Patient Preference and Adherence

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ORIGINAL RESEARCH

The Impact of Perceived Usefulness of Wearable Devices on Treatment Adherence in Fracture Patients: The Chain Mediating Roles of Self-Efficacy and Meaning in Life

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Background: Fractures patients often exhibit low treatment adherence, resulting in prolonged recovery and increased complications. Wearable devices provide real-time monitoring and feedback and are expected to improve adherence, but the psychological mechanisms remain underexplored. This study is among the first to extend the Technology Acceptance Model (TAM) to fracture rehabilitation by incorporating self-efficacy and meaning in life as mediators.

Objective: The purpose of this study was to analyze the effect of perceived usefulness of wearable devices on treatment adherence of fracture patients and its internal mechanism.

Methods: A cross-sectional study was conducted with 473 fracture patients (45.5% male, mean age 44.42 ± 16.24 years) from four tertiary hospitals in Zhejiang, China, between May and June 2025. Participants completed validated scales assessing perceived usefulness, self-efficacy, meaning in life, and treatment adherence. Structural equation modeling and SPSS Macro Process Model 6 with bias-corrected bootstrapping were used to test direct and mediating effects.

Results: Perceived usefulness significantly predicted treatment adherence β = 0.167, 95% CI = [0.042, 0.291]. Self-efficacy (indirect effect = 0.089, 95% CI=[0.019, 0.174]) and meaning in life (indirect effect = −0.135, 95% CI=[−0.215, −0.033]) mediated this relationship, with a chain mediation effect through both variables (indirect effect = 0.149, 95% CI = [0.077, 0.229]). The total effect accounted for 62% of adherence variance.

Conclusion: The findings reveal a complex psychological mechanism wherein the perceived usefulness of wearable devices influences fracture patients' treatment adherence through multiple pathways, involving both positive and negative mediating effects. This underscores the importance of addressing patients' self-efficacy and meaning in life to maximize the effectiveness of technology-based rehabilitation interventions.

Keywords: wearable devices, perceived usefulness, fracture patients, treatment adherence, self-efficacy, meaning in life

Introduction

Fractures are a common type of musculoskeletal injury worldwide.[1,2] Approximately 27% to 42% (of middle-aged fracture patients) of patients experience serious complications such as non-union, non-healing, and poor functional recovery due to poor rehabilitation adherence.[3] Under the traditional rehabilitation model, patients' post-discharge treatment adherence primarily relies on their self-awareness and doctor-patient communication,[4] with a lack of quantifiable assessment tools leading to low adherence rates for key interventions such as physical therapy, weight-bearing

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exercises, and nutritional supplements. Wearable devices are intelligent medical devices that closely integrate with the human body and possess real-time interactivity.[5,6] These devices provide dynamic, quantifiable feedback to fracture patients by continuously monitoring physiological indicators and movement data,[7] while also offering clinicians more accurate diagnostic evidence. However, despite the significant technical advantages of wearable devices, their actual efficacy is often limited by patients' adherence to treatment.[5,8] Previous studies have shown that patients' lower adherence to wearable devices is often influenced by factors such as device user experience, privacy and safety concerns, detection accuracy, and economic costs,[9–11] especially among fracture patients. Most common wearable devices are designed for normal activity scenarios, such as smart wristbands, smart headbands, and smart clothing.[12,13] When worn, these devices may cause discomfort or even secondary injury due to factors such as limb swelling, friction from fixation devices, or restricted movement.[14,15] This perception may further lead fracture patients to believe that fracture-specific wearable devices are useless, thereby reducing treatment adherence.

During the treatment and rehabilitation period, fracture patients often need to remain immobilised or rely on assistive devices for an extended duration.[16,17] Wearable devices specifically designed for fracture patients, such as smart braces and wearable exoskeletons,[18,19] help monitor movement data, stress conditions, and assist limb movement. These specialised devices can further improve treatment and rehabilitation outcomes. For instance, wearable exoskeletons utilise smart joint drive systems and sensory networks to achieve dynamic weight control, protect fracture sites, stimulate bone remodelling, and correct gait asymmetry.[20] However, the relationship between the perceived usefulness of wearable devices and treatment adherence in fracture patients has rarely been explored in previous studies. As wearable devices become more widespread, this technology not only provides patients with opportunities for active monitoring and feedback but also enhances their sense of participation and control in the rehabilitation process through real-time data and interactive features.[21,22] This creates a critical research gap: how the perceived usefulness of wearable devices translates into actual treatment adherence among fracture patients, and through which psychological pathways this occurs.

Grounded in the Technology Acceptance Model (TAM), which posits that perceived usefulness influences technology adoption and behavior,[23] this study examines how perceived usefulness of wearable devices affects treatment adherence in fracture patients, with self-efficacy and meaning in life as mediators. Self-efficacy reflects beliefs in one's ability to execute rehabilitation tasks,[24] while meaning in life involves a sense of purpose that buffers trauma and motivates adherence.[25] Prior research has linked perceived usefulness to adherence in general health contexts but overlooks chained mediation in fracture rehabilitation, where patients face unique psychological challenges like loss of autonomy.[8]

However, TAM has known limitations in healthcare applications, including its emphasis on utilitarian factors (eg, usefulness and ease of use) while often neglecting deeper psychological, emotional, or contextual elements such as social influences, habit formation, or existential motivations.[26] In fracture rehabilitation, these limitations are particularly salient, as patients frequently experience profound psychosocial distress, including anxiety, depression, and identity disruptions from sudden functional loss.[27] To address this, we extend TAM by incorporating meaning in life from existential psychology, as fractures can precipitate existential crises—questioning life's purpose and direction—potentially undermining adherence.[28] Meaning in life complements TAM by providing a motivational layer: When patients perceive wearables as useful, it may enhance their sense of purpose in recovery, fostering resilience and internalized goals beyond mere efficacy beliefs.[29] This extension is supported by evidence linking meaning in life to better psychological well-being and physical recovery in rehabilitation contexts.[30] This gap limits understanding of how wearable devices can optimize psychological resources to improve outcomes. By constructing a structural equation model to test direct and mediated effects, this study elucidates these mechanisms, offering theoretical extensions to TAM and practical insights for device design, such as incorporating motivational features.

The study elucidates how patients' perceived usefulness of fracture treatment enriches their psychological resources, further altering their behavioural tendencies, and reveals the deeper psychological mechanisms underlying the enhancement of treatment adherence to wearable devices. Specifically, the construct of meaning in life explains how perceived usefulness promotes adherence by enhancing the internalisation of rehabilitation goals. At the same time, self-efficacy provides insight into how perceived usefulness strengthens patients' beliefs in their ability to manage their rehabilitation, thereby maintaining adherent behaviour. Moreover, this study has significant practical implications for the development

of wearable devices, offering precise optimisation directions, such as embedding goal achievement reminders and personalised motivational messages within wearable devices.

Based on the theoretical framework and literature, we propose the following hypotheses in one paragraph:

H1: The perceived usefulness of wearable devices significantly positively predicts the treatment adherence of fracture patients;

H2: Self-efficacy significantly mediates the relationship between the perceived usefulness of wearable devices and the treatment adherence of fracture patients;

H3: Meaning in life significantly mediates the relationship between the perceived usefulness of wearable devices and treatment adherence in fracture patients;

H4: Meaning in life and self-efficacy significantly mediate the relationship between the perceived usefulness of wearable devices and the treatment adherence of fracture patients in a chained manner.

Literature Review and Theoretical Derivation

Perceived Usefulness of Wearable Devices and Treatment Adherence in Fracture Patients

The TAM serves as the foundational framework for understanding users' adoption of information technology,[31] with its core tenets being that perceived usefulness and perceived ease of use directly influence attitudes and behavioural intentions toward technology.[32] Perceived usefulness encompasses not only the functional attributes of the technology itself but also patients' subjective evaluations of its ability to support rehabilitative goals.[33,34] In recent years, the TAM has been increasingly applied to studies on the acceptance and utilisation of medical technologies,[23,26] particularly in the context of fracture treatment. This is primarily because fracture patients often face challenges such as lengthy treatment cycles and low adherence to rehabilitation exercises,[35] while traditional methods of monitoring adherence suffer from recall bias and delayed feedback. To address these issues, wearable devices offer a groundbreaking solution by enabling real-time, objective, and continuous monitoring of activity.[36] Research has shown that patients' perceived usefulness of wearable devices is a core antecedent to their continued use.[37,38] Fracture patients are not only concerned with whether wearable devices are useful but also place a high value on their ability to accurately perceive pain, avoid risks, provide reliable rehabilitation guidance, and alleviate fears of secondary injuries.

Further analysis reveals that the perceived usefulness of wearable devices lies in their ability to empower patients and optimise rehabilitation management, thereby overcoming adherence barriers at both cognitive and behavioural levels.[21,39] The real-time biofeedback and progress visualisation provided by wearable devices make abstract rehabilitation goals concrete, measurable, and safely controllable.[40] Additionally, perceived usefulness can enhance adherence by supporting personalisation and dynamic adjustments.[41] Based on objective data collected by wearable devices, clinicians can accurately assess patient status and adjust exercise intensity or provide targeted guidance in real time.[42] This data-driven, personalised intervention makes patients acutely aware of the device's precise responsiveness to their individual needs,[43] thereby significantly enhancing perceived usefulness and translating into higher levels of treatment adherence.

