Expert Consensus on the Application of Virtual Reality Technology in Home-Based Rehabilitation for Cancer-Related Insomnia (2025 Edition) Post-Print

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Abstract

To thoroughly implement the whole-cycle rehabilitation concept and further standardize the application and management of virtual reality (VR) technology in home-based rehabilitation for patients with cancer-related insomnia (CRI), the Community Rehabilitation Working Committee of the Chinese Association of Rehabilitation Medicine, in collaboration with experts from multidisciplinary fields including oncology, psychology, rehabilitation medicine, nursing, public health, and digital medical technology, has jointly formulated the "Expert Consensus on the Application of Virtual Reality Technology in Home-Based Rehabilitation for Cancer-Related Insomnia (2025 Edition)" based on evidence-based medical evidence and clinical practice experience from both domestic and international sources. This consensus provides standardized guidance on core aspects such as the intervention mechanism, intervention protocol, intervention implementation process, efficacy evaluation indicators, and safety assessment of VR technology in home-based rehabilitation for CRI, aiming to construct a scientific and standardized procedural framework with diverse optional protocols. Through implementation of this consensus, it will ensure the rational and effective application of VR technology in CRI patients undergoing home-based rehabilitation, enhance the scientific rigor and safety of clinical practice, promote standardized development of digital technology in the field of oncology rehabilitation, assist patients in achieving whole-cycle rehabilitation, and improve their quality of life.

Full Text

Expert Consensus on the Application of Virtual Reality Technology in Home-based Rehabilitation for Cancer-related Insomnia (2025 Edition)

Community Rehabilitation Working Committee of Chinese Rehabilitation Medicine Association

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Abstract

To thoroughly implement the concept of whole-cycle rehabilitation and further standardize the application and management of virtual reality (VR) technology in home-based rehabilitation for patients with cancer-related insomnia (CRI), the Community Rehabilitation Working Committee of Chinese Rehabilitation Medicine Association, in collaboration with experts from multidisciplinary fields including oncology, psychology, rehabilitation medicine, nursing, public health, and digital medical technology, has jointly formulated the *Expert Consensus on the Application of Virtual Reality Technology in Home-based Rehabilitation for Cancer-related Insomnia (2025 Edition)* based on evidence-based medicine principles and domestic and international clinical practice experiences. This consensus provides standardized guidance on the intervention mechanisms, protocols, implementation processes, efficacy evaluation indicators, and safety assessments of VR technology in home-based CRI rehabilitation. It aims to establish a scientific and standardized process framework with diverse optional solutions. Through implementation of this consensus, VR technology can be applied reasonably and effectively in home-based rehabilitation for CRI patients, enhancing the scientific rigor and safety of clinical practice, promoting standardized development of digital technologies in cancer rehabilitation, facilitating patients' achievement of whole-cycle rehabilitation, and improving their quality of life.

Keywords: Virtual reality; Cancer-related insomnia; Sleep initiation and maintenance disorders; Home-based rehabilitation; Expert consensus

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1.1 Scope of the Consensus

This consensus applies to adult patients (18–75 years) diagnosed with CRI, where insomnia must be directly related to cancer itself or anti-tumor treatments (such as chemotherapy, radiotherapy, or targeted therapy). Clinical manifestations include difficulty falling asleep, sleep maintenance problems, or early awakening accompanied by daytime functional impairment. Applicable cancer types include both solid tumors and hematological malignancies. Patients with severe mental disorders (such as schizophrenia, major depression, etc.), cognitive impairment (such as Alzheimer' s disease, etc.), history of epilepsy, severe motion sickness, or glaucoma should be excluded. The applicable stages include the perioperative period, postoperative rehabilitation, intervals between radiotherapy and chemotherapy, and palliative care. This consensus focuses on the application of VR technology in home-based rehabilitation for CRI, covering core aspects including intervention mechanisms, protocols, implementation processes, efficacy evaluation indicators, and safety assessments.

1.2 Initiating Organization and Development Principles

This consensus was initiated by the Community Rehabilitation Working Committee of Chinese Rehabilitation Medicine Association in conjunction with the Department of Rehabilitation Medicine of Huashan Hospital Affiliated to Fudan University in January 2025, with formal development commencing in March 2025. The modified Delphi method was employed, strictly adhering to evidence-based medicine principles and expert consensus development standards.

1.3 Expert Panel Selection Criteria

To ensure the professionalism and clinical applicability of this consensus, expert panel selection strictly followed multidisciplinary collaboration and practice experience-oriented principles. Selected experts were required to: (1) have worked in relevant fields for $ $5 years and hold senior professional titles; (2) prioritize healthcare workers from community/primary care institutions with experience in cancer insomnia management or rehabilitation support. A total of 70 experts were included (39 with senior professional titles and 22 with associate senior titles), covering 23 provincial-level administrative regions. The composition included 51 physicians, 12 therapists, 3 nurses, 3 technical developers, and 1 other professional.

