RESEARCH ARTICLE

Nursing effect of mobile health-based psychological resilience intervention on postoperative rehabilitation after total knee arthroplasty

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The increasing burden of knee osteoarthritis has made total knee arthroplasty (TKA) an increasingly common procedure, while traditional rehabilitation models have limited effects in alleviating postoperative pain and anxiety and improving compliance. Based on the theory of psychological resilience, this study constructed a mobile health (mHealth) intervention system, integrating modules of cognitive restructuring, mindfulness training, and resource activation, and implemented a closed-loop management of “assessment-feedback-intervention” through the WeChat platform. A 12-week randomized controlled trial was conducted among 120 patients after TKA. The results showed that, in terms of postoperative pain relief, knee joint function recovery, and improvement in activities of daily living (ADL), the intervention group had significantly better visual analog scale (VAS) scores, Hospital for Special Surgery (HSS) scores, and ADL scores at 12 weeks compared to the control group (*P* < 0.001). Simultaneously, psychological resilience (Connor-Davidson Resilience Scale) (CD-RISC) was significantly enhanced, and anxiety and depression levels (Hospital Anxiety and Depression Scale) (HADS) were significantly reduced (*P* < 0.001). The system exhibited good compliance with task completion rate of 85.3% and high user satisfaction (average score 4.2). This study indicated that mHealth-based psychological resilience intervention could effectively promote physical and psychological recovery after TKA and provided a new pathway for individualized and intelligent nursing.

Keywords: total knee arthroplasty; mobile health; psychological resilience; nursing.

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Introduction

The 2021 Global Burden of Disease study showed that the number of people developing knee osteoarthritis reached 30.85 million with a total of 375 million cases, and this number is projected to continue to increase by 2046 [1]. Against this backdrop, the quality of postoperative rehabilitation in total knee arthroplasty (TKA), a pivotal intervention for end-stage knee osteoarthritis, directly determines patients’ long-term quality of life [2]. However, common postoperative issues of TKA such as difficult pain control, low rehabilitation compliance, and psychological problems like anxiety and depression seriously restrict functional recovery and the rehabilitation process [3, 4]. Consequently, providing effective, continuous, and integrated physical-psychological nursing interventions during the early postoperative phase has become a critical research focus in orthopedic rehabilitation.

In recent years, psychological resilience recognized as a core capacity for coping with stress, facilitating adaptation, and maintaining psychological stability has gained increasing attention in rehabilitation medicine [5]. Studies showed that a higher level of psychological resilience helped postoperative patients better adapt to the rehabilitation process and promoted subjective well-being and objective functional recovery. The REGAIN study found that elderly patients with high preoperative psychological resilience had a significantly higher probability of maintaining independent living for 60 days after surgery [6]. A systematic review in 2024 also pointed out that interventions focusing on psychological resilience could significantly improve the emotions and stress levels of chronic disease patients [7]. In TKA patients, a prospective study by Nwankwo *et al.* demonstrated that preoperative psychological resilience scores were independently and positively correlated with postoperative physical function improvement [8]. Furthermore, an Australian cohort study emphasized that psychological states such as anxiety and depression significantly prolonged hospital stays, reflecting the direct impact of psychological factors on the rehabilitation process [9]. Nevertheless, existing research predominantly focuses on correlation analyses between psychological resilience and postoperative outcomes, lacking systematic and generalizable intervention practices. Concurrently, mobile health (mHealth) technology, as a vital component of smart healthcare, has demonstrated broad application prospects in chronic disease management and postoperative rehabilitation due to its advantages of immediacy, personalization, and accessibility. Leveraging platforms such as smartphone applications and wearable devices, mHealth systems enable personalized rehabilitation plan delivery, dynamic data feedback, and remote guidance, significantly enhancing patient compliance and self-management capabilities [10-12]. Pellegrini *et al*. applied randomized controlled trial to effectively reduce sedentary time in post-TKA patients through an app combined with vibration prompts [13]. Buneviciene *et al*. developed a behavioral psychology-integrated mobile application that sustainably enhanced psychological coping abilities in cancer survivors [14]. However, existing mHealth platforms in TKA rehabilitation predominantly focus on physiological indicator monitoring and rehabilitation task reminders, remaining in the nascent stages of emotional support and psychological resilience enhancement, and have yet to establish a multidimensional "psychological-behavioral" integrated intervention mechanism.