Based on the above analysis, the following hypothesis is proposed:

H1: The perceived usefulness of wearable devices significantly positively predicts the treatment adherence of fracture patients.

The Mediating Role of Self-Efficacy

Self-efficacy refers to an individual's belief in their ability to successfully execute specific behaviours and achieve desired outcomes.[44] In the context of fracture rehabilitation, self-efficacy has been identified as a psychological factor influencing patients' functional recovery and treatment outcomes.[45,46] Previous research has found that self-efficacy in fracture patients is significantly correlated with pain management levels, participation in physical therapy, recovery of

daily living activities, and overall quality of life.[47–49] For example, Rittharomya, Krua-aum and Aree-Ue[50] on elderly hip fracture patients found that self-efficacy significantly predicted walking ability and fear of falling six months post-surgery. This is largely because high self-efficacy enhances patients' resilience when facing rehabilitation challenges, encouraging more persistent effort and the adoption of more proactive coping strategies while reducing the risk of avoidance behaviours and catastrophic thinking.[51] Interventions based on the self-efficacy theory framework, such as goal setting, vicarious learning, verbal persuasion, and positive reinterpretation of physical states, have been validated as effective in enhancing patient rehabilitation confidence, exercise adherence, and functional prognosis.[52,53] However, previous studies have paid little attention to the role of fracture patients' self-efficacy in the relationship between the perceived usefulness of wearable devices and treatment adherence.

According to the TAM, the critical antecedent to users' acceptance of a technology is their perception of its ability to enhance task performance.[54] In the context of fracture rehabilitation, the core value of perceived usefulness provided by wearable devices lies in their ability to offer real-time and objective biofeedback, personalised progress monitoring, risk warnings, and visualisation of goal achievement.[55,56] However, the transformation of perceived usefulness into actual adherence behaviour is not direct, with self-efficacy playing a crucial mediating role. When patients perceive the information provided by specialised wearable devices as useful, this cognitive evaluation enhances their rehabilitation self-efficacy through multiple pathways.[44] On the one hand, the success metrics fed back by the specialised wearable devices serve as direct evidence of achievements, reinforcing efficacy beliefs.[57] On the other hand, positive prompts generated by the specialised wearable devices or encouragement from clinicians based on device data strengthen confidence. Conversely, even if a device possesses powerful functions, adherence may suffer if patients with low self-efficacy fail to perceive its value effectively.

Based on the above analysis, the following hypothesis is proposed:

H2: Self-efficacy significantly mediates the relationship between the perceived usefulness of wearable devices and the treatment adherence of fracture patients.

The Mediating Role of Meaning in Life

Meaning in life refers to an individual's psychological state characterised by a sense of purpose, direction, and value in life.[25] Fractures often result in sudden bodily functional impairments, loss of independence, and disruption of social roles, which can easily lead to anxiety, depression, and post-traumatic stress reactions.[27,58] In such situations, a firm sense of meaning in life becomes a crucial coping resource. Previous research has found that fracture patients with higher levels of meaning in life exhibit greater pain tolerance, more positive rehabilitation beliefs, and lower levels of disability identity.[59,60] The core mechanism underlying this relationship lies in the role of meaning reconstruction processes. Patients integrate their sudden traumatic experiences into their personal life narratives, assigning them growth-oriented interpretations.[61] This process buffers the impact of trauma and motivates proactive rehabilitation behaviours. Thus, the meaning in life is an important psychological mechanism driving both physiological recovery and positive rehabilitation behaviours.

While wearable devices can enhance the efficiency of management in the treatment process for fracture patients, their effectiveness is highly dependent on patients' perceived usefulness of these devices. Previous research has found that meaning in life can influence perceived usefulness through cognitive restructuring.[62] Specifically, patients with a high sense of meaning in life are more likely to view wearable devices as empowering tools for achieving their inherent rehabilitation goals rather than mere medical burdens, thereby significantly enhancing their internalised perception of the technology's value. Furthermore, the pain and setbacks experienced during rehabilitation can evoke negative emotions and consume cognitive resources, weakening patients' ability to judge the value of the technology.[63] Meaning in life mitigates emotional distress by providing positive ideas beyond the current adversity, ensuring the effective allocation of cognitive resources to the processing and application of information from wearable devices.[64] For example, in a study on elderly osteoporotic fracture patients, enhanced meaning in life improved patients' understanding of the functional features of wearable devices and alleviated treatment-related fears.[65] Therefore, meaning in life can significantly enhance patients' internal motivation and goal orientation, thereby improving their perceived usefulness and adherence to treatment.

Based on the above analysis, the following hypothesis is proposed:

H3: The meaning in life significantly mediates the relationship between the perceived usefulness of wearable devices and treatment adherence in fracture patients.

Chain Mediating Effects of Meaning in Life and Self-Efficacy

Perceived usefulness influences fracture patients' subjective well-being and meaning in life by shaping their cognitive evaluations of the functionality of wearable devices. When individuals perceive the practical value of wearable devices in health monitoring, exercise supervision, or rehabilitation assistance, their clarity regarding life goals and meaning is enhanced. For instance, Choudhury and Asan[66] found that the perceived usefulness of wearable devices significantly positively predicted individuals' perception of meaning in life. This may occur because technology-enhanced confidence in controlling and achieving life goals strengthens the sense of purpose and meaning.[67] Furthermore, enhanced meaning in life contributes to increased self-efficacy, ie, individuals' belief in their ability to manage health issues and complete treatment tasks effectively. Individuals with higher levels of self-efficacy are more likely to adhere to treatment protocols.[68]

Based on the above analysis, the following hypothesis is proposed:

H4: Meaning in life and self-efficacy significantly mediate the relationship between the perceived usefulness of wearable devices and the treatment adherence of fracture patients in a chained manner.

The theoretical model framework is shown in Figure 1.

Method

Participant

This cross-sectional, convenience sample survey was conducted between May and June 2025 across four Grade A tertiary hospitals in Zhejiang Province, China. All procedures were performed by the ethical standards outlined in the 1964 Declaration of Helsinki and its subsequent amendments. The study obtained informed consent from the all participants and was reviewed and approved by the ethics committee of the First Affiliated Hospital of Zhejiang Chinese Medical University (No.:2025-KLS-475-01). This single IRB approval covered all participating sites through China's mutual recognition mechanism for multi-center ethical reviews, as per the 2016 Measures for the Ethical Review of Biomedical Research Involving Humans issued by the National Health Commission.[69,70] The study utilised a professional data collection platform, Credamo (https://www.credamo.com/), for questionnaire design and data collection. The questionnaire link and QR code were distributed to investigators at four of these Grade A tertiary hospitals. This study was conducted and reported in accordance with the STROBE guidelines for cross-sectional studies.

Data Collection Process: Investigators initially contacted the orthopaedic department directors of the three hospitals to explain the study's purpose, background, and methodology, obtaining the necessary departmental approval. The questionnaires were then printed in both paper and electronic formats (the latter via QR codes). Subsequently, researchers explained the study's background, objectives, benefits, and procedures to patients in the orthopaedic inpatient departments. Following the

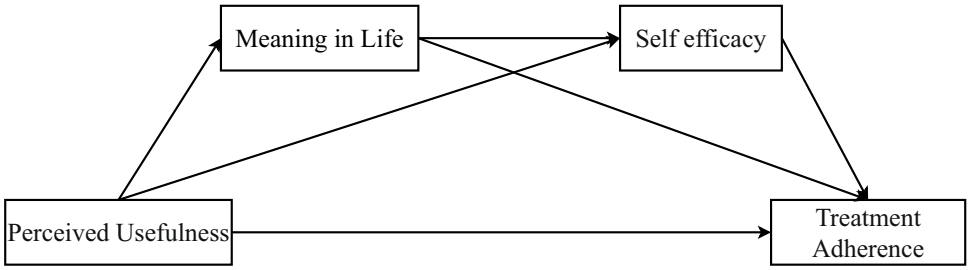

Figure 1 Conceptual model of the relationships among perceived usefulness, self-efficacy, meaning in life, and treatment adherence.

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obtainment of informed consent, patients completed either the paper or electronic questionnaire. Once data collection was completed, electronic questionnaire data were downloaded into Excel and imported into SPSS software for further analysis.

To ensure the validity and reliability of the data, strict inclusion and exclusion criteria were applied. Inclusion Criteria: (1) Patients diagnosed with acute, single, closed, or low-energy open fractures via imaging. (2) Patients undergoing standardised fracture treatment and in the rehabilitation phase. (3) Patients with clear consciousness, no severe cognitive impairments, and adequate reading comprehension skills. (4) Patients willing to sign an informed consent form. (5) Patients capable of wearing and operating wearable devices or using devices for the lower limbs or torso. (6) Patients can perform daily activities or rehabilitation exercises with the assistance of wearable devices.