1.4 Literature Search Strategy and Evidence Evaluation

A search strategy combining subject headings and free-text terms was adopted, with corresponding Chinese and English search terms identified. Systematic searches were conducted across databases including PubMed, Web of Science, Cochrane Library, CNKI, Wanfang Data Knowledge Service Platform, Chinese Medical Association Website, Chinese Biomedical Literature Database, and professional websites such as the National Comprehensive Cancer Network (NCCN), National Cancer Institute (NCI), European Society for Medical Oncology (ESMO), American Academy of Sleep Medicine (AASM), Multinational Association of Supportive Care in Cancer (MASCC), Chinese Society of Clinical Oncology (CSCO), and World Health Organization (WHO). Included literature types comprised guidelines, expert consensus, randomized controlled trials, systematic reviews, Meta-analyses, and case reports, with search dates from database inception to March 1, 2025. The Grading of Recommendations Assessment, Development, and Evaluation (GRADE) system was used to grade evidence quality and recommendation strength. Based on the evidence and quality evaluation results, the development expert panel formulated recommendations considering China' s clinical reality and rehabilitation resources. For issues lacking high-quality evidence, expert opinions were formed through consensus meetings. Recommendations required approval by over 80% of experts. The drafting group conducted five rounds of discussion and revision. Additionally, expert panel members voted on recommendations through three rounds, with controversial opinions discussed and refined, ultimately finalizing this consensus. This consensus has been registered with the Practice guideline REgistration for transPAREncy (PREPARE) platform (https://www.guidelines-registry.org/) with registration number PREPARE-2025CN825.

2 Core Issues and Consensus on VR Technology Application in Home-based Rehabilitation for CRI

To ensure the scientific rigor, comprehensiveness, and practicality of this consensus, the development group constructed five core issues based on in-depth analysis and expert discussion. These issues aim to guide subsequent evidence retrieval, analysis, and consensus formulation, providing clear and actionable guidance for VR technology application in home-based rehabilitation for CRI. The core issues and consensus recommendations regarding VR technology application in home-based rehabilitation for CRI are summarized in Table 1 .

3 Application of VR Technology in Home-based Rehabilitation for CRI

3.1 Basic Principles and Characteristics

VR technology creates three-dimensional dynamic environments through computer generation, providing users with multi-sensory immersive experiences via

head-mounted displays and other devices. Its core lies in utilizing visual, auditory, and tactile simulation technologies to create realistic scenarios, achieving natural interaction between users and the virtual world through real-time motion capture and sensor feedback [7]. In healthcare, VR effectively manages pain, psychological therapy, and motor rehabilitation by customizing scenarios to distract patients, reduce anxiety, and regulate physiological responses. It can also enhance treatment efficacy and sleep quality through immersive experiences and personalized interventions.

3.2 Intervention Mechanisms

Recommendation 1: VR technology effectively intervenes in CRI through multiple core mechanisms working synergistically, including attention distraction, immersive multi-modal relaxation induction, cognitive restructuring, and real-time biofeedback with self-regulation. These mechanisms alleviate patients' hyperarousal state and maladaptive cognition from psychological and physiological perspectives, thereby improving sleep quality and forming an organically integrated intervention framework. (Evidence quality: B; Recommendation strength: Strong recommendation)

3.2.1 Attention Distraction Theory When individuals are troubled by stress or overactive thoughts, attention remains focused on real-world stressors, leading to hyperarousal of the nervous system. VR technology actively guides user attention through highly immersive audio-visual environments, shifting cognitive resources from stressors to low-threat stimuli in virtual scenarios (such as marine life swimming or forest campfires) [7,10]. This attention-shifting mechanism can reduce amygdala activity while activating the prefrontal cortex' s emotion regulation function [11], thereby promoting sleep at the psychophysiological level.

3.2.2 Immersive Multi-modal Relaxation Induction Pre-sleep relaxation protocols have been proven to facilitate sleep onset and improve sleep quality. When insomnia patients are guided to imagine interesting, engaging, and relaxing scenarios (i.e., image distraction), their sleep onset latency decreases and pre-sleep distress is reduced. VR experiences can simulate natural environments such as tranquil forests or beaches, helping patients enter a deeply relaxed psychological state through multi-sensory stimulation of vision and hearing, which belongs to the experiential immersion mode [12]. This relaxed state is key to promoting sleep initiation. Emerging mind-body practices like mindfulness belong to the participatory immersion mode [7], and VR platforms can integrate these practices into immersive experiences, guiding patients through mindfulness meditation and breathing training to help them learn and practice relaxation techniques, manage sleep symptoms, and establish healthier sleep patterns. Both immersion modes actually promote sleep by mobilizing participants' cognitive resources and distracting attention [13].