Current TKA postoperative rehabilitation faces three critical challenges, which include that traditional intervention models prioritize physiological recovery over psychological well-being, lacking systematic attention to emotional and cognitive factors. Rehabilitation protocols often lack personalized design and standardized frequency, making precise matching difficult to achieve. Most approaches rely on in-person follow-ups or patient self-management, lacking dynamic adjustment mechanisms based on real-time feedback [15]. These limitations collectively result in significant deficiencies in the continuity and overall effectiveness of existing rehabilitation measures. This study proposed a mHealth intervention system integrated with psychological resilience training modules. By incorporating educational content, goal setting, breathing relaxation exercises, social connection tasks, and real-time feedback mechanisms, the study established an intelligent, personalized, and dynamically adjustable rehabilitation pathway for post-TKA recovery. This research evaluated the system's effects on TKA patients' psychological status, functional recovery, and intervention adherence with the objective of establishing a scalable early-stage integrated physical-psychological rehabilitation model that provided theoretical and practical foundations for enhancing overall TKA rehabilitation quality.

Materials and methods

Study participants

From September 2024 to March 2025, 120 inpatients (54 males and 66 females), aged 55 - 80 years old, scheduled for their first TKA in the orthopedic ward of Zhengzhou Eighth People's Hospital (Zhengzhou, Henan, China), were selected as the research subjects. The recruitment of patients was uniformly carried out by the research nurse with all patients having preoperative Connor-Davidson Resilience Scale (CD-RISC-25) scores ranging from 30 to 70, meeting the inclusion criteria for mild to moderate psychological resilience decline and primary underlying diseases of essential hypertension and type 2 diabetes. All participants were informed of the research purpose, procedures, and related risks by the research team before surgery and signed the written informed consent. All procedures of this research were approved by the Ethics Review Committee of the Eighth People's Hospital of Zhengzhou (Zhengzhou, Henan, China). The inclusion criteria included 55 - 80 years old with a clear preoperative diagnosis, basic ability to operate a smartphone or with the assistance of family members, CD-RISC-25 score of 30 - 70 indicating mild to moderate decline in psychological resilience, basic communication and cooperation abilities, and willing to participate in the intervention and sign the informed consent. The exclusion criteria included patients with severe mental disorders or moderate to severe cognitive impairments, experienced serious complications during or after surgery that affected rehabilitation, underwent systematic psychological therapy or under antidepressants in the past six months, and those with severe hearing or visual impairments that would affect the use of the system.

Grouping and intervention methods

Patients who met the inclusion criteria were grouped by the random number table method with a 1:1 ratio into the intervention group (60 patients) and the control group (60 patients). The randomization process was completed by an independent researcher, and the grouping results were sealed. On the third day after surgery, the research nurse informed the patients of their group assignments. The intervention group received a 12-week "mHealth Psychological Resilience Intervention System" in addition to standard postoperative rehabilitation care. This system integrated elements of cognitive behavioral therapy and mindfulness training based on the principles of "multimodal intervention + behavior-driven logic + visual feedback". The overall architecture comprised two components including the Patient Interface and the Clinician Dashboard (Figure 1). The patient interface was developed as a WeChat mini program (Tencent, Shenzhen, Guangdong, China) compatible with both Android and iOS systems, which incorporated the CD-RISC-25 [16] and the hospital anxiety and depression scale (HADS) [17] as core assessment tools with copyright and source information detailed in the respective references. The system dynamically adjusted intervention content based on patient anxiety scores. When HADS-A scores increased, breathing relaxation exercises were prioritized, while emotional states were stable, social connection tasks were recommended. By utilizing an icon-based layout and voice prompts to accommodate elderly patients' operational preferences, it centered on "daily check-in tasks" to support patients in completing the 12-week psychological resilience training. The system comprised four functional modules including the learning module delivering micro-lessons based on the six-factor resilience structure across three phases (initiation, enhancement, and maintenance), the assessment module automatically administering the aforementioned scales at three time points (postoperative week 1 (T0), week 4 (T1), and week 12 (T2)) and generating visual feedback, the check-in module setting daily tasks across emotional, behavioral, and cognitive domains and producing weekly progress reports, and the prompt and incentive mechanism enhancing intervention adherence and self-efficacy through scheduled notifications, event-triggered reminders, and badge rewards. Simultaneously, the research team utilized a web-based clinician dashboard to categorize