Exclusion Criteria: (1) Patients with severe cardiovascular diseases, hepatic or renal insufficiency. (2) Patients with neurological disorders affecting motor function. (3) Patients with a history of severe mental illness. (4) Patients with skin allergies, severe visual or hearing impairments, or inability to use devices. (5) Patients participating in other clinical trials that could influence fracture recovery, adherence, or psychological state. (6) Patients with strong resistance to wearable devices.

A total of 500 participants were recruited for the study. After applying the inclusion and exclusion criteria, 26 patients were excluded, as detailed in Figure 2. This resulted in an effective sample size of 473, with an effective response rate of 94.6%. The sample consisted of 215 male and 258 female orthopaedic patients, with an average age of 44.42 ± 16.24 years. The educational background of the participants mainly ranged from middle school to high school, accounting for 53.7% of the total sample (N=254); 345 patients were married (72.9%); manual workers accounted for 37.4% of the total sample (N=177); the participants mainly lived in cities (N=281, 59.4%). Detailed demographic information is presented in Table 1.

Measurement Tools

This study employed the Perceived Usefulness Scale, the Self-Efficacy Scale, the Meaning in Life Scale, and the Treatment Adherence Scale, all of which were adapted from existing literature; for any scales that had not been previously validated in Chinese, back-translation was conducted. A bilingual language expert translated the items from English to Chinese, followed by back-translation by another bilingual expert. Confirmatory factor analysis (CFA) using AMOS 29.0 software was then performed to assess the model fit of each scale. The model fit indices included the chi-square to degrees of freedom ratio (CMIN/DF), comparative fit index (CFI ≥ 0.90), Tucker-Lewis index (TLI ≥ 0.90), root mean square error of approximation (RMSEA < 0.08), adjusted goodness of fit index (AGFI ≥ 0.80), and goodness

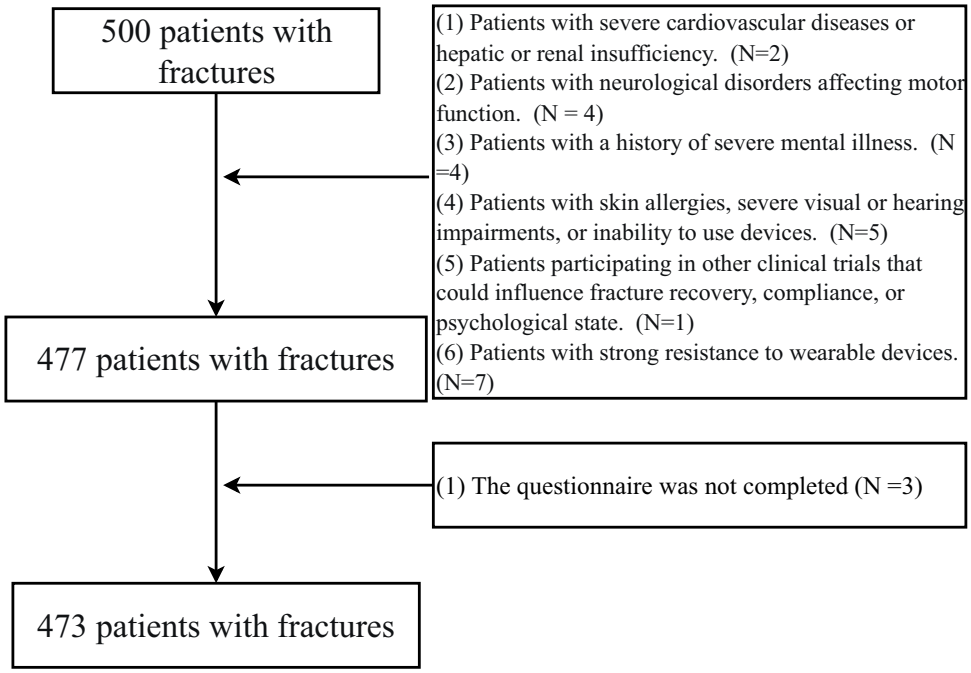

Figure 2 The data cleaning process for the sample.

Table 1 Demographic Information

Variables	Items	Number	Proportion
Gender	Male	215	45.5%
	Female	258	54.5%
Education	Primary school and below	85	18.0%
	Middle school - High school	254	53.7%
	Bachelor degree or above	134	28.3%
Marriage	Married	345	72.9%
	Unmarried	108	22.8%
	Get divorced	10	2.1%
	Widowed spouse	10	2.1%
Occupations	Student	26	5.5%
	Office worker	114	24.1%
	Manual laborer	177	37.4%
	Health care workers	65	13.7%
	Retirement	91	19.2%
Place of residence	Cities	281	59.4%
	Countryside	192	40.6%
Types of Fracture	Upper extremity fractures	124	26.2%
	Lower extremity fractures	201	42.5%
	Spinal fractures	38	8.0%
	Pelvic fractures	13	2.7%
	Other	97	20.5%
Causes of fracture	Traffic accident	134	28.3%
	A fall/injury	224	47.4%
	Sports injuries	72	15.2%
	Work related injury	43	9.1%
Methods of treatment	Surgical treatment	327	69.1%
	Non-surgical treatment	95	20.1%
	Rehabilitation training	51	10.8%

of fit index (GFI $\geq$ 0.80).[71–73] All scales have been validated in Chinese populations, with specific confirmations in clinical contexts as noted below. The translation and back-translation procedures were psychometrically verified through CFA and reliability testing (Cronbach's α) in the current sample, confirming good model fit and internal consistency, as recommended in guidelines for cross-cultural adaptation of self-report measures.[74]

All scales used in this study demonstrated satisfactory internal consistency reliability among Chinese fracture patients. Specifically, the Perceived Usefulness Scale showed a Cronbach's α coefficient of 0.891, indicating high internal reliability. The Self-Efficacy Scale exhibited excellent reliability with a Cronbach's α of 0.932, while the Meaning in Life Scale also displayed high internal consistency (α = 0.924). The Treatment Adherence Scale achieved good reliability with a Cronbach's α of 0.871. These coefficients all exceed the commonly accepted threshold of 0.70, thereby supporting the psychometric robustness of the instruments employed in this study.

To further ensure the psychometric soundness of the measurement model, both construct reliability (CR) and average variance extracted (AVE) were calculated for each latent variable. The CR reflects the internal consistency of the latent construct based on the standardized factor loadings and error variances; a CR value greater than 0.70 indicates acceptable construct reliability.[75] In contrast, the AVE represents the proportion of variance in the indicators accounted for by the underlying latent construct, with values exceeding 0.50 suggesting adequate convergent validity.[76] In the present study, all constructs demonstrated satisfactory reliability and validity: the CR values ranged from 0.868 to 0.933, and the AVE values ranged from 0.529 to 0.674, confirming that each latent factor exhibited both internal consistency and convergent validity consistent with the recommended psychometric standards.

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Demographic Information

The study collected data on patients' gender, age, education level, marital status, occupation, residence, fracture type, fracture cause, and treatment method. These variables helped to reflect the distribution of the fracture patient population, control for demographic effects, and enhance the reliability of the results.

Perceived Usefulness Scale

The Perceived Usefulness Scale was reassessed and validated by Segars and Grover.[77] The original scale consists of three dimensions: perceived usefulness, perceived ease of use, and effectiveness, with a total of 8 items. Chen and Boore[78] validated the cultural adaptation and psychometric properties of the scale using back-translation. This study used the 4-item perceived usefulness dimension to assess patients' perceptions of the usefulness of wearable devices. For example, one item was: "Do you agree that wearable devices allow doctors to obtain higher-quality biological information to develop better treatment plans?" A 5-point Likert scale was used, ranging from 1 ("strongly disagree") to 5 ("strongly agree"). Higher scores indicated greater perceived usefulness. This scale, as part of the TAM, has been validated in Chinese clinical populations, including patients using smart healthcare devices.[79] Confirmatory factor analysis revealed a good model fit for the perceived usefulness scale (χ^2/df = 1.216; CFI = 1.000, TLI = 0.999, RMSEA = 0.021, GFI = 0.998, AGFI = 0.988; AVE =0.674, CR = 0.892). The Cronbach's α coefficient for this scale was 0.891, indicating good reliability.

Self-Efficacy Scale

The self-efficacy scale was based on the General Self-Efficacy Scale developed by Chen, Gully and Eden,[80] which contains 8 items. Zhou[81] adapted the scale for a Chinese population and validated its cultural appropriateness among Chinese university students. In this study, the full 8-item scale was used to assess patients' self-efficacy. For example, one item was: "During fracture rehabilitation, do you agree that you believe you will complete difficult tasks when faced with them?" A 5-point Likert scale was applied (1 = "strongly disagree", 5 = "strongly agree"). Higher scores indicated stronger self-efficacy. The General Self-Efficacy Scale has been validated in Chinese clinical populations, such as individuals with chronic diseases patient[82] and hypertensive patient.[83] Confirmatory factor analysis demonstrated good model fit for the self-efficacy scale (χ^2/df = 4.814; CFI = 0.971, TLI = 0.959, RMSEA = 0.090; GFI = 0.952; AGFI = 0.913; AVE = 0.634, CR = 0.933). The Cronbach's α coefficient was 0.932, indicating good reliability.