3.2.3 Cognitive Restructuring The NCI notes that CBT-I is helpful for managing sleep and is recommended as first-line therapy for insomnia [14]. VR provides a more immersive and experiential platform for key components of CBT-I. Multiple studies show that VR does not replace CBT-I but effectively enhances or serves as a "beneficial supplement"to it [15,16]. VR technology helps patients identify, challenge, and correct sleep-related negative thoughts and beliefs through its unique immersive and customizable environments, greatly enhancing the cognitive restructuring process. VR supports "real-time cognitive restructuring," allowing negative thoughts to be captured, examined, and modified instantly in virtual contexts, thereby strengthening the connection between identifying and correcting problematic thinking patterns. Additionally, VR can concretize abstract cognitive distortions as physical obstacles in virtual environments, making these distortions appear more manageable through "experiential restructuring,"thus promoting deeper psychological insight and lasting cognitive change [17,18].

3.2.4 Real-time Biofeedback and Self-regulation VR can activate the parasympathetic nervous system and inhibit sympathetic excitation through specific virtual scenarios and stimulation patterns, regulating physiological indicators such as heart rate and heart rate variability [19], alleviating the hyperarousal state in insomnia patients and directly addressing the physiological barriers of insomnia. This regulation is achieved through multiple pathways of the neuro-endocrine-immune network, creating a physiological foundation for cognitive restructuring and achieving organic integration of psychological and physiological interventions. Visualizing internal states such as heart rate or breathing as external, controllable elements like fire or light circles makes the abstract concrete. This immediate feedback significantly promotes patients' mastery and internalization of self-regulation techniques through operant conditioning that reinforces target physiological responses [20]. Simultaneously, real-time biofeedback data provides therapists with quantifiable objective evidence, enabling them to precisely formulate and instantly adjust intervention plans, overcoming the limitations of traditional therapies in data acquisition and feedback timeliness, and achieving dynamic treatment optimization based on evidence-based medicine [21,22].

3.3 Application Scenarios and Protocols

Recommendation 2: For CRI, home-based VR rehabilitation can select from the following intervention protocols based on patients' specific needs and conditions: VR natural scene simulation intervention, recommended at 1 session/day, 15–20 min/session, for 3–4 weeks; VR-guided mind-body practices (such as mindfulness meditation and breathing training), recommended at 1 session/day, 30 min/session, for 6 weeks; VR-assisted cognitive behavioral therapy for insomnia (CBT-I), recommended at 1–2 sessions/day, 15–30 min/session, for 3–6 weeks; VR combined with biofeedback (VR-BF), recommended at 1 session/day, 15–30 min/session, for 7–10 days or longer. These protocols have different em-

phases and collectively provide diverse home-based rehabilitation options for CRI patients. (Evidence quality: C; Recommendation strength: Strong recommendation)

3.3.1 VR Natural Scene Simulation Nature-based VR environments have significant benefits for insomnia treatment, consistent with attention restoration theory and psychophysiological stress recovery theory, reflecting the human brain' s innate positive response to natural stimuli [23]. For cancer patients unable to access nature due to physical limitations or psychological distress, virtual natural environments provide a crucial and accessible "sanctuary"that effectively offers coping mechanisms and a sense of escape, which is a key consideration in VR sleep intervention design. Related studies confirm that VR combined with natural landscapes can directly or indirectly improve sleep quality. A clinical trial in breast cancer patients found that daily intervention with a 360° snow scene VR environment for 3 weeks improved reported sleep quality and reduced hot flashes and night sweats by 50% [24]. Another VR mindfulness training model for ovarian cancer patients using 360° 3D natural scenes and multi-sensory stimulation for 15 min/day over 4 weeks significantly reduced anxiety, depression, and cancer-related fatigue, with these symptom improvements indirectly promoting sleep [25]. Additionally, research shows that interactive VR in natural environments such as islands, forests, mountains, and seas is more effective than music therapy in reducing anxiety, depression, and fatigue [26]. This evidence demonstrates that VR interventions combining natural landscapes and sounds have significant effects in improving psychophysiological symptoms in cancer patients, thereby effectively promoting sleep quality enhancement.

3.3.2 VR-Guided Mind-Body Practices VR-guided mindfulness meditation and breathing should be considered an innovative psychotherapeutic approach, particularly suitable for insomnia in cancer patients where treatment effects are difficult to quantify through traditional methods. VR technology integrates mind-body practices such as mindfulness meditation and breathing training into immersive experiences, making these exercises easier to understand and follow through engaging visual and auditory cues [7], such as guiding diaphragmatic breathing or body scanning to identify and release physical tension. A Meta-analysis of VR and mobile interventions for cancer patients showed that mindfulness training improved sleep quality, anxiety, and depression [27]. Another 6-week VR intervention study in chronic insomnia patients also demonstrated that 30 min/day of relaxation, mindfulness meditation, and hypnotherapy significantly reduced Pittsburgh Sleep Quality Index (PSQI) and Insomnia Severity Index (ISI) scores and alleviated depressive and anxiety symptoms [6]. Additionally, a VR meditation intervention for nursing students significantly improved subjective sleep quality, wake-after-sleep-onset time, sleep efficiency, and deep sleep quality [28]. This evidence indicates the effectiveness of VR-guided mindfulness meditation and breathing training for insomnia.