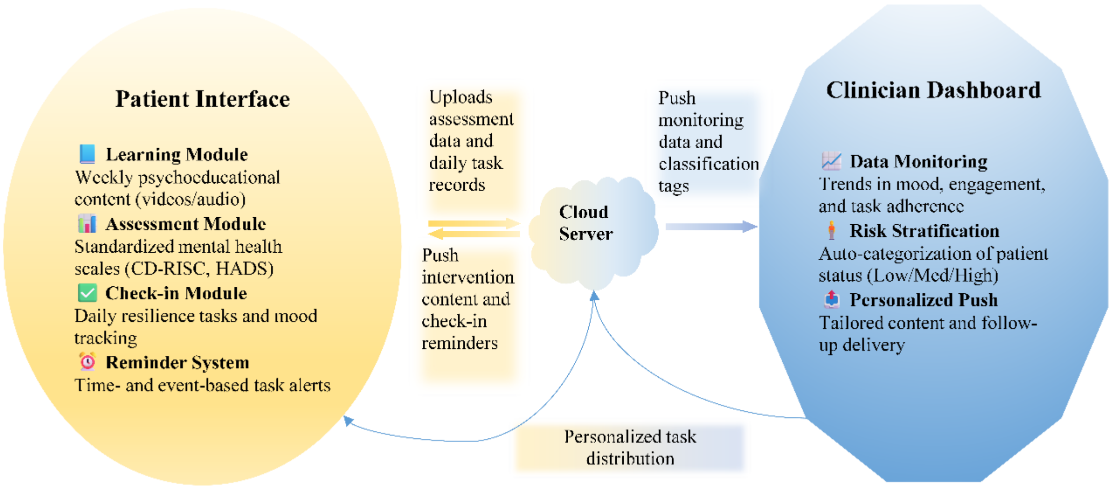

Figure 1. Overall architecture of the mHealth psychological resilience intervention system.

patients' psychological states as stable, fluctuating, or high-risk, enabling case follow-up management, data monitoring and analysis, and personalized content delivery. The system's AI rule engine automatically adjusted intervention content based on variables including patient anxiety scores and behavioral preferences. The intervention content structured on the CD-RISC theoretical framework integrated three core modules including cognitive restructuring training (identifying and modifying common postoperative negative thoughts), mindfulness awareness exercises (5 - 10 minutes daily audio-guided sessions), and resilience resource building including positive emotion logging, goal tracking, and social support network mapping. The control group received routine postoperative rehabilitation care without using the intervention system. To ensure the consistency of the intervention and the quality of care, all research nurses, rehabilitation therapists, and psychological intervention assistants received unified training before the beginning of this research. The intervention procedures were standardized and regularly checked for quality control and data verification.

Observation indicators and evaluation tools

The research assessed the effects from three aspects including physiological recovery level, changes in psychological state, and system use compliance and acceptability. The evaluation time points were set at the first week (T0), the fourth week (T1), and the twelfth week (T2) after surgery. The physiological function recovery indicators were analyzed. The visual analogue scale (VAS) pain score was calculated with 0-to-10-point scale to assess the subjective pain intensity of patients in both resting and activity states with 0 indicating no pain and 10 indicating severe pain [18]. Hospital for special surgery (HSS) knee score was determined by evaluating the postoperative knee joint function from five dimensions of pain, functional activity, range of motion, muscle strength, and stability. The maximum score was 100 with higher scores indicating better functional recovery [19]. Activities of daily living (ADL) score (Barthel index) was calculated by assessment of the self-care ability of patients in daily life, which included 10 sub-items covering washing, dressing, toileting, eating, and climbing stairs. The total score was 100, reflecting the level of postoperative life independence [20]. The psychological state indicators included CD-RISC scale consisting of 25 items and using a 5-point Likert scale (0 - 4 points). The total score ranged from 0 to 100 with higher scores indicating stronger psychological resilience. The HADS anxiety and depression scale consisted of 14 items comprising two subscales of anxiety (HADS-A) and depression (HADS-D). Each item was

