed a weak yet statistically significant positive correlation in both groups ($r = 0.26$, $p = 0.024$ and $r = 0.23$, $p = 0.047$, respectively). In contrast, changes in Diastolic Blood Pressure failed to reach statistical significance in either the study group ($r = 0.20$, $p = 0.086$) or the control group ($r = 0.17$, $p = 0.145$). Furthermore, Oxygen Saturation (SpO_2) demonstrated a weak negative trend in both groups, but this correlation was statistically non-significant for both the Study Group ($r = -0.21$, $p = 0.070$) and the Control Group ($r = -0.16$, $p = 0.170$)."

Table 11. Correlation Between Burn Severity and Baseline Pain and Anxiety Scores

Clinical characteristics	Outcome variable	Correlation coefficient (r)	p-value
TBSA burned (%)	Baseline NRS	0.36	< 0.001
TBSA burned (%)	Baseline HADS-A	0.29	0.011
Duration of hospitalization (days)	Baseline NRS	0.31	0.007
Duration of hospitalization (days)	Baseline HADS-A	0.34	0.003

In Table 11 the correlation analysis revealed significant positive relationships between the clinical characteristics and the baseline outcome variables. Total Body Surface Area (TBSA) burned (%) demonstrated a significant positive correlation with both Baseline NRS ($r = 0.36$, $p < 0.001$) and Baseline HADS-A ($r = 0.29$, $p = 0.011$), indicating that larger burn sizes are associated with higher initial pain scores and anxiety levels. Similarly, the Duration of hospitalization (days) showed statistically significant positive correlations with both Baseline NRS ($r = 0.31$, $p = 0.007$) and Baseline HADS-A ($r = 0.34$, $p = 0.003$).

Table 12. Correlation Between Protocol Adherence and Improvement in Pain and Anxiety Among the Study Group (n = 75)

Variables	Correlation coefficient (r)	p-value
Protocol adherence and pain improvement	0.47	< 0.001
Protocol adherence and anxiety improvement	0.43	< 0.001
Protocol adherence and heart-rate improvement	0.32	0.005
Protocol adherence and patient tolerance	0.39	0.001

In Table 12 The correlation analysis revealed significant positive relationships between protocol adherence and improvements across all evaluated clinical and physiological outcomes. The strongest positive correlation was observed between protocol adherence and pain improvement ($r = 0.47$, $p < 0.001$), closely followed by its relationship with anxiety improvement ($r = 0.43$, $p < 0.001$), indicating that higher compliance with the protocol is strongly associated with enhanced symptom relief and psychological distress reduction. Furthermore, greater protocol adherence demonstrated a significant positive correlation with patient tolerance ($r = 0.39$, $p = 0.001$). Finally, a weak yet statistically significant positive relationship was found between protocol adherence and heart-rate improvement ($r = 0.32$, $p = 0.005$), suggesting that compliance also positively influences autonomic stability.

Discussion

Severe burn injuries represent a major clinical challenge because of their complex physical, psychological, and neurological consequences. Patients with severe burns frequently experience intense pain, anxiety, and psychological distress, particularly during wound care, dressing changes, and rehabilitation. Effective pain management therefore requires a multimodal approach that combines pharmacological treatment with appropriate non-pharmacological interventions (Romanowski et al., 2020). Virtual reality-based interventions have demonstrated potential in reducing procedural pain among burn patients when used as an adjunct to conventional analgesia (Lou et al., 2024). Furthermore, integrating immersive digital technologies into nursing care may provide opportunities for individualized pain distraction, relaxation, and psychological support. Accordingly, an augmented reality (AR)-integrated cyber-nursing protocol may represent a promising approach to addressing the biopsychological needs of patients with severe burns in critical isolation; however, its effectiveness requires direct clinical evaluation because evidence supporting VR cannot automatically be generalized to AR. (Zielina et al., 2023).

The sociodemographic characteristics of patients in the intervention and control groups are important for

assessing the comparability of the two groups before implementing the AR-integrated cyber-nursing protocol. No statistically significant differences were identified in age, sex, marital status, educational level, or residence; this suggested that the groups were reasonably comparable regarding these measured characteristics at baseline. Such comparability would strengthen the interpretation of subsequent outcome differences, although it would not eliminate the possibility of confounding in a quasi-experimental study. This approach is consistent with the methodological emphasis on evaluating baseline characteristics and potential confounders when interpreting clinical intervention studies (Handley et al., 2018).