3.3.3 VR-Enhanced CBT-I The AASM strongly recommends CBT-I as the preferred treatment for chronic insomnia in adults [14]. VR can simulate daily scenarios, enabling patients to actively practice coping skills in controlled yet realistic environments that are difficult to achieve in traditional clinical settings. VR can transform cognitive behavioral therapy (CBT) into a more tactile and experiential process, shifting it from purely talk-based or imaginative therapy to an experiential, data-driven intervention. The latest 2025 research found that digital therapeutic interventions incorporating VR elements were significantly superior to traditional CBT-I and placebo in reducing ISI scores and increasing remission rates, highlighting the potential of digital modalities to deliver effective treatment at scale [29]. A clinical trial of 42 breast and ovarian cancer patients showed that VR artificial intelligence intervention combining CBT and mindfulness-based stress reduction, administered 2 times/day for 24 days, significantly reduced reported hot flash frequency, stress levels, mental distress, and sleep problems while improving quality of life and illness perception, confirming that VR can effectively alleviate physical and psychological symptoms through intuitive, vivid interactions [30]. Another pilot study found that mobile application interventions had positive effects on sleep in cancer patients [31]. A systematic review of 136 randomized controlled trials further demonstrated that digital CBT and VR therapy are very promising options for reducing psychological distress and improving quality of life in cancer patients, with both superior to non-active control conditions in relieving depression, anxiety, and fatigue, and VR therapy showing significant effects across multiple outcomes including sleep [32]. Notably, VR also has significant effects in relieving anxiety, which is closely related to insomnia improvement. A study of experiential VR training based on CBT for anxiety populations found it achieved better results than traditional CBT, significantly reducing chronic "trait" anxiety [33]. This evidence collectively supports the strong potential of VR technology as an effective supplement to CBT-I.

3.3.4 VR Combined with Biofeedback The core of biofeedback lies in conscious physiological self-regulation, an effective non-pharmacological method for coping with insomnia, particularly hyperarousal. VR combined with biofeedback technology provides real-time objective biofeedback through multi-modal channels, helping patients learn to regulate their own states to promote sleep. Additionally, VR can transform abstract physiological data into immersive, gamified visual cues that enhance engagement and accelerate self-regulation learning, making treatment more intuitive and motivating. Multiple studies support the potential of VR combined with biofeedback in improving insomnia: a home-based heart rate variability biofeedback (HRV-BF) study showed that cancer patients who trained before bedtime for 7–10 days had significantly improved sleep efficiency and reduced sedative dependence [34]. Furthermore, VR combined with neurofeedback can improve anxiety and pain in cancer patients, laying the foundation for sleep improvement [35]. Another study confirmed that biofeedback-based VR games can effectively improve stress cognition and

reshape positive mindset in patients with stress coping disorders [36]. This evidence collectively indicates that VR combined with biofeedback is a promising intervention tool for improving insomnia.

4 Implementation Process

Recommendation 3: The implementation process of VR technology in home-based rehabilitation for CRI should include four core stages: pre-intervention screening and assessment, equipment debugging and intervention, safety management and monitoring, and regular evaluation and adjustment (Figure 1 [Figure 1: see original paper]). (Evidence quality: D; Recommendation strength: Strong recommendation)

4.1 Pre-Intervention Screening and Assessment Stage

Use ISI (ISI $\geq$ 8 points) [37] or PSQI (PSQI $\geq$ 5 points) [38] to quantify sleep disturbance severity; determine whether patients meet inclusion criteria, strictly excluding contraindications such as cognitive dysfunction [Mini-Mental State Examination (MMSE) <24 points] [39], major depression [Hospital Anxiety and Depression Scale (HADS) depression subscale >10 points] [40], or history of epilepsy. All patients must pass a VR adaptability test, i.e., 5-minute static scene exposure [Visual Analogue Scale (VAS) for dizziness $\leq$ 3 points].

4.2 Equipment Debugging and Intervention Stage

Before intervention, clearly inform patients and guardians about common VR adverse reactions and data privacy protection mechanisms, and obtain written consent. Both environment and equipment must meet standards: treatment requires an independent space ($ 3m^{2}$, noise <35 dB, temperature control 22-26°C), VR equipment disinfected with 75% alcohol, and equipped with one-click pause button and emergency call bell. Family members or caregivers first debug equipment, including confirming virtual scene safety boundaries, device volume, and visual clarity. The operation process strictly follows four steps: proper device wearing $\rightarrow$ visual clarity confirmation $\rightarrow$ volume calibration $\rightarrow$ program initiation.

4.3 Safety Management and Monitoring Stage

Implement real-time dynamic monitoring: family members or caregivers closely observe lip color, breathing, and limb responses during the initial 5 minutes, and initiate progressive exit prompts 3 minutes before session end. If adverse reactions occur, immediately pause intervention, implement emergency measures, document and record reasons, and report promptly.