Meaning in Life Scale

The Meaning in Life Questionnaire was developed by Steger, Frazier, Oishi and Kaler[84] to assess the presence of and search for meaning in life, consisting of 10 items. Chan[85] adapted the scale for a Chinese population in Hong Kong. This study used the full 10-item scale to assess patients' sense of meaning in life. For example, one item was: "During fracture rehabilitation, do you agree that you understand the meaning of your life?" A 5-point Likert scale was used, ranging from 1 ("strongly disagree") to 5 ("strongly agree"). Higher scores reflected a greater sense of meaning in life. The Meaning in Life Questionnaire has been validated in Chinese clinical-related populations, including breast cancer patient facing health burdens.[86] Confirmatory factor analysis indicated a good model fit (χ^2/df = 3.085, CFI = 0.977, TLI = 0.968, RMSEA = 0.066, GFI = 0.960, AGFI = 0.931; AVE = 0.557, CR = 0.925). The Cronbach's α coefficient was 0.924, showing good reliability.

Treatment Adherence Scale

The Treatment Adherence Scale was adapted from the tool developed by Delgado and Lima,[87] consisting of 7 items. A professional bilingual language expert translated the items from English to Chinese, and another expert conducted back-translation to ensure linguistic equivalence.[88] This study used the full 7-item scale to assess patients' treatment adherence. A 5-point Likert scale was applied (1 = "strongly disagree", 5 = "strongly agree"). Higher scores indicated greater adherence. The Treatment Adherence Scale has been validated in Chinese clinical-related populations, including magnetic resonance imaging patient.[89] Confirmatory factor analysis demonstrated a good model fit (χ^2/df = 1.932, CFI = 0.993, TLI = 0.987, RMSEA = 0.044, GFI = 0.986, AGFI = 0.968; AVE = 0.529, CR = 0.868). The Cronbach's α coefficient was 0.871, indicating good reliability.

Data Analysis

The analysis process proceeded as follows: AMOS 29.0 software was used to conduct confirmatory factor analysis for each study variable to evaluate their reliability and validity. SPSS 27.0 software was applied to perform Harman single-factor analysis to test for common method bias among the study variables. Descriptive statistics and correlation analysis were conducted for all study variables to examine their interrelations. SPSS Macro Process Model 6 was used to test the mediating effects of meaning in life and self-efficacy on the perceived usefulness of wearable devices and treatment adherence among fracture patients. Bias-corrected percentile bootstrapping with a 95% confidence interval (CI) was employed for statistical analysis. If the effect was within the 95% CI and did not include 0, it was considered statistically significant. The significance levels were denoted as ***$p < 0.001$, **$p < 0.01$, and *$p < 0.05$, with $p < 0.05$ indicating statistical significance.

Prior to structural equation modeling (SEM), the assumptions of multivariate normality, sample adequacy, and absence of multicollinearity were carefully examined. According to Kline[90] standards, this study measured the skewness and kurtosis of each research variable and evaluated their approximate normality. Outliers were screened using standardized Mahalanobis distances ($p < 0.001$ criterion). The sample size ($N = 473$) satisfied established recommendations for SEM (at least 10 cases per estimated parameter and $N \geq 200$),[90] demonstrating adequate statistical power for parameter estimation and model fit assessment.

Model fit was evaluated using multiple indices, including the chi-square to degrees of freedom ratio (χ^2/df), Comparative Fit Index (CFI), Tucker–Lewis Index (TLI), and Root Mean Square Error of Approximation (RMSEA). As recommended by Hu and Bentler[91] and Byrne,[92] acceptable model fit was defined as $\chi^2/df \leq 3.00$, CFI and TLI ≥ 0.90, and RMSEA ≤ 0.08 (with values ≤ 0.05 indicating close fit). The final hypothesized model met all these criteria, indicating good overall model fit and supporting the theoretical structure proposed in this study.

To examine the mediating mechanisms, the total, direct, and indirect effects among study variables were estimated following the recommendations of Preacher and Hayes.[93] The total effect represents the overall association between perceived usefulness and treatment adherence. The direct effect indicates the effect of perceived usefulness on treatment adherence controlling for the mediators (self-efficacy and meaning in life). The indirect effects capture the mediating pathways through each mediator separately (single mediation) and in sequence (chain mediation).

The bootstrapping method (Model 6 of PROCESS Macro and verified via AMOS) was employed to test the significance of indirect effects using 5000 bias-corrected resamples and a 95% confidence interval (CI). An indirect effect was considered significant if the 95% CI did not contain zero. This non-parametric resampling approach minimizes potential violations of normality in indirect effect estimation and provides more robust inference for mediation effects.

Result

Common Method Bias

Common method bias refers to the phenomenon in which spurious correlations or variations arise between variables due to the inherent characteristics of the measurement methods themselves.[94] The primary causes typically include the use of single data sources, social desirability bias, privacy concerns, or the repetition of the same rating scales.[95] To minimize the potential influence of common method variance, both procedural and statistical remedies were employed. Procedurally, several strategies were implemented during data collection and survey design: (a) all respondents were assured of anonymity and confidentiality to reduce evaluation apprehension; (b) the order of measurement items across constructs was randomized to avoid sequential response bias; and (c) neutral, non-loading wording was adopted to minimize social desirability bias.

Additionally, we utilised Harman's single-factor test to assess common method bias. All measurement variables were subjected to exploratory factor analysis. The results indicated that five factors with eigenvalues greater than one were extracted, and the first factor explained 43.760% of the variance. This value was below the critical threshold of 50%,[96] suggesting that common method bias was not a significant concern in this study. To further validate this, an unmeasured latent method factor test was conducted by adding a latent common method bias factor in the full measurement model, allowing all observed items to load on both their theoretical constructs and the method factor. The results showed only a marginal

improvement in model fit (ΔCFI = 0.004; ΔRMSEA = 0.002), all below the conservative criterion of 0.010, indicating that the inclusion of a method factor did not meaningfully alter the parameter estimates. Therefore, both procedural and statistical evidence jointly support that common method bias was unlikely to substantially influence the study results.

Assessment of Multicollinearity and Normality of Residuals

Before performing the structural equation modeling, we rigorously examined the assumptions of multicollinearity and residual normality to ensure the validity of model estimation. Variance Inflation Factors (VIFs) were calculated for all observed variables in the preliminary regression models, and the results ranged from 1.802 to 3.468, well below the conservative threshold of 5, indicating the absence of multicollinearity. Additionally, none of the pairwise correlations among latent variables exceeded |r| = 0.85, further supporting acceptable discriminant independence among constructs.

To assess residual normality, standardized residuals and multivariate normality indices (skewness and kurtosis) were examined. The values of skewness ranged between –0.521 and 0.402, and kurtosis ranged between –0.077 and 0.281, falling within the acceptable range (|skewness| < 3, |kurtosis| < 8) proposed by Kline.[90]

Taken together, the tests indicated that neither multicollinearity nor non-normal residuals materially influenced the structural model estimation or the goodness-of-fit indices (χ^2/df = 2.31, CFI = 0.957, TLI = 0.945, RMSEA = 0.049). Therefore, the model estimation and mediation effects reported are considered robust and statistically sound.

Relationship Between Demographic Information and Treatment Adherence

We used a one-way ANOVA with demographic information as the independent variable and treatment adherence as the dependent variable, and the specific results are shown in Table 2. Educational background (F = 3.296, p = 0.038, η^2 = 0.014) and occupation (F = 0.014, p = 3.159, η^2 = 0.026) were significantly associated with treatment compliance. However, there was no significant difference in the patient's demographic information such as gender, marriage, residence, and fracture type between the two groups (p > 0.05).

Descriptive Statistics and Correlation Analysis

This study employed descriptive statistics and correlation analysis to examine the relationships between the research variables, including perceived usefulness, self-efficacy, meaning in life, and treatment adherence, as shown in Table 3.

The mean value of perceived usefulness was 3.664 (SD=0.850), the mean value of meaning in life was 3.762 (SD=0.768), the mean value of self-efficacy was 3.712 (SD=0.751), and the mean value of treatment adherence was

Table 2 Analysis of Variance for Demographic Information and Treatment Adherence

Variables	Items	M	SD	F	p	η^2
Gender	Male	2.984	0.838	3.476	0.063	0.007
	Female	3.133	0.886			
Education	Primary school and below	2.903	0.837	3.296	0.038	0.014
	Middle school - High school	3.047	0.843			
	Bachelor degree or above	3.204	0.913			
Marriage	Married	3.066	0.864	0.753	0.521	0.005
	Unmarried	3.111	0.873			
	Get divorced	2.857	0.732			
	Widowed spouse	2.743	1.054			
Occupations	Student	3.154	0.829	3.159	0.014	0.026
	Office worker	3.024	0.808			
	Manual laborer	3.126	0.878			
	Health care workers	3.277	0.939			
	Retirement	2.823	0.832			
Place of residence	Cities	3.118	0.885	2.569	0.110	0.005
	Countryside	2.988	0.836			

(*Continued*)

Table 2 (Continued).