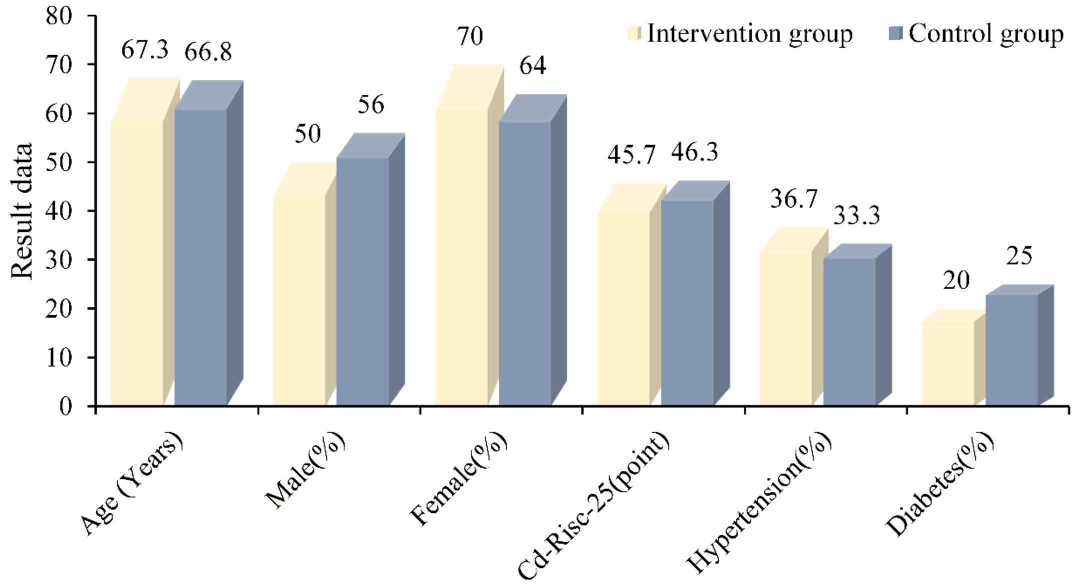

Figure 2. Comparison of baseline characteristics of participants.

scored from 0 to 3 with subscale totals ranging from 0 to 21. Scores of ≥ 8 indicated mild emotional disorders. The system used compliance and user acceptability indicators (for the intervention group only) were as follows. For intervention check-in completion rate, the system automatically recorded the completion of emotional, behavioral, and cognitive intervention tasks by patients each week over twelve weeks. The ratio of completed tasks to total tasks was calculated to assess the implementation of the intervention. APP usage frequency and duration were recorded. The system backend recorded daily login frequency, course click-through rate, and average usage duration to assess the intensity of intervention exposure. User satisfaction rating scale including A Likert 5-point scale was used to assess the practicality of system content, user interface friendliness, information push rhythm, and overall experience. Patients' subjective feedback and usage suggestions were collected.

Statistical analysis

SPSS 26.0 (IBM, Armonk, New York, USA) was employed for statistical analysis of this research. Measurement data were described as mean ± standard deviation or median (interquartile range), while count data were described as frequency and percentage. Comparisons of baseline characteristics and outcome measures between the two groups were conducted using independent samples t-test or χ^2 test based on data properties. Changes in indicators over time were compared using repeated measures analysis of variance. All statistical analyses employed two-sided tests with *P* values less than 0.05, 0.01, and 0.001 as statistically significant, highly significant, and very highly significant.