4.4 Regular Evaluation and Adjustment Stage

Establish a multi-dimensional evaluation system combining subjective and objective assessments. Monitor weekly improvements in sleep efficiency and PSQI/ISI scores, assess nighttime awakening frequency every 4 weeks, and analyze deep sleep proportion and quality of life improvement at treatment completion. Conduct comprehensive evaluation every 4 weeks based on efficacy results, adverse reaction records, and compliance to adjust protocols.

5 Efficacy Evaluation Indicators

Recommendation 4: A multi-dimensional evaluation system combining subjective and objective indicators should be used to assess the efficacy of home-based VR rehabilitation for CRI, comprehensively covering core sleep issues, comorbid symptoms, and quality of life. Sleep scales PSQI and ISI are recommended for initial screening, with caution regarding subjective cognitive bias. For vulnerable cancer populations, the core home monitoring protocol is recommended as "actigraphy continuously worn for $ $7 days + synchronized sleep diary," with the former objectively tracking parameters such as sleep efficiency (SE) and wake-after-sleep-onset (WASO) time, and the latter calibrating device misjudgment of quiet wakefulness by recording bedtime/wake time and nocturnal symptoms. This combination can dynamically assess treatment response, replacing repeated polysomnography (PSG). PSG, as the gold standard for sleep medicine diagnosis, is recommended for CRI patients suspected of organic comorbidities but cannot achieve long-term home monitoring. Additionally, to comprehensively understand the overall effects of VR intervention, comorbid symptom scales [such as Patient Health Questionnaire-9 (PHQ-9), Generalized Anxiety Disorder-7 (GAD-7), Numeric Rating Scale (NRS), Brief Fatigue Inventory-Chinese version (BFI-C)] and quality of life scales [such as European Organization for Research and Treatment of Cancer Quality of Life Questionnaire Core 30 (EORTC QLQ-C30)] should be combined to clarify VR intervention' s improvement of patients' overall physical and mental health and quality of life. (Evidence quality: A; Recommendation strength: Strong recommendation)

5.1 Subjective Evaluation Indicators

5.1.1 PSQI The PSQI is a 19-item questionnaire assessing patients' sleep quality over the past month. Developed by Buysse et al. at the University of Pittsburgh in 1989 [38], it is one of the most widely used sleep disturbance assessment tools domestically and internationally, applicable to healthy individuals, university students, depression patients, and cancer patients. A score >5 indicates sleep disturbance [41]. PSQI' s advantages include simplicity, intuitive results, and comprehensive assessment of sleep quality and quantity with high reliability and validity (Cronbach' s α coefficient of 0.80) [42] and good correlation with PSG [43]. However, its complex scoring rules can be time-consuming,

and PSQI is primarily a comprehensive assessment of sleep quality and schedule rather than specifically designed for insomnia [44,45].

5.1.2 ISI The ISI is a 7-item self-report questionnaire assessing patients' subjective experience of insomnia over the past 2 weeks, including insomnia severity and satisfaction with daily life. The total score ranges from 0–28, with higher scores indicating more severe insomnia. Some studies suggest a cutoff score of 10 for community settings [46]. ISI is very useful for evaluating insomnia treatment effects [45], covering both daytime and nighttime insomnia assessment. ISI demonstrates good consistency with Cronbach' s α coefficients above 0.9 [37]. ISI is proven to be an effective insomnia screening tool and can serve as a clinical assessment tool for testing insomnia intervention research effects, with different versions for patients, relatives, and medical staff [37]. However, ISI is not a diagnostic tool, and its score thresholds may vary across studies [45].

5.1.3 Sleep Diary The sleep diary, as the gold standard for subjective sleep assessment [47], requires patients to continuously record for 7–14 days [46], systematically documenting parameters including actual bedtime, subjective sleep onset latency, nighttime awakening frequency and duration, and final morning awakening time, with extended items recording naps/dozing and alcohol, caffeine, and medication use [47]. Sleep diaries can quantify differences between subjective sleep perception and objective monitoring data, revealing insomnia-specific cognitive biases (such as systematic underestimation of actual sleep duration) [48]. When combined with actigraphy, it provides accurate "time in bed" definitions for actigraphy, reducing device misjudgment [49,50]. It can also identify causal associations between environmental-behavioral confounding variables (such as afternoon caffeine intake or unplanned daytime naps) and sleep quality fluctuations [47]. Compared with instrument monitoring, sleep diaries offer zero cost, no device dependency, and high ecological validity, but rely on patient compliance and recall accuracy, requiring standardized recording guidance. In cancer sleep medicine, its capture of treatment-specific information such as "chemotherapy-induced nausea-related sleep difficulty" and "opioid failure-related nighttime awakening" provides irreplaceable evidence for symptom cluster management.