Variables	Items	M	SD	F	p	η^2
Types of Fracture	Upper extremity fractures	3.161	0.844	0.473	0.884	0.007
	Lower extremity fractures	3.006	0.819			
	Spinal fractures	2.955	0.992			
	Pelvic fractures	3.220	1.016			
	Other	3.087	0.920			
Causes of fracture	Traffic accident	3.081	0.802	0.103	0.958	0.001
	A fall/injury	3.056	0.855			
	Sports injuries	3.095	1.018			
	Work related injury	3.013	0.877			
Methods of treatment	Surgical treatment	3.034	0.852	0.932	0.425	0.006
	Non-surgical treatment	3.089	0.860			
	Rehabilitation training	3.172	0.935			

Table 3 Descriptive Statistics and Correlation Analysis of Each Variable

Variables	Range	M	SD	Skewness	Kurtosis	1	2	3	4
1. Perceived Usefulness	1~5	3.664	0.850	−0.521	0.281	1			
2 Mean in Life	1~5	3.762	0.768	−0.357	0.178	0.667**	1		
3 Self-efficacy	1~5	3.712	0.751	−0.322	0.281	0.693**	0.820**	1	
4 Treatment Adherence	1~5	3.065	0.867	0.402	−0.077	0.269**	0.194**	0.283**	1

Note: ***p < 0.01*.
Abbreviations: M, Mean; SD, Standard Deviation.

3.065 (SD= 0.867), which were all higher than the intermediate value (M=2.5). The skewness of the studied variables ranged from −0.521 to 0.402, and the kurtosis ranged from −0.077 to 0.281. Based on prior research, the skewness and kurtosis of all variables in this study were within the ranges of ±3 and ±8, respectively, indicating that the data were normally distributed.

The correlation analysis revealed the following results: Perceived usefulness of wearable devices was significantly and positively correlated with meaning in life ($r = 0.667$, $p < 0.01$). Perceived usefulness was significantly and positively correlated with self-efficacy ($r = 0.693$, $p < 0.01$). Perceived usefulness was significantly and positively correlated with treatment adherence ($r = 0.269$, $p < 0.01$). Meaning in life was significantly and positively correlated with self-efficacy ($r = 0.820$, $p < 0.01$). Meaning in life was significantly and positively correlated with treatment adherence ($r = 0.194$, $p < 0.01$). Self-efficacy was significantly and positively correlated with treatment adherence ($r = 0.283$, $p < 0.01$).

Chain Mediating Effects of Meaning in Life and Self-Efficacy

In the present analysis, the total effect (c) of perceived usefulness on treatment adherence was decomposed into the direct effect (c′) and a set of indirect effects (a_1b_1, a_2b_2, and $a_1d_2b_2$) through self-efficacy, meaning in life, and their sequential mediation paths. Significance of the indirect effects was determined via 5,000-sample bias-corrected bootstrapping with 95% CI; an interval excluding zero indicated a significant mediation pathway.

To examine the chain mediating effects of meaning in life and self-efficacy on the relationship between perceived usefulness of wearable devices and treatment adherence among orthopaedic patients, this study used SPSS Macro Process Model 6 to test the mediating roles of meaning in life and self-efficacy. Confirmatory factor analysis showed that the model had a good fit ($\chi^2/df = 3.592$, CFI = 0.904, TLI = 0.893, RMSEA = 0.074, GFI = 0.847, AGFI = 0.817).

According to the results of one-way ANOVA, we found that the patients' occupation and educational background had a significant difference in treatment adherence. Based on this, we included the patient's occupation and educational background as control variables in the chain mediation analysis. The results of the analysis are as follows: Perceived

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usefulness of wearable devices significantly and positively predicted treatment adherence among orthopedic patients (β = 0.167, p < 0.01, 95% CI = [0.042, 0.291]). Perceived usefulness significantly and positively predicted patients' meaning in life (β = 0.603, p < 0.001, 95% CI = [0.542, 0.664]). Perceived usefulness significantly and positively predicted patients' self-efficacy (β = 0.229, p < 0.001, 95% CI = [0.173, 0.287]). Patients' meaning in life significantly and positively predicted their self-efficacy (β = 0.635, p < 0.001, 95% CI = [0.572, 0.699]). Meaning in life significantly predicted treatment adherence (β = −0.224, p < 0.05, 95% CI = [−0.399, −0.048]). Patients' self-efficacy significantly and positively predicted treatment adherence (β = 0.387, p < 0.001, 95% CI = [0.202, 0.573]).

Total and Mediating Effects Analysis: The results indicated that the total effect of perceived usefulness of wearable devices on treatment adherence among orthopedic patients was 62%. Of this, 38% was mediated through meaning in life and self-efficacy. Specifically: Meaning in life demonstrated a significant mediating effect between perceived usefulness and treatment adherence (indirect effect = −0.135, SE = 0.046, 95% CI = [−0.215, −0.033]). Self-efficacy also demonstrated a significant mediating effect between perceived usefulness and treatment adherence (indirect effect = 0.089, SE = 0.041, 95% CI = [0.019, 0.174]). Meaning in life and self-efficacy together demonstrated a significant chain mediating effect between perceived usefulness and treatment adherence (indirect effect = 0.149, SE = 0.039, 95% CI = [0.077, 0.229]). These results are presented in Tables 4, 5 and Figure 3.

Effect Size Reporting

To enhance the interpretability of the statistical results, the effect sizes, 95% confidence intervals, and model explanatory power (R^2) for all key paths were systematically examined. First, in the regression model predicting meaning in life from perceived usefulness, the model explained 44.6% of the variance (R^2 = 0.446). The path coefficient was significant (β = 0.603, 95% CI = [0.542, 0.664]), indicating a large effect size.

Table 4 Decomposition of the Pathways and Effects of the Perceived Usefulness of Wearable Devices on the Treatment Adherence of Fracture Patients

Type	Effect Size	SE	LLCI	ULCI	Proportion of Effect
Total effect	0.269	0.045	0.181	0.358	100%
Direct effect	0.167	0.064	0.042	0.291	62%
Ind1	−0.135	0.046	−0.215	−0.033	−50%
Ind2	0.089	0.041	0.019	0.174	33%
Ind3	0.149	0.039	0.077	0.229	55%

Notes: Ind1: Perceived usefulness - Meaning in life - Treatment adherence; Ind 2: Perceived usefulness - Self-efficacy - Treatment adherence; Ind3: Perceived usefulness - Meaning in life - Self-efficacy - Treatment adherence.
Abbreviations: SE, Standard Error; LLCI, Lower-Level Confidence Interval; ULCI, Upper-Level Confidence Interval.

Table 5 Coefficients of the Regression Model for the Impact of the Perceived Usefulness of Wearable Devices on the Treatment Adherence of Fracture Patients

Model	Predictor Variable	Outcome Variable	R	R^2	F	β	t	p	LLCI	ULCI
Model 1	Perceived Usefulness	Mean in Life	0.668	0.446	125.887***	0.603	19.355	<0.001	0.542	0.664
Model 2	Perceived Usefulness	Self-efficacy	0.848	0.719	298.919***	0.229	7.889	<0.001	0.173	0.287
	Mean in Life					0.635	19.732	<0.001	0.572	0.699
Model 3	Perceived Usefulness	Treatment Adherence	0.342	0.117	12.334***	0.167	2.624	0.009	0.042	0.291
	Mean in Life					−0.224	−2.507	0.013	−0.399	−0.048
	Self-efficacy					0.387	4.095	<0.001	0.202	0.573

Notes: *p < 0.05; **p < 0.01; ***p < 0.001.
Abbreviations: R, Correlation Coefficient; R^2, Coefficient of Determination; F, F-statistic; β, Standardized Regression Coefficient; t, t-statistic; p, Probability Value; LLCI, Lower-Level Confidence Interval; ULCI, Upper-Level Confidence Interval.

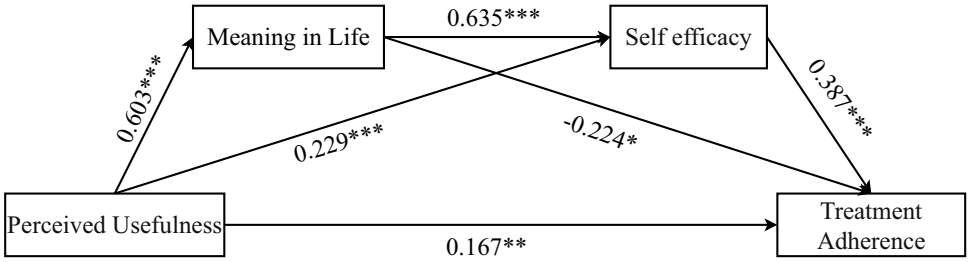

Figure 3 Arrows represent hypothesized directional relationships. Numbers adjacent to paths indicate standardized regression coefficients (β). Solid lines denote significant paths (*p < 0.05; **p < 0.01; ***p < 0.001.).