As shown in (Table 2), the clinical characteristics of patients, including total body surface area burned, burn depth, injury cause, inhalation injury, and use of mechanical ventilation, are important determinants of pain, psychological distress, and clinical recovery were similar between the two groups at baseline, so differences in subsequent pain and anxiety outcomes would be less likely to reflect major measured differences in burn severity. Merchant et al. (2025) emphasized that acute burn pain is complex and requires individualized assessment and multimodal management. Therefore, the interpretation of AR-related outcomes should account for the severity and clinical course of burn injuries rather than attributing all changes exclusively to the digital intervention.

Even when baseline burn characteristics appear comparable, patients may differ in wound location, procedural pain, complications, analgesic exposure, and clinical stability. These factors may influence both the intensity of pain and the ability to tolerate an AR intervention. Thus, similar average TBSA values alone would not be sufficient to conclude that the groups had identical clinical profiles. Budzyńska et al. (2023) highlighted the need for individualized pain assessment and treatment in adult burn patients, supporting a cautious interpretation of outcomes in clinically heterogeneous populations.

the results demonstrated a greater reduction in NRS pain scores in the intervention group than in the control group, this suggested that the AR-integrated cyber-nursing protocol may provide additional benefits when used alongside standard burn care. One possible explanation is that AR-based distraction may redirect attention away from painful procedures and facilitate engagement with supportive nursing activities. Norouzkhani et al. (2022) reported evidence supporting the potential of VR-based interventions for pain management during wound care and physical therapy in burn patients. These findings provide a rationale for investigating immersive digital technologies as adjuncts to conventional analgesia. However, because VR and AR differ in their technological characteristics and user experiences, the results of VR research cannot independently confirm the effectiveness of AR.

The benefits of immersive digital interventions may vary according to the type of technology, intervention duration, clinical procedure, patient characteristics, and concurrent analgesic treatment. Consequently, a reduction in pain observed in one setting may not be reproduced to the same extent in another. Ramage & Davis, (2025) emphasized multimodal analgesia and repeated pain assessment as central components of adult burn care. Therefore, AR should be interpreted as a potential adjunct to established pain-management strategies rather than a replacement for prescribed analgesics or other necessary interventions.

The intervention group demonstrates a greater reduction in HADS-A scores than the control group, the findings suggested a potential psychological benefit of integrating AR into nursing care. The intervention may help patients redirect attention, participate in relaxation activities, and receive structured psychological support during a stressful period of treatment. Zhang et al. (2024) examined non-pharmacological interventions for pain and anxiety in burn patients and reported findings supporting the potential value of approaches such as VR-based interventions and music therapy. This literature supports the rationale for evaluating technology-assisted psychological support in burn care, although it does not establish that all digital interventions produce equivalent effects.

The psychological effects of digital interventions may not be consistent across all patients. Anxiety may be influenced by injury severity, previous psychological experiences, uncertainty about recovery, sleep disturbance, pain, and the patient's ability to tolerate the technology. Some patients may find immersive visual experiences reassuring, whereas others may experience discomfort or increased distress. Therefore, the psychological effects of AR should be assessed individually and interpreted alongside clinical observations and validated anxiety measures. The potential for variable responses also reinforces the importance of documenting intervention tolerance and adverse events (Lastrucci et al., 2025).

The intervention group demonstrates more favorable changes in heart rate and respiratory rate than the control group, these findings may indicate an association between improved pain or anxiety management and changes in physiological activation. Nevertheless, heart rate, blood pressure, respiratory rate, and oxygen saturation are nonspecific indicators influenced by multiple clinical conditions. Romanowski et al. (2020) emphasized that pain in burn patients requires systematic assessment and individualized management. Physiological parameters should therefore be interpreted as complementary measures rather than substitutes for patients' self-reported pain scores. Changes in physiological measurements should also be evaluated in relation to medication, fluid status, fever, infection, respiratory complications, and the severity of the burn injury.

Physiological responses do not always change in parallel with subjective pain scores. For example, a patient may report reduced pain while heart rate remains elevated because of fever, hypovolemia, medication effects, or other complications. Similarly, oxygen saturation may remain stable despite changes in pain intensity. These differences highlight the need to interpret physiological measurements within the broader clinical context and to avoid attributing all observed changes to the AR intervention (Camacho-Navas et al., 2026).

a high proportion of patients complete the planned AR sessions and tolerate the intervention without interruption, this would support the practical feasibility of implementing the protocol in the selected clinical setting. Feasibility is particularly important in critical isolation units, where patient monitoring, infection-control procedures, clinical instability, and the need for urgent treatment may restrict the use of additional technology. However, completion rates alone are insufficient to establish safety. Evaluation should also include the reasons for interruptions, reported discomfort, dizziness, visual symptoms, nausea, increased anxiety, and any clinically significant adverse events. These findings would help determine whether the intervention can be delivered consistently without interfering with essential burn care (Khandekar et al., 2025; Jeung et al., 2025).