Results and discussion

Analysis of baseline characteristics of patients

The results showed that there was no statistical difference between both groups in baseline characteristics including age, gender, preoperative CD-RISC-25 score, and major underlying diseases in the subjects, which showed good comparability (Figure 2). The baseline characteristics of the subjects were balanced, which excluded the influence of confounding factors on subsequent intervention effects and ensured that the observed intergroup differences were primarily attributable to the intervention measures.

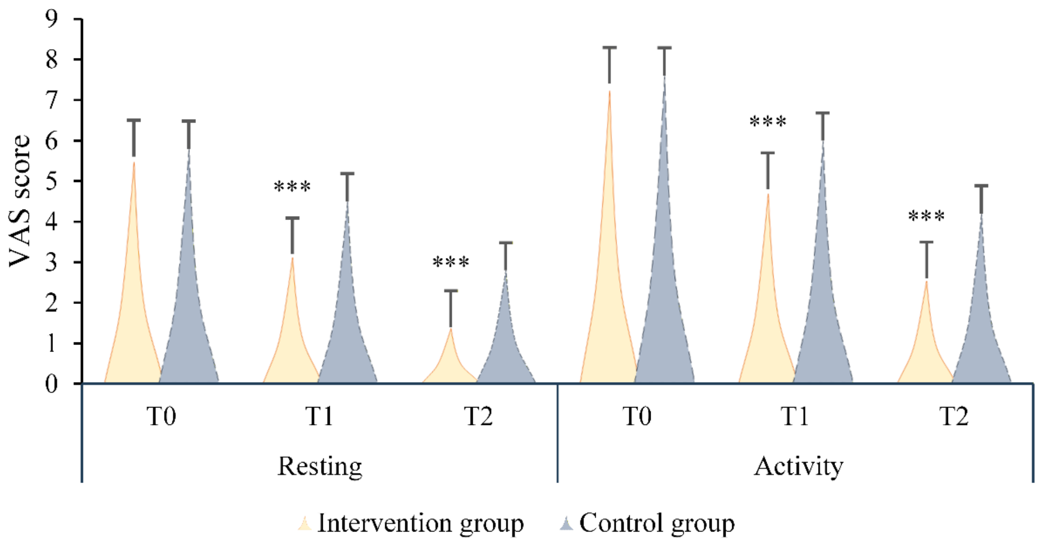

Figure 3. Comparison of VAS pain scores in resting and activity states. ***: $P < 0.001$ compared with the control group.

Comparison of physiological function recovery indicators

(1) VAS pain score

During the first week after surgery (T0), there were no statistically significant differences in VAS pain scores between the two groups of subjects, both at rest and during activity. However, by the fourth week (T1) and the twelfth week (T2), the VAS scores in both states were significantly lower in the intervention group than that in the control group ($P < 0.001$) with the differences further widening over time. The results of repeated measures analysis of variance showed that VAS scores decreased significantly over time ($P < 0.001$), and the decrease was greater in the intervention group than in the control group ($P < 0.01$). A significant interaction effect was also observed ($P < 0.05$) (Figure 3). The significant reduction in VAS scores within the intervention group aligned with emerging evidence on digital health interventions. Recent studies confirmed that mHealth platforms integrating psychological and behavioral components enhanced pain management by modifying patients' pain perception and coping strategies [21]. Specifically, the cognitive restructuring elements in this intervention helped reduce pain catastrophizing, a known mediator of postoperative pain outcomes [22]. This psychological approach compensated the limitations of physical rehabilitation, establishing a virtuous cycle of "pain reduction, increased activity, and functional recovery."

(2) HSS knee score

The HSS scores of the two groups at the first postoperative week were 55.1 ± 7.6 and 54.8 ± 8.1, respectively ($P > 0.05$). At weeks 4 and 12, the intervention group's scores were 70.3 ± 6.5 and 85.7 ± 5.3, significantly higher than the control group's 62.7 ± 7.0 and 75.9 ± 6.1 ($P < 0.001$). During the follow-up period, participants' scores showed improvement over time ($P < 0.001$), and there were significant differences between groups ($P < 0.01$) (Figure 4). The superiority in HSS scores within the intervention group revealed a synergistic effect between psychological resilience training and physical rehabilitation. Attributional retraining, by modifying patients' explanatory style for rehabilitation progress, has been demonstrated to enhance rehabilitation adherence and functional outcomes in elderly TKA patients [23]. The proposed mHealth system likely provided similar mechanisms through progress tracking and personalized feedback, offering positive reinforcement. This sustained engagement was crucial for improving muscle strength and joint