Second, in the model predicting self-efficacy from perceived usefulness and meaning in life, the explanatory power reached $R^2 = 0.712$, meaning that these predictors accounted for 71.2% of the variance in self-efficacy. Meaning in life had the strongest effect (β = 0.635, 95% CI = [0.572, 0.699]), followed by perceived usefulness (β = 0.229, 95% CI = [0.173, 0.287]).

Third, in the model predicting treatment adherence from perceived usefulness, meaning in life, and self-efficacy, the explanatory power was $R^2 = 0.117$, indicating that these variables jointly accounted for 11.7% of the variance in adherence. All indirect effects were significant, with 95% CIs not containing zero. The sequential mediating effect (perceived usefulness → meaning in life → self-efficacy → adherence) demonstrated a medium effect size of 0.149 (95% CI = [0.077, 0.229]). These findings provide robust statistical support for the model structure and mediation pathways.

Model Robustness and Sensitivity Analysis

To assess the robustness of the structural equation model, we employed alternative model validation tests. A competing model reversing the order of the mediators (Self-efficacy → Meaning in life) was evaluated. The alternative specification resulted in substantially poorer fit ($\chi^2/df = 3.605$, CFI = 0.903, TLI = 0.892, RMSEA = 0.074, GFI = 0.846, AGFI = 0.816), indicating that the originally hypothesized chain mediation structure is more appropriate.

Standardized path coefficients were re-estimated using 5,000 bootstrap samples. All key paths (Perceived usefulness → Meaning in life, Meaning in life → Self-efficacy, Self-efficacy → Treatment adherence, Perceived usefulness → Treatment adherence) remained significant, demonstrating stable parameter estimates.

Discussion

Theoretical Significance

Based on the analysis of the aforementioned results, this study has the following theoretical significance. First, this study confirmed that the perceived usefulness of wearable devices can significantly and positively predict treatment adherence among fracture patients. Specifically, fracture patients' perception of the device's usefulness in monitoring recovery progress, providing real-time feedback, and offering personalised guidance can significantly enhance their adherence to medical recommendations. The TAM emphasises that perceived usefulness is a core antecedent variable in technology adoption.[97] However, its role in complex health behaviours, especially in the psychological and behavioural interactions following orthopaedic trauma, lacks sufficient situational theoretical interpretation. This study extended the influence path of perceived usefulness on behavioural intention and actual behaviour based on the TAM and applied it to the field of fracture patient rehabilitation. Traditional research has often focused on the functional aspects of technology itself. At the same time, this study emphasised the relationship between users' perceived usefulness of technology and their behaviour, filling the gap left by the lack of attention to psychological factors in previous research. Through cross-sectional data, the study confirmed that perceived usefulness is not only a key factor in technology acceptance but also an important psychological intervention point influencing patients' treatment adherence.

Second, this study explored the significant mediating role of self-efficacy between the perceived usefulness of wearable devices and the treatment adherence of fracture patients, providing an in-depth explanation of the intrinsic relationship between psychological factors and the application of medical technology in patient behaviour. According to

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Self-Efficacy Theory, self-efficacy is the core driver of behavioural change.[98] However, there is a lack of systematic exploration of how wearable devices, as external technical tools, can enhance patients' internal efficacy beliefs to drive their adherence behaviour in the field of fracture rehabilitation. This study confirmed that wearable devices, by providing real-time physiological data feedback, progress visualisation, and personalised reminders, substantially strengthened patients' beliefs in their ability to perform rehabilitation exercises, manage pain, and achieve recovery goals. This enhanced sense of efficacy, as a key psychological cognitive mechanism, ultimately translated into higher levels of treatment adherence. Therefore, in fracture treatment scenarios, when patients perceive the usefulness of wearable devices, this perception enhances their belief in their ability to effectively participate in treatment and promote recovery, thereby encouraging them to follow medical advice and improve treatment adherence more actively. This finding not only deepens the understanding of the role of Self-Efficacy Theory in technology acceptance and health behaviour but also provides theoretical support for the development of more targeted intervention strategies.

Interestingly, the indirect effect of perceived usefulness on treatment adherence through meaning in life was statistically significant but negative. This suggests that, while greater perceived usefulness tends to enhance adherence directly, when it strengthens patients' sense of meaning in life, the subsequent effect on adherence may become attenuated. Conceptually, this pattern can be understood within the meaning-as-burden perspective: for certain individuals, increased reflection on existential meaning and life purpose during recovery may induce heightened self-focus, rumination, or fatalistic acceptance (eg, "this injury is part of my destiny"),[99] which could paradoxically dampen behavioral motivation to strictly follow treatment protocols. Moreover, existential reflection triggered by illness may sometimes redirect efforts toward emotional coping rather than behavioral adherence, resulting in a suppressing effect on adherence behaviors.[100] In the cultural context of collectivist societies, "acceptance of fate" and "peace with circumstance" are often regarded as meaningful,[101] but such mindsets can reduce the urgency of strict adherence to medical advice. Therefore, although meaning in life generally serves as a psychological resource, under certain conditions it may operate as a double-edged mediator, buffering distress yet modestly reducing concrete adherence behaviors.

The mediating path of meaning in life exhibited a significant but negative coefficient in the final model. This result diverges from most prior research, which typically conceptualizes meaning as a protective and motivating psychological resource. However, such a negative association can be interpreted within the framework of existential reflexivity and over-reflection theory. For some fracture patients, the rehabilitation process may trigger excessive contemplation of life purpose and personal vulnerability, leading to existential distress and emotional exhaustion rather than motivation.[102] In other words, when patients engage in overly abstract reflections on the meaning of illness and suffering, they may paradoxically experience a sense of resignation or fatalistic acceptance (eg, viewing injury as "destined"), thereby attenuating practical rehabilitation efforts and adherence.

Culturally, this pattern also resonates with characteristics of collectivist and fatalistic orientations prevalent in East Asian societies. In such contexts, meaning making may emphasize acceptance, endurance, and harmony rather than active behavioral change. Consequently, experiencing "peaceful acceptance" as a form of meaning might undermine adherence behaviorally, despite reducing psychological tension. Methodologically, an additional explanation could involve a partial measurement artifact: the Meaning in Life Questionnaire simultaneously captures both the "presence" and the "search" dimensions. The latter component has been shown to correlate negatively with well-being and engagement in certain clinical populations, potentially introducing a suppressor-like effect when combined in composite scoring. Therefore, the observed negative indirect path may reflect an interplay of existential over-reflection, culturally specific meaning orientations, and psychometric overlap between the search and presence facets. Future longitudinal and cross-cultural studies are warranted to disentangle these subdimensional influences.

While the present study extends the TAM by incorporating psychological constructs such as self-efficacy and meaning in life, it is essential to recognize the inherent limitations of applying TAM to health-related behavioural contexts. Originally developed to explain technology adoption in organizational and information-system settings, TAM mainly emphasizes utilitarian cognition—perceived usefulness and ease of use—as predictors of users' intention to employ a technology.[103] However, health behaviour differs fundamentally from mere technology use. Rehabilitation adherence involves emotional regulation, fear of reinjury, bodily awareness, social identity, and internalized motivation, which extend far beyond rational cost–benefit considerations.[104] Therefore, TAM's cognitive–instrumental orientation

may insufficiently capture the affective, existential, and contextual dimensions that determine whether a patient engages with prescribed health technology. For example, emotional resistance, perceived stigma, or existential distress following injury may override perceived usefulness, rendering TAM's explanatory power partial in health psychology domains.[105] This study's integration of self-efficacy and meaning in life addresses this gap by embedding TAM within a broader psychosocial framework that accounts for motivational and existential processes underpinning adherence. Future theoretical work should further refine TAM by integrating emotional, relational, and moral dimensions of patients' engagement to enhance its adequacy in healthcare behavioural contexts.

The finding that 62% of the total effect of perceived usefulness on treatment adherence operated through a direct pathway underscores the substantial clinical importance of patients' initial cognitive appraisal of wearable devices. This large direct contribution suggests that when fracture patients clearly perceive wearable technologies as beneficial—particularly in terms of safety monitoring, progress visualization, and rehabilitation guidance—they are more likely to engage in the recommended therapeutic activities, regardless of their psychological state. Clinically, this indicates that improving device usability, accuracy, and clarity of feedback can produce immediate and meaningful increases in adherence behaviors.

The remaining 38% of the total effect occurred through indirect pathways involving self-efficacy, meaning in life, and their sequential influence. Although smaller than the direct effect, this mediated proportion is clinically meaningful because it reflects psychological mechanisms that are both modifiable and highly responsive to targeted interventions. The significant indirect effects suggest that enhancing patients' confidence in their rehabilitation capabilities or supporting their sense-making processes after injury can translate device-related perceptions into sustained behavioral adherence. The presence of a robust sequential mediation effect further implies that perceived usefulness may shape deeper cognitive–motivational resources, which in turn support long-term adherence. Taken together, the balance between the direct (62%) and mediated (38%) effects highlights the dual importance of optimizing device design and addressing psychological processes to maximize rehabilitation outcomes.