5.2 Objective Evaluation Indicators

5.2.1 PSG PSG, as the gold standard for sleep medicine diagnosis, simultaneously collects physiological signals including EEG, EOG, EMG, ECG, respiration, and blood oxygen throughout the night, precisely quantifying core sleep parameters (including sleep stages REM/NREM, total sleep time, sleep onset latency, wake time, and sleep efficiency) and expandable monitoring of body position, snoring, and neuroendocrine function. It is widely used for objective diagnosis and efficacy evaluation of over 30 sleep disorders including sleep apnea and restless legs syndrome [51], with irreplaceable diagnostic value for cancer-related sleep apnea and drug-induced hypersomnia. However, it requires

professional technicians in laboratory settings, and the multi-lead equipment easily induces "first-night effects," with most patients forced to change sleep positions and unfamiliar environments interfering with real sleep states, making it particularly unsuitable for sleep-sensitive populations and impossible for long-term monitoring [52].

5.2.2 Actigraphy Actigraphy, as a portable sleep monitoring device, continuously collects limb movement data through triaxial accelerometers (typically worn on the non-dominant wrist), automatically generating key parameters including total sleep time, sleep efficiency, sleep onset latency, and wake-after-sleep-onset time via specialized algorithms, applicable to natural sleep environments such as homes [53]. Compared with PSG, actigraphy offers advantages of non-invasiveness, low cost, and long-term continuous wear [48], and was recommended by AASM as an auxiliary tool for sleep assessment in 2007 [54]. Studies confirm that actigraphy correlates with PSG sleep parameters at 78%–95%, with significantly higher sensitivity than sleep diaries in tracking chronic insomnia treatment efficacy [55]. However, actigraphy has systematic error tendencies, overestimating total sleep time and sleep efficiency and underestimating wake-after-sleep-onset during quiet rest states, thus requiring calibration with sleep diary-provided bedtime/wake time anchors [50]. Despite minimal skin irritation risk, its tolerability far exceeds PSG lead interference, making it the preferred objective tool for home longitudinal sleep monitoring (such as tumor treatment-related insomnia dynamics) [56], with future algorithm optimization promising further precision improvement.

5.3 Comorbid Symptoms and Quality of Life Evaluation Indicators

5.3.1 PHQ-9 The PHQ-9 is a depression self-rating scale developed by Spitzer et al. in 1999 based on depression symptom descriptions in the Diagnostic and Statistical Manual of Mental Disorders (4th edition) (DSM-IV) [57], comprising the 9-item self-report section specifically for depression screening within the Primary Care Evaluation of Mental Disorders (PRIME-MD) assessment tool. The scale assesses patients' depressive status over the past 2 weeks, with each item having four options: "not at all" (0 points), "several days" (1 point), "more than half the days" (2 points), and "nearly every day" (3 points), with total scores ranging from 0–27. A total score $ $5 suggests possible depressive mood, with 5–9, 10–14, and 15–27 points corresponding to mild, moderate, and severe depression respectively. Despite its concise items, PHQ-9 demonstrates good reliability, validity, sensitivity, and specificity [58], with strong logical relevance, simple and practical operation, and is widely used to screen for varying degrees of depressive disorders, assisting clinical decision-making and treatment adjustment. Notably, one item directly assesses patients' sleep problems (such as insomnia or hypersomnia), which not only serves as a core symptom for depression diagnosis but also provides important basis for identifying and assessing comorbid or depression-induced insomnia.

5.3.2 GAD-7 The GAD-7 is a brief self-rating scale developed by Spitzer et al. in 2006 based on DSM-IV for assessing anxiety symptoms over the past 2 weeks [59]. The scale contains 7 items, each with four options: "not at all" (0 points), "several days" (1 point), "more than half the days" (2 points), and "nearly every day" (3 points), with total scores ranging from 0–21. A total score $ $5 suggests possible anxiety, with 5–9, 10–14, and 15–21 points corresponding to mild, moderate, and severe anxiety. GAD-7 has been validated in domestic and general hospital studies with good reliability and validity [59], simple operation, and is an effective tool widely used clinically for anxiety disorder screening. The somatic anxiety symptoms assessed in GAD-7 are often highly comorbid with insomnia or mutually causal [60], and its assessment results provide important clinical clues for identifying and intervening in anxiety-related sleep disorders (especially insomnia symptoms such as difficulty falling asleep or sleep maintenance problems).

5.3.3 NRS The NRS is a concise and effective pain self-assessment tool widely used for various pain evaluations including cancer pain [61]. The scale requires patients to self-rate pain intensity on a 0–10 scale, where 0 represents "no pain" and 10 represents "the most severe pain imaginable" or "extremely severe pain," with higher scores indicating more significant pain [62]. For cancer patients, persistent cancer pain is one of the core factors causing difficulty falling asleep, frequent sleep interruptions (pain-induced awakenings), and decreased sleep quality; conversely, sleep deprivation lowers pain thresholds and intensifies pain perception, forming a vicious cycle of pain-insomnia [63]. Therefore, routine NRS monitoring is not only fundamental for pain management but also a critical entry point for identifying and intervening in cancer-related insomnia, with effective pain control being an indispensable measure for improving patients' sleep quality and overall quality of life.