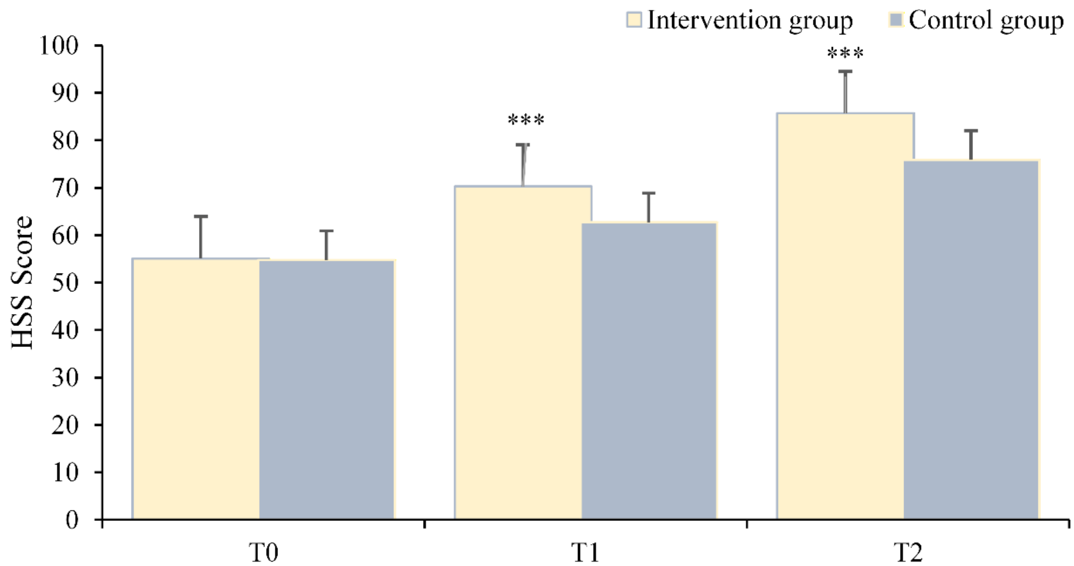

Figure 4. Comparison of HSS knee scores of participants at different time points. ***: *P* < 0.001 compared with the control group.

stability, as recent trials indicated that app-based rehabilitation programs significantly enhanced isokinetic knee muscle strength and range of motion [24]. The continuous, guided support provided by proposed platform appeared to address a critical gap in traditional rehabilitation that lacked persistent motivation and personalized adjustments.

(3) ADL score

ADL scores at all three postoperative time points (T0, T1, T2) demonstrated superior functional recovery in the intervention group compared to the control group. At the first postoperative week (T0), ADL scores were comparable between the two groups with intervention group as 58.7 ± 5.3 and control group as 57.9 ± 5.8. There was no statistically significant intergroup difference observed. By week 4 (T1), the intervention group's score increased to 70.4 ± 6.1, significantly higher than the control group's 64.2 ± 6.5 (P < 0.001), while at week 12 (T2), the intervention group's score further rose to 88.4 ± 6.7 with the advantage continuing to widen compared to the control group's 79.1 ± 7.3 (P < 0.001). Repeated measures ANOVA indicated that ADL scores continuously improved over time (P < 0.001) with the intervention group showing significantly greater improvement than the control group (P < 0.01), and a significant group-time interaction was observed (P < 0.05). The significant improvement in ADL scores reflected the positive impact of the psychological resilience intervention on patients' daily living abilities. Recent studies indicated that digital health interventions could enhance patients' independence in daily activities by strengthening self-management capabilities and providing continuous social support. The "resource building" module and "progress report" feedback mechanism in proposed system likely promoted the gradual recovery of ADL abilities by enhancing patients' self-efficacy and rehabilitation initiative. This psychological-behavioral synergistic support proved particularly valuable during the home-based rehabilitation phase after discharge, aligning closely with the recently emphasized concept of "smart home-based rehabilitation" [25]. Such a continuous support system holds significant value for sustaining rehabilitation outcomes and preventing functional decline.