Finally, this research systematically introduced the concept of life meaning into the psychological and behavioural mechanism studies of fracture rehabilitation. Frankl[106] and subsequent Meaning-of-Life-oriented intervention studies emphasise that seeking and experiencing life meaning is a core psychological resource for coping with trauma and disease.[29,107] However, there has been little research in the field of fracture rehabilitation on how wearable devices, as a type of technical intervention, influence patients' life meaning and subsequently promote adherence behaviour. This study found that wearable devices, by providing objective functional monitoring and positive recovery feedback, can help patients regain a sense of control over their recovery progress, see hope and progress in their recovery, and thus reconstruct or strengthen their sense of life meaning after experiencing sudden physical limitations. This enhanced sense of meaning, as a deep existential motive, becomes the internal driving force for fracture patients to overcome difficulties and persist in their rehabilitation plans. This not only provides a profound, existence-based explanation for understanding patient adherence beyond instrumental motivation but also theoretically links the psychology of orthopaedic rehabilitation with existential psychology, expanding the humanitarian care dimension in this field.

Interpretation of Effect Sizes and Clinical Significance

The effect size analysis further highlights the psychological and behavioral mechanisms underlying fracture rehabilitation. Perceived usefulness exerted medium to large effects on both meaning in life and self-efficacy, suggesting that real-time feedback, quantifiable data, and progress visualization provided by wearable devices substantially strengthen patients' sense of control and perceived value during recovery. Self-efficacy demonstrated a medium-sized effect on treatment adherence, underscoring its central role in rehabilitation behavior change. As widely noted in rehabilitation psychology, self-efficacy is both highly influential and highly modifiable, making it a critical target for interventions such as graded goal-setting,[108] data-driven feedback, and personalized motivational prompts delivered through wearable devices.

Interestingly, meaning in life showed a small but significant negative effect on adherence. Although modest in magnitude, this effect suggests the possibility of over-reflection, maladaptive existential rumination, or culturally influenced fatalistic acceptance, indicating that meaning in life can function as a "double-edged sword" in rehabilitation contexts.

Finally, the overall explanatory power for treatment adherence indicates that adherence is influenced by a broad array of psychological, social, and physiological factors. Although the explained variance is modest, the psychological constructs examined in this study are highly modifiable, making them clinically valuable intervention targets. Wearable device–based behavioral support strategies therefore remain practical and impactful for improving adherence.

Practical Significance

The findings of this study, which reveal that the perceived usefulness of wearable devices significantly improves the treatment adherence of fracture patients, provide important directions for clinical interventions. Traditional rehabilitation management heavily relies on patients' self-awareness and the limited supervisory capacity of medical staff during outpatient visits, often resulting in delayed recovery or suboptimal functional restoration. Wearable devices, by enabling real-time, objective monitoring of activity levels, weight-bearing status, and the completion of rehabilitation exercises, and synchronising feedback data to both patient mobile devices and clinical teams, significantly enhance patients' perceived usefulness of the rehabilitation process. Fracture patients can tangibly experience the core value of devices in understanding their conditions, guiding correct behaviour, avoiding secondary injuries, and predicting recovery outcomes. This kind of technology-enabled, transparent management can be effectively transformed into behavioural changes, such as patients more strictly adhering to weight-bearing restrictions, more regularly completing rehabilitation training, and more actively participating in follow-up appointments.

Therefore, healthcare institutions and rehabilitation centres can, based on this research, prioritise the inclusion of wearable devices in the standard rehabilitation protocols for fracture patients and, through training and guidance, enhance patients' ability to use these devices, thereby improving rehabilitation outcomes. For instance, rehabilitation physicians can use the data provided by the devices to develop personalised rehabilitation plans for patients, increasing the specificity and effectiveness of the rehabilitation process. Additionally, healthcare institutions can use the data provided by the devices to monitor and evaluate patients' rehabilitation progress in real-time, identify issues, and intervene promptly, further improving treatment adherence and rehabilitation outcomes. By these means, healthcare institutions can enhance patients' perceived usefulness of wearable devices, thereby improving treatment adherence and the effectiveness of rehabilitation.

This study revealed the mediating role of self-efficacy in the relationship between perceived usefulness of devices and treatment adherence, highlighting the clinical value of combining technical interventions with psychological empowerment. Fracture patients with higher self-efficacy are more likely to believe in their ability to effectively use the devices and improve rehabilitation outcomes through the feedback provided. This belief not only increases patients' reliance on the devices but also enhances their proactiveness and sense of responsibility during the rehabilitation process. Based on this finding, healthcare institutions and rehabilitation centres can design interventions based on Self-Efficacy Theory to help patients build confidence in their rehabilitation, enabling them to execute medical recommendations and rehabilitation plans better. Specifically, healthcare institutions can utilise psychological counselling, education, and encouragement to enhance patients' self-efficacy. Additionally, healthcare institutions can use the data provided by the devices to monitor and evaluate patients' rehabilitation progress in real-time. By emphasising patients' capabilities and resilience during follow-ups and converting objective data into cognitive feedback that enhances self-efficacy, healthcare providers can improve treatment adherence.

The finding that life meaning significantly mediates the relationship between the perceived usefulness of wearable devices and treatment adherence in fracture patients provides a more humane and compassionate pathway for rehabilitation. When patients experience a sense of life meaning and purpose in their recovery, they are more likely to view wearable devices as essential tools for achieving their rehabilitation goals rather than merely as technical devices. Fractures often lead patients to question their bodily integrity, independence, and control over their lives, resulting in feelings of meaninglessness and a decline in rehabilitation motivation. Wearable devices, by quantitatively demonstrating small, daily functional improvements, can help patients alleviate feelings of powerlessness, concretising the rehabilitation process into positive, measurable, and cumulative actions. This enables fracture patients to regain a sense of agency in the face of adversity and experience the intrinsic value of striving to restore a meaningful life. Thus, healthcare providers should guide patients in setting rehabilitation goals related to their core life roles and, during follow-ups, utilise data from wearable devices to enhance patients' confidence in treatment, improve their negative psychological states, and increase their overall quality of life.

While the findings underscore the potential of wearable devices in improving treatment adherence, several practical barriers may limit their large-scale clinical implementation. First, financial cost remains a notable concern. Specialized wearable devices for fracture rehabilitation are relatively expensive, and the absence of insurance reimbursement mechanisms or maintenance subsidies can hinder their accessibility, especially among low-income or rural populations. Second, comfort and physical suitability represent another major challenge. Fracture patients often experience swelling, fixation, or pain at the injury site, making prolonged device wear uncomfortable or even counterproductive. Device design must therefore prioritize ergonomic adaptability, lightweight materials, and compatibility with orthopedic supports.

Third, user training and digital literacy are critical determinants of successful adoption. Many patients—particularly older adults—require structured guidance to correctly operate the devices, interpret data feedback, and integrate their use into daily rehabilitation routines. Simultaneously, medical professionals need standardized training to interpret device data and translate it into individualized clinical decisions. Fourth, privacy and data security issues must be addressed rigorously, as wearable devices continuously collect sensitive physiological information. Without robust data protection frameworks and transparent consent protocols, patients may be reluctant to fully engage with such technology. Addressing these barriers requires a coordinated strategy that combines technological innovation, patient education, clinician training, and institutional support. Policy-level interventions—such as subsidizing device costs, integrating wearable data into electronic medical records under strict privacy regulation, and promoting usability-centered design—will be essential to ensure equitable, safe, and effective clinical translation of wearable technologies in fracture rehabilitation.

Building on these findings, the integration of wearable device data with psychological or behavioural coaching techniques represents a promising direction for future digital-health interventions. Real-time biofeedback generated by wearable devices could serve not only as a monitoring tool but also as a catalyst for personalized behaviour change. For example, mobile applications linked to wearable devices could deliver adaptive behavioural coaching, where clinicians or AI-driven systems provide supportive messages, motivational prompts, and corrective feedback based on patients' actual activity patterns. Such interventions can reinforce self-efficacy by transforming abstract progress indicators into tangible achievements and can strengthen patients' sense of meaning in life by aligning daily rehabilitation goals with personally valued outcomes.

Furthermore, blending wearable data analytics with therapy-based digital platforms—such as cognitive-behavioural or meaning-centered modules—may enable comprehensive, multidimensional rehabilitation support. This hybrid approach can address not only physical adherence but also emotional resilience, motivational engagement, and existential adjustment following injury. From a systems perspective, integrating behavioural coaching dashboards into hospital telemedicine platforms could facilitate continuous clinician–patient feedback loops, making rehabilitation more interactive, individualized, and psychologically supportive. Future digital-health research should therefore prioritize the co-design of such integrated interventions, ensuring that wearable technology functions not merely as a data collector but as an intelligent, empathetic partner in the patient's recovery journey.

