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Study on the Effect of Mobile Health Technology-Based Interventions on Out-of-Hospital Anticoagulant Medication Adherence in Patients with Venous Thromboembolism

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Abstract

Background Venous thromboembolism (VTE) is the third leading cause of death among cardiovascular diseases, and anticoagulant therapy is currently the main approach for treatment and prevention. Existing studies have shown that out-of-hospital adherence to anticoagulant medication is one of the major factors affecting anticoagulant efficacy, and mobile health technology has certain potential in the long-term management of various chronic diseases. However, whether mobile health technology interventions can help improve patients' out-of-hospital medication adherence, and the extent of such effects, remain unclear. Objective To explore the effectiveness of mobile health technology in assisting out-of-hospital adherence to anticoagulant medication among patients with VTE. Methods This was a single-center, prospective, single-arm cohort study with a before-and-after controlled design. A total of 274 patients with VTE admitted to the Sixth Medical Center of the Chinese People' s Liberation Army General Hospital from May to August 2025 were selected as study participants. All patients received mobile health technology-assisted out-of-hospital anticoagulation management for 90 d after discharge. The Chinese version of the Morisky Medication Adherence Scale-8 (MMAS-8) was used to assess changes in out-of-hospital adherence to anticoagulant medication before and after the intervention. Results The mean age of the 274 patients was $(62.54\$\pm15.28)years; 239patients(87.2\pm0.47)and(0.58\pm0.50), respectively.Aftertheintervention, thenumbero$ respectively, with statistically significant differences (P<0.05). Conclusion Mobile health technology can improve out-of-hospital adherence to anticoagulant medication among patients with VTE to a certain extent, especially in reducing missed doses and the burden of medication management, suggesting its positive application value in out-of-hospital anticoagulation self-management for patients with VTE.

Full Text

Study on the Effect of Mobile Health Technology-Based Interventions on Out-of-Hospital Anticoagulant Medication Adherence in Patients with Venous Thromboembolism

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Abstract

Background Venous thromboembolism (VTE) is the third leading cause of death among cardiovascular diseases, and anticoagulant therapy is currently the main approach for treatment and prevention. Existing studies have shown that patients' out-of-hospital adherence to anticoagulant medication is one of the major factors affecting anticoagulation efficacy, and mobile health technologies have certain potential in the long-term management of various chronic diseases. However, whether mobile health technology interventions can help improve patients' out-of-hospital medication adherence, and the magnitude of such effects, remain unclear.

Objective To explore the effectiveness of mobile health technology in assisting out-of-hospital anticoagulant medication adherence among patients with VTE.

Methods This was a single-center, prospective, single-arm cohort study using a before-and-after control design. A total of 274 patients with VTE treated at the Sixth Medical Center of Chinese PLA General Hospital from May to August 2025 were selected as study participants. All patients received mobile health technology–assisted out-of-hospital anticoagulation management for 90 days after discharge. The Chinese version of the Morisky 8-item Medication Adherence Scale (MMAS-8) was used to evaluate changes in patients' out-of-hospital anticoagulant medication adherence before and after the intervention.

Results The mean age of the 274 patients was (62.54 ± 15.28) years; 239 patients (87.2%) had deep vein thrombosis (DVT), and 35 patients (12.8%) had pulmonary embolism (PE). Before the intervention, among the 274 patients, 69 (25.2%) had good adherence, 114 (41.6%) had moderate adherence, and 91 (33.2%) had low adherence. The main manifestations of poor adherence were "sometimes forgetting to take medication" and "finding it troublesome to adhere to the treatment plan," with mean item scores of (0.58 ± 0.47) and (0.58 ± 0.50), respectively. After the intervention, the number of patients with high adherence increased to 101 (36.9%), an increase of 46.4%, which was significantly higher than before the intervention, with a statistically significant difference (P<0.001). The mean scores for the two items "sometimes forgetting to take medication" and "finding it troublesome to adhere to the treatment plan" increased to (0.73 ± 0.45) and (0.66 ± 0.48), respectively, with statistically significant differences (P<0.05).

Conclusion Mobile health technology can improve out-of-hospital anticoagulant medication adherence among patients with VTE to a certain extent, especially in addressing problems such as missed doses and the burden of medication management, suggesting its positive application value in out-of-hospital anticoagulation self-management among patients with VTE.

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Keywords: venous thromboembolism; mobile health technology; anticoagulant medication adherence; personalized management; prospective study; intervention effect

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Abstract

Background Venous thromboembolism (VTE) is the third leading cause of cardiovascular mortality. Anticoagulant therapy remains the mainstay of treatment and prevention. Previous studies have shown that postdischarge adherence to anticoagulant therapy is one of the major determinants of anticoagulation effectiveness. Mobile health technologies have shown