Changes in psychological state

(1) CD-RISC score

Preoperatively, no significant difference in CD-RISC scores was observed between the two groups with the scores of intervention group as

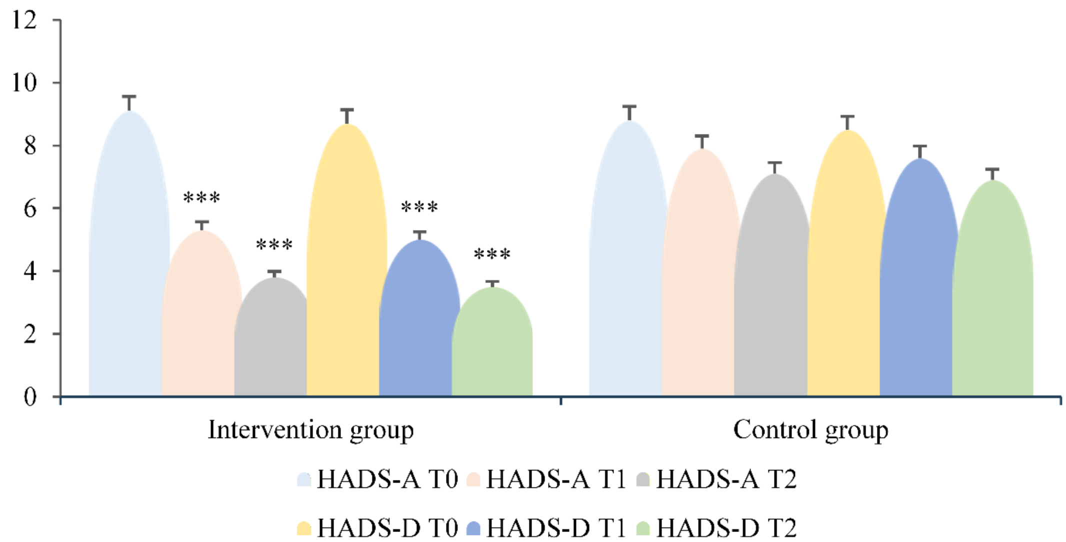

Figure 5. Comparison of HADS anxiety and depression scores of participants at different time points. ***: $P < 0.001$ compared with the control group.

45.7 ± 9.2 and control group as 46.1 ± 8.9. During the first postoperative week (T0), score changes remained insignificant, indicating no substantial improvement in psychological resilience during the early intervention phase. By postoperative week 4 (T1), the intervention group's score increased to 58.8 ± 7.8, significantly higher than the control group's 48.1 ± 8.3 ($P < 0.001$) and further rose to 66.5 ± 6.9 by postoperative week 12 (T2), while the control group showed only a modest increase to 50.2 ± 8.0 ($P < 0.001$). Repeated measures ANOVA revealed statistically significant main effects of time and group, as well as a significant interaction effect ($P < 0.001$). The progressive improvement in CD-RISC scores highlighted the cumulative effect of building psychological resilience through sustained digital intervention. The results aligned with recent study reports, indicating that structured mHealth interventions could systematically enhance psychological resilience by providing continuous coping strategy training and stress management tools [26, 27]. The fact that significant improvement emerged at T1 and further strengthened at T2 demonstrated that psychological resilience was not merely a trait but a capacity that could be developed over time with appropriate support, which corresponded to the theoretical framework positing that psychological resilience involved dynamic adaptation to adversity, facilitated by cognitive-behavioral techniques and positive emotion regulation. The mindfulness training and cognitive restructuring integrated into the proposed platform provided the essential tools for this adaptive process, supporting patients through the challenging postoperative period.