5.3.4 BFI-C The BFI-C is a fatigue-specific assessment tool developed by the Pain Research Group of the University of Texas MD Anderson Cancer Center [64] and validated through Chinese translation for measuring fatigue levels in cancer patients. The scale contains 9 items, all using a 0 (no fatigue/no impact) to 10 (most severe fatigue/complete impact) scoring standard. BFI-C comprises two parts: global fatigue severity and global fatigue impact, with either part' s mean score or the total mean of all 9 items reflecting fatigue severity, where 0–3 indicates mild, 4–6 moderate, and 7–10 severe fatigue. BFI-C demonstrates good structural validity and internal consistency, with simple operation [65]. Severe fatigue in cancer patients (BFI-C $ $7) has a strong bidirectional association with insomnia: on one hand, treatment side effects/toxicities (such as pain, nausea) or disease-induced insomnia significantly exacerbate fatigue; on the other hand, persistent severe fatigue can disrupt sleep rhythms, causing difficulty falling asleep or sleep maintenance problems [66]. Therefore, moderate-to-severe fatigue assessed by BFI-C is an important warning signal for screening potential comorbid insomnia, prompting clinical attention and intervention for patients'

sleep problems.

5.3.5 EORTC QLQ-C30 The EORTC QLQ-C30 [67] is a quality-of-life instrument developed by the European Organization for Research and Treatment of Cancer (EORTC) and widely used globally for quality-of-life assessment in cancer patients, with good cross-cultural adaptability and reliability/validity. The scale contains 30 items comprehensively assessing cancer patients' quality of life, covering five functional dimensions (physical, role, emotional, cognitive, social), three symptom dimensions (fatigue, nausea/vomiting, pain), six single-symptom items (dyspnea, sleep disturbance, appetite loss, constipation, diarrhea, financial difficulty perception), and one global quality-of-life dimension, with total scores ranging from 0–100 (higher scores indicate better quality of life). The single-symptom item "sleep disturbance" directly assesses patients' insomnia problems over the past week (such as difficulty falling asleep, sleep interruption, or early awakening), providing standardized, quantifiable basis for identifying treatment-related or disease-induced insomnia commonly present in cancer patients, and tracking dynamic changes in insomnia symptoms during treatment and their impact on overall quality of life (such as fatigue and emotional function). QLQ-C30 is an internationally recognized core evaluation tool for cancer medical outcomes, widely used in treatment selection and efficacy monitoring.

6 Safety Assessment

Recommendation 5: When applying VR technology in home-based rehabilitation for CRI, comprehensive attention and management of safety risks in three aspects—physiological, psychosocial, and technical—are required. Physiologically, vigilance is needed for motion sickness, visual system load, and cardiovascular effects. For motion sickness, assessment via the Cybersickness Questionnaire for Virtual Reality (CSQ-VR) and objective indicators such as heart rate (HR) and heart rate variability (HRV) is recommended. For visual system load, limiting single VR intervention sessions to $ 30 $ minutes is recommended (10 minutes for first use), with increased rest and blinking and regular ophthalmolog frequency dynamic scenes are recommended. Psychosocially, vigilance is needed for immersive environments spo 9, and GAD−7 are recommended for monitoring before and after VR intervention; caregivers should closely mon per eye), high refresh rate (90–120 Hz), minimal latency (<45 ms), and wide field of view (central $ $60°, overall ideal $ $100°); patient data privacy must be strictly protected through anonymization, encryption, and access control. (Evidence quality: B; Recommendation strength: Strong recommendation)

6.1 Physiological Safety

6.1.1 Motion Sickness Motion sickness, also known as simulator sickness or VR dizziness, is a common adverse reaction when using VR, with symptoms similar to car or seasickness including nausea, dizziness, disorientation, headache, and eye fatigue [68]. This is primarily due to sensory conflict theory, where

there is a discrepancy between visual information (perceived motion in VR) and vestibular/proprioceptive information (actual lack of body movement) [69]. This conflict can lead to autonomic nervous system dysregulation [68]. Cancer patients may show higher sensitivity to adverse reactions due to their generally weakened physical condition, pervasive fatigue, increased emotional stress, or existing comorbidities.

The Simulator Sickness Questionnaire (SSQ) is the most commonly used subjective evaluation tool for assessing simulator sickness in VR environments [69], categorizing symptoms into nausea, oculomotor disorders, and disorientation [68]. However, some studies note limitations of SSQ in specifically assessing VR dizziness symptoms [70]. The CSQ-VR has been developed as a more effective and psychometrically robust cybersickness assessment tool with good internal consistency and better characteristics in detecting temporary performance degradation [69]. Additionally, pupil size has been identified as an important predictor of cybersickness intensity [69].

6.1.2 Visual System Load Prolonged VR use can cause eye strain, visual fatigue, and dry eye syndrome [71] due to reduced blinking frequency. The vergence-accommodation conflict (VAC) caused by mismatched cues between eye convergence (angle of gaze) and accommodation (lens focus) in stereoscopic displays is a primary cause of visual discomfort and headache. This can temporarily affect the eye' s accommodation reflex and depth perception after VR use [72].