Applicability Across Fracture Types and Patient Demographics

Although subgroup analyses were not part of the primary design, the findings of this study hold important implications for different fracture types and demographic groups. Clinically, patients with lower-extremity fractures—who typically face longer periods of immobilization, weight-bearing restrictions, and functional dependency—may benefit more from wearable-assisted rehabilitation because perceived usefulness is likely more salient when mobility is severely compromised. Conversely, patients with upper-extremity fractures may rely less on gait or load-monitoring data but may still experience gains through feedback on movement quality or range-of-motion exercises, suggesting that device functions should be tailored to injury location.

Age-related differences may further shape the applicability of the findings. Younger patients, who generally exhibit higher digital literacy and familiarity with smart devices, may translate perceived usefulness into adherence more readily through efficient navigation of device features. In contrast, older adults—who often experience lower self-efficacy regarding technology use—may rely more heavily on the psychological pathways identified in this study. For example, enhancing meaning in life and self-efficacy may be particularly important for older fracture patients, who frequently face greater fear of falling, slower functional recovery, and emotional distress related to loss of independence. Therefore,

interventions for elderly patients may require additional usability support, simplified interfaces, and structured coaching to maximize perceived usefulness.

Furthermore, demographic factors such as educational background and occupation—which showed significant associations with adherence in our analyses—suggest differential receptivity to wearable devices across patient subgroups. These differences highlight the need for personalized wearable design and stratified rehabilitation strategies that consider patients' cognitive, occupational, and functional characteristics. Future research incorporating stratified analyses across fracture types and demographic groups will be valuable for refining precision rehabilitation frameworks.

Limitations and Future Research Directions

Despite the significant contributions of this study in revealing the influence of the perceived usefulness of wearable devices on the treatment adherence of fracture patients, several limitations remain. First, the study employed a cross-sectional design, limiting the establishment of causal relationships. Due to this design, causal inferences cannot be made; the observed associations may reflect bidirectional or spurious effects, and longitudinal studies are needed to establish temporal precedence and causality. Future research should adopt longitudinal designs, tracking the entire rehabilitation process of fracture patients to capture the interplay of variables over time and more accurately test the dynamic influence mechanisms of perceived usefulness on adherence. Additionally, convenience sampling was used, which may introduce selection bias, as participants were recruited from accessible inpatient populations in tertiary hospitals, potentially overrepresenting motivated or severely affected patients.

Although significant associations were identified among perceived usefulness, self-efficacy, meaning in life, and treatment adherence, these relationships should be interpreted with caution regarding causality. Because the present study employed a cross-sectional design, the observed mediation patterns cannot definitively establish temporal order or causal direction among variables. It remains possible that patients with stronger adherence may retrospectively evaluate wearable devices as more useful or report higher self-efficacy and life meaning as a consequence of positive rehabilitation experiences. Future longitudinal or experimental studies are needed to test the dynamic causal mechanisms proposed in our theoretical model, verify directional hypotheses, and capture within-person changes over the course of rehabilitation. Recognizing this limitation helps ensure that our interpretations remain statistically sound and conceptually conservative.

Another limitation concerns the potential social desirability and recall bias associated with self-reported adherence. Although the Treatment Adherence Scale used in this study demonstrated good reliability and validity, self-report measures are inherently susceptible to respondents' tendencies to overreport desirable behaviors or underestimate lapses in adherence. Social desirability may have led some patients—particularly those who perceived stronger expectations from healthcare professionals—to report higher adherence than their actual behavior. In addition, recall bias may have occurred because patients were required to retrospectively evaluate their rehabilitation behaviors over several weeks, potentially reducing the accuracy of their responses. Future research should consider incorporating objective adherence indicators, such as wearable device usage logs, sensor-based activity records, rehabilitation session timestamps, or clinician-verified adherence data, to triangulate self-report measures and further enhance the precision of adherence assessment.

The study's sample was limited to fracture patients from tertiary hospitals in Zhejiang Province, China, potentially introducing sample bias and limited generalizability beyond this region. Although multiple hospitals were included to increase sample diversity, differences in medical resources, cultural backgrounds, socio-economic factors, and patients' acceptance of wearable devices across provinces may affect the applicability of the results. For instance, in areas with limited medical resources or different demographic profiles (eg, rural western provinces), patients' accessibility to wearable devices and adherence behaviors may differ substantially, as national fracture epidemiology shows regional variations in incidence and burden. Future studies should expand the sample to include hospitals and community medical centres in different regions and conduct cross-national research to verify the model's applicability in various cultural and socio-economic contexts. Unmodeled confounding factors may have influenced the relationships among perceived usefulness, meaning in life, self-efficacy, and adherence. Variables such as pain severity, fracture severity, comorbidities, prior experience with digital devices, or social support were not included in the structural model and may partially account for the observed effects. Additionally, although the sample included patients with various types of fractures and treatment approaches, no in-depth analysis was conducted on the differences in perceived usefulness and adherence based

on specific fracture types or treatment methods. Future research can further stratify the sample to explore the specific influence of perceived usefulness on adherence for particular fracture types or treatment methods, providing more targeted evidence for precision medical interventions.

In addition, the theoretical framework used in this study extends the original Technology Acceptance Model beyond its intended conceptual boundaries. Meaning in life, as incorporated here, is not an integral component of TAM and does not traditionally function as a cognitive antecedent of technology acceptance. Rather, it represents an existential and motivational construct drawn from rehabilitation psychology and meaning-centered theories. While this integration allowed us to explore deeper psychological processes relevant to fracture recovery, it also constitutes a theoretical overextension that should be interpreted cautiously. The expanded model is better understood as a hybrid framework combining TAM with broader psychosocial factors, rather than as a direct application of TAM in its classical form. Future research should more formally evaluate the validity of such extensions and consider whether alternative health-behavior models may provide a more coherent theoretical fit.

Finally, this study focused primarily on the mediating roles of self-efficacy and life meaning in the chain-like mediating effect between perceived usefulness and adherence. However, the psychological states of fracture patients are complex and multifaceted, and there may be other potential mediating or moderating variables not included in this study. For example, psychological factors such as patients' rehabilitation expectations, social support, and pain perception may also play important roles in this process. Future research can explore additional psychological variables and their mediating or moderating mechanisms based on the existing model to construct a more comprehensive psychological-behavioural model. Additionally, this study did not consider the influence of differences in the technical characteristics of wearable devices on perceived usefulness and adherence. Wearable devices vary in functionality, comfort, and data accuracy, and these differences may further influence patients' evaluations of perceived usefulness and adherence behaviours. Future research can conduct an in-depth analysis of the relationship between the technical characteristics of different wearable devices and patients' perceived usefulness and adherence, providing more practical and actionable recommendations for the development and optimisation of wearable devices.

Conclusion

This study examined the relationships among perceived usefulness of wearable devices, self-efficacy, meaning in life, and treatment adherence in fracture patients, using a cross-sectional sample from four tertiary hospitals in Zhejiang Province, China. The findings indicated that higher perceived usefulness was associated with better treatment adherence, and this relationship operated partly through both self-efficacy and meaning in life as mediators, with an additional sequential mediation effect. These results support the theoretical extension of the TAM to include psychosocial variables in the context of fracture rehabilitation.

The present study demonstrates that perceived usefulness of wearable devices is positively associated with treatment adherence among fracture patients and that this relationship is partially mediated by self-efficacy and meaning in life. Importantly, however, meaning in life did not function as a uniformly facilitating factor. Although perceived usefulness increased patients' sense of meaning, the direct pathway from meaning in life to adherence was negative, suggesting that existential reflection may, for some individuals, orient coping toward acceptance rather than active engagement in rehabilitation behaviors. This nuanced pattern highlights that meaning in life may operate as a context-dependent psychological process rather than a uniformly motivating one. These findings emphasize the value of incorporating psychological constructs into technology-supported rehabilitation models while underscoring the need for longitudinal and multi-method designs to clarify the causal dynamics underlying these pathways.

Given the study's cross-sectional design and regional sample, the observed associations should be interpreted as correlational rather than causal, and their generalizability to other patient groups or healthcare settings remains to be verified. Future research should employ longitudinal or mixed-methods designs to capture how adherence and its psychological determinants evolve dynamically throughout different rehabilitation stages, integrating both quantitative tracking of behavioural change and qualitative exploration of patient experiences. Within these empirical boundaries, the study provides preliminary evidence that psychological factors such as self-efficacy and meaning in life are relevant considerations when designing patient-centered wearable rehabilitation programs.

Data Sharing Statement

The datasets generated and/or analyzed during the current study are available from the corresponding author, Min Xu, upon reasonable request.

Ethics Approval and Consent to Participate

I confirm that all methods were performed according to the relevant guidelines. All procedures were performed by the ethical standards outlined in the 1964 Declaration of Helsinki and its subsequent amendments. The study obtained informed consent from the all participants. The study was reviewed and approved by the ethics committee of the First Affiliated Hospital of Zhejiang Chinese Medical University (No.:2025-KLS-475-01). This study was conducted and reported in accordance with the STROBE guidelines for cross-sectional studies.

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Disclosure

The authors report no conflict of interest.

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