(2) HADS anxiety and depression scores

Preoperatively, HADS-A (anxiety) and HADS-D (depression) scores were comparable between the two groups. The intervention group recorded 9.0 ± 2.8 and 8.7 ± 3.0, respectively, while the control group recorded 8.8 ± 3.0 and 8.5 ± 3.2, respectively, indicating comparable baseline emotional states. No significant changes in scores were observed during the first postoperative week, suggesting limited short-term intervention effects. By postoperative week 4, the intervention group's HADS-A and HADS-D scores decreased to 5.3 ± 2.1 and 5.0 ± 2.3, respectively, significantly lower than the control group's 7.9 ± 2.7 and 7.6 ± 2.8 ($P < 0.001$). At week 12, the intervention group's anxiety and depression scores further declined to 3.8 ± 1.9 and 3.5 ± 1.8, respectively, outperforming the control group's 7.1 ± 2.5 and 6.9 ± 2.6 ($P < 0.001$). Repeated measures ANOVA revealed statistically significant main effects of group and time, as well as a significant group × time interaction ($P < 0.05$) (Figure 5). The significant reduction in HADS scores in the intervention group reinforced the value of targeted psychological support in TKA rehabilitation. Recent studies consistently demonstrate that anxiety and depressive symptoms following TKA improve when patients receive structured psychological interventions [28, 29]. The digital approach in the present study aligned with emerging evidence indicating that brief mind-body interventions and digital cognitive behavioral therapy (dCBT) effectively reduced anxiety levels in TKA patients. The underlying mechanisms might involve multiple pathways, including that the mindfulness component helped regulate emotional responses to pain and functional limitations, cognitive restructuring reduced catastrophic thinking patterns, and daily tracking functions provided a sense of control and accomplishment. This comprehensive approach addressed psychological factors significantly influencing postoperative recovery, including pain perception, opioid consumption, and rehabilitation engagement.

System use compliance and user acceptance in intervention group

During the 12-week mHealth-based psychological resilience intervention, the intervention group demonstrated strong system adherence and high user acceptance. The average intervention completion rate was 85.3% ± 9.4% with a mean daily login frequency of 2.1 ± 0.7 times and an average daily usage duration of 15.2 ± 4.8 minutes. This adherence level aligned with previous mobile/tele-rehabilitation studies targeting postoperative recovery and elderly users, indicating that well-designed mHealth platforms incorporating remote monitoring and regular prompts could effectively sustain postoperative patient engagement [30]. User satisfaction ratings were similarly positive with the content usefulness score of 4.3 ± 0.6, interface friendliness score of 4.2 ± 0.7, satisfaction with information delivery pace score of 4.1 ± 0.8, and overall experience score of 4.2 ± 0.5. A recent systematic review on mobile application usability and user-centered design for older adults indicated that clear interface layouts, enlarged text/touch targets, simplified interactions, and participatory/co-design approaches significantly enhanced usability ratings and satisfaction among elderly audiences, corroborating the high scores for content and interface observed in this study [31]. The average daily usage duration of approximately 15 minutes in this study aligned with the recommended optimal exposure time for digital behavioral interventions that were effective without being burdensome [32]. Positive user feedback regarding content usefulness and interface friendliness underscored the importance of user-centered design in digital health interventions, particularly for elderly patients with varying levels of digital literacy. Future iterations of the research platform could incorporate more personalized interactive elements and adaptive algorithms to further enhance user experience and long-term engagement, addressing suggestions provided by users.

Conclusion

The mHealth psychological resilience intervention system developed in this study integrated cognitive behavioral therapy, mindfulness exercises, and social support strategies to deliver continuous, dynamic, and personalized psychological support through a digital platform. Validation of the intervention effects demonstrated that the system exhibited clear advantages in enhancing patients' psychological resilience, alleviating anxiety and depressive symptoms, promoting pain relief and knee function recovery, and improving daily living activities. The system demonstrated strong overall adherence and positive user feedback, confirming its feasibility and acceptability in clinical settings. The deep integration of mHealth technology with psychological resilience theory established a novel intelligent rehabilitation model driven by "psychological-behavioral synergy," which not only enhanced the overall quality of postoperative TKA rehabilitation but also provided robust support for extending this intervention model to other surgical populations. Future research could further optimize system algorithms and personalized response mechanisms to improve intervention precision and advance smart nursing to a higher level.

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