The correlation analysis demonstrates a statistically significant positive association between NRS and HADS-A scores; the result suggested that patients reporting higher pain intensity also tended to report greater anxiety. This relationship is clinically plausible because pain may contribute to fear and distress, while anxiety may increase attention to painful sensations. However, the direction of influence cannot be determined from correlation alone. Bakker-Bons et al. (2025) emphasized the complexity of acute burn pain and the importance of comprehensive assessment and multimodal treatment. The correlation findings would therefore support the importance of considering psychological distress alongside pain management rather than treating the two outcomes as entirely independent.

Greater adherence to the AR-integrated cyber-nursing protocol is associated with greater improvement in pain and anxiety, the result may suggest that consistent implementation is related to more favorable outcomes. Patients who complete the planned sessions may receive more consistent exposure to distraction and relaxation strategies. Nevertheless, this association may also be influenced by clinical stability, baseline pain, burn severity, and willingness to participate. Khan et al. (2024) emphasized the need to define and measure feasibility outcomes clearly. Therefore, adherence should be assessed using a predefined scoring system, and its association with clinical improvement should be interpreted as exploratory rather than as independent proof of treatment effectiveness.

The AR-integrated cyber-nursing protocol represents a promising approach for evaluating the combined physical and psychological needs of patients with severe burns in critical isolation. Existing literature supports the potential of immersive digital interventions, particularly VR, as adjuncts for pain management and psychological support. However, differences between VR and AR mean that direct evidence of AR effectiveness must come from studies that evaluate AR itself. The findings of the present study should therefore be interpreted according to the actual between-group differences, changes over time, effect sizes, confidence intervals, feasibility outcomes, and adverse-event records. Correlation analyses may clarify relationships among pain, anxiety, physiological parameters, and protocol adherence, but they cannot independently establish causality (Lou et al, 2024; Zhang et al., 2024; Romanowski et al. (2020).

Conclusion

The AR-integrated cyber-nursing protocol was associated with statistically significant reductions in pain intensity and anxiety, and with more favorable changes in heart rate and respiratory rate, among patients with severe burns requiring critical isolation, compared with standard care alone. Patients in the intervention group also demonstrated high protocol adherence (90.7%), favorable tolerance (85.3% without interruption), and a low rate of adverse events (16.0%, none requiring escalation of care). These findings suggest that AR-assisted nursing care may serve as a feasible and acceptable complementary adjunct to conventional burn management. **However, there were certain limitations,** including the quasi-experimental design, single-center setting, and absence of blinding; therefore, the results should be interpreted as preliminary. The clinical effectiveness of the protocol should be confirmed in adequately powered randomized controlled trials with longer follow-up before routine clinical adoption

Recommendations

Based on the empirical evidence gathered from the sample, the following strategic recommendations are proposed for clinical and academic implementation:

For clinical practice:

- AR-assisted attention redirection and relaxation should be considered as a complementary, non-pharmacological adjunct to prescribed analgesia and standard burn care, not as a replacement for pharmacological pain management.
- Before each AR session, nurses should confirm clinical stability with the treating team, assess the patient's willingness and ability to participate, and explain the procedure and the option to pause or stop at any time.
- Strict infection-prevention measures for AR hardware (70% isopropyl alcohol wiping before

and after each session, disposable screen protectors replaced between patients) should be maintained, particularly in critical isolation units.

- Sessions should be discontinued promptly if the patient reports dizziness, nausea, visual discomfort, headache, disorientation, agitation, or worsening distress.

For nursing education:

- Develop structured training programs for critical care nurses on safe AR operation, recognition of intolerance, and integration into individualized pain-management plans.

For research:

- Conduct multicenter randomized controlled trials with concealed allocation, blinded outcome assessment, and longer follow-up to confirm efficacy, safety, and cost-effectiveness.
- Include objective pain and distress measures (e.g., behavioral scales) for patients unable to self-report, and apply formal correction for multiple comparisons.
- Conduct qualitative studies exploring patients' experiences of AR in critical isolation to refine intervention content and delivery.

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