To minimize visual fatigue, it is recommended to strictly limit single VR intervention sessions to <30 minutes (10 minutes for first use), with gradual duration increases thereafter [10,73]. Additionally, a 10–15 minute rest is recommended after every 30 minutes of intervention [74]. Patients should be encouraged to blink more consciously to counteract the observed reduction in blinking frequency during VR use. Regular and comprehensive ophthalmologic examinations are crucial for all VR intervention patients, especially cancer patients with additional health vulnerabilities. Core assessment indicators should include: refraction, accommodation function, phoria examination, convergence function, and tear film function [75].

6.1.3 Cardiovascular and Autonomic Nervous System Effects Cancer patients often have cardiovascular comorbidities, with systemic hypertension being most common. Additionally, many cancer treatments (such as anthracyclines, targeted therapies, radiotherapy) have known hypertensive effects and can cause short- and long-term cardiovascular toxicity, including acute blood pressure elevation and decreased left ventricular ejection fraction (LVEF), significantly increasing patients' overall risk of adverse cardiovascular events [76,77]. Although VR is commonly used for relaxation and has shown HR and blood pressure reduction effects in some contexts [74,78,79], it may also cause stress or trigger motion sickness, thereby affecting HR and HRV. Baseline blood pressure

screening before any VR intervention is recommended as a fundamental step to identify cancer patients at higher cardiovascular risk [76,77]. High-frequency dynamic scenes should also be avoided to prevent potential motion sickness and stress responses that could negatively impact cardiovascular stability [74]; VR content for insomnia treatment should prioritize calm, static, or slowly moving natural scenes.

6.2 Psychosocial Safety

6.2.1 Immersive Environment Inducing Anxiety/Depression Exacerbation or Trauma Flashbacks Although VR is effective in reducing anxiety and depression, immersive environments may exacerbate individuals' pre-existing psychological vulnerabilities, particularly for cancer patients who often experience high distress, fear of recurrence, and trauma. Clinicians must screen patients for trauma history, severe anxiety disorders, or mental disorders before VR use. The HADS, originally trialed in hospital settings, has been widely validated in community and primary care environments and can be used to detect patients' anxiety and depressive symptoms [80]. Comparing HADS scores before and after VR intervention can effectively monitor psychological state changes, with other scales such as PHQ-9 or GAD-7 also applicable.

6.2.2 Reality Confusion and Social Avoidance Immersive VR can produce a strong "sense of presence," making virtual experiences feel real. This may sometimes lead to temporary reality confusion or mild dissociative symptoms when returning to the real world [81], especially after prolonged or highly immersive sessions. Although usually short-term, this requires attention. For cancer patients who may face social isolation due to disease and treatment, over-reliance on virtual environments could theoretically exacerbate social avoidance or reduce real-world social participation. Caregivers play a key role in monitoring patients' social behavior changes, increased social avoidance, difficulty distinguishing virtual from real experiences, or other concerning psychological transformations.

6.3 Technical Safety

6.3.1 Hardware and Interaction Design Risks Optimal hardware specifications are crucial for user safety and comfort, including high resolution ($ $2K per eye), high refresh rate (90–120 Hz), minimal latency (<45 ms), and wide field of view (central $ $60°, overall ideal $ $100°) [75,82] to prevent visual discomfort, motion sickness, and ensure smooth, realistic experiences. Suboptimal hardware may exacerbate motion sickness, eye strain, headache, and general discomfort. Poor interaction design may also cause disorientation and frustration, reducing user engagement and potentially causing falls in home environments.

6.3.2 Data Privacy and Cybersecurity Home-based medical VR systems collect highly sensitive patient data, including physiological responses (HR,

brain activity), psychological states (anxiety, depression scores), and potential behavior patterns. Protecting patient health information is crucial for maintaining patient trust and complying with laws and regulations. Patient identity information should be anonymized or de-identified with real-time processing at data collection endpoints, using end-to-end encryption meeting Advanced Encryption Standard (AES-256) or higher standards for data transmission and storage. Strict access control strategies should be established with audit trails for data access behavior [83]. Additionally, strict compliance with national laws and regulations such as the *Personal Information Protection Law of the People's Republic of China* is recommended to ensure lawful and secure processing of patient data.

Conclusion

CRI is a core issue affecting patients' whole-cycle rehabilitation, with traditional interventions facing accessibility and compliance bottlenecks. This expert consensus, as the first domestic guiding document for VR technology in home-based rehabilitation for CRI, fills a gap in this field. The consensus systematically elucidates how VR alleviates patients' insomnia through multiple mechanisms and provides a complete framework covering protocol selection, implementation process, efficacy evaluation, and safety management, offering scientific, standardized, and actionable guidance for clinicians and patients. Moreover, this consensus has high generalizability; its standardized processes and multi-dimensional evaluation systems can be applied across different levels of medical institutions and home environments. Its flexible application and diverse optional solutions can also adapt to individualized needs and resource conditions of different patients, providing a solid practical foundation for widespread adoption of VR technology in cancer rehabilitation.

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