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potential in the long-term management of chronic diseases. However, whether mobile health–based interventions can improve postdischarge medication adherence in patients with VTE, and the magnitude of such benefit, remain unclear. **Objective** To evaluate the effectiveness of mobile health technology in improving postdischarge adherence to anticoagulant therapy among patients with VTE. **Methods** This was a single-center, prospective, single-arm cohort study with a pre–post intervention design. A total of 274 patients with VTE admitted to the Sixth Medical Center of the Chinese PLA General Hospital between May and August 2025 were enrolled. All patients received mobile health–assisted postdischarge anticoagulation management for 90 days after discharge. Changes in postdischarge anticoagulant adherence before and after the intervention were assessed using the Chinese version of the 8-item Morisky Medication Adherence Scale (MMAS-8). **Results** The mean age of the 274 patients was 62.54 ± 15.28 years. Of these, 239 patients (87.2%) had deep vein thrombosis, and 35 patients (12.8%) had pulmonary embolism. Before the intervention, 69 patients (25.2%) had high adherence, 114 patients (41.6%) had moderate adherence, and 91 patients (33.2%) had low adherence. The main manifestations of poor adherence were "sometimes forgetting to take medication" and "feeling hassled about adhering to the treatment plan," with mean item scores of 0.58 ± 0.47 and 0.58 ± 0.50, respectively. After the intervention, the number of patients with high adherence increased to 101 (36.9%), representing a relative increase of 46.4% compared with baseline; this improvement was statistically significant ($P < 0.001$). The mean scores for the items "sometimes forgetting to take medication" and "feeling hassled about adhering to the treatment plan" increased to 0.73 ± 0.45 and 0.66 ± 0.48, respectively, with statistically significant differences compared with baseline ($P < 0.05$). **Conclusion** Mobile health technology can improve outpatient anticoagulant medication adherence among patients with VTE to a certain extent, particularly in reducing missed doses and alleviating the burden of medication management. These findings suggest its potential value in supporting self-management of outpatient anticoagulation in patients with VTE.

[Key words] Venous thromboembolism; Mobile health technology; Anticoagulant adherence; Personalization management; Prospective study; Intervention effect

Venous thromboembolism (VTE) is the third leading cause of death worldwide after ischemic heart disease and stroke. It is characterized by numerous risk factors, insidious onset, rapid progression, and high mortality, and it is also one of the important causes of adverse outcomes among hospitalized patients [1–3]. Anticoagulant therapy is currently the main approach for the prevention and treatment of VTE. It usually needs to be continued for at least 3 months to reduce the risk of recurrence, and patients with complex conditions require

a longer course of treatment [4,5]. Although the use of direct oral anticoagulants has improved the convenience of treatment and reduced the risk of bleeding, medication adherence remains a key factor affecting therapeutic efficacy [6]. Studies have shown that only about 72% of patients can persist with treatment for 3 months, and the proportion continuing for 1 year decreases to 53%; among patients who discontinue medication without following medical advice, the risk of VTE recurrence exceeds 14.6% within 3 months after discontinuation and reaches approximately 28.3% within 1 year [7–8].

Mobile health technology has shown promising application prospects in the long-term management of chronic diseases. It can assist physicians in formulating individualized treatment plans and help improve patients' self-management abilities [9–10]. However, dedicated research on outpatient management for patients with VTE remains relatively limited. Therefore, based on previous experience with the mobile health atrial fibrillation management software (mhealth app for managing AF application, mAFA) [11–12], this study developed a mobile health VTE management application (mhealth app for managing VTE application, mVTEA) for patients with VTE. This study aims to observe and analyze changes in patients' medication adherence after mVTEA intervention, thereby exploring the intervention effect of mobile health technology in assisting individualized outpatient management of patients with VTE and improving adherence to anticoagulant therapy.

1 Subjects and Methods

1.1 Study Participants

This study was a single-center, prospective, single-arm cohort study using a pre-post comparison design. Patients who visited the Sixth Medical Center of the Chinese PLA General Hospital from May to August 2025 were recruited. Inclusion criteria were: (1) hospitalized patients aged $\geq$ 18 years at admission; (2) patients diagnosed with VTE [deep vein thrombosis (DVT) or pulmonary embolism (PE)] or identified as having moderate-to-high risk of VTE according to the Padua prediction score (score $\geq$ 4) or the Caprini risk assessment model (score $\geq$ 2); (3) patients currently using anticoagulant drugs for the treatment or prevention of VTE and planning to use them for $\geq$ 90 d; (4) patients able to understand the study procedures and willing to sign informed consent; (5) patients able to use a smartphone proficiently and willing to download and use the mVTEA application. Exclusion criteria were: (1) severe cognitive impairment or psychiatric disease, resulting in inability to use mVTEA; (2) inability to use a smartphone; (3) participation in other interventional clinical trials.

The study protocol was approved by the Independent Ethics Committee of the Sixth Medical Center of the Chinese PLA General Hospital (approval No.: HZKY-PJ-2024-25). All procedures complied with the principles of the Declaration of Helsinki. All patients participating in the study provided written informed consent, permitting participation in the study and use of mVTEA.

Participants were clearly informed that they had the right to withdraw from the study at any time without incurring any penalty. Patients participating in the study did not receive any economic compensation, material rewards, or other forms of remuneration for enrollment or participation. Participation was entirely voluntary, and refusal or withdrawal did not affect receipt of standard clinical care or follow-up management. To ensure data privacy and security, all patient data were de-identified during processing and assigned unique study codes. The collected data were securely stored by designated personnel.

and management. Access is limited to authorized personnel, and the data are used only for the purposes of this study. No data are disclosed to any third party.

1.2 Overall Patient Intervention Process

Patients participating in the study registered for mVTEA using a smartphone. During registration, necessary demographic and clinical information was collected, including name, sex, age, height, weight, inpatient department, anticoagulant use, and contact information. During hospitalization, medical staff in each department provided VTE health education in accordance with the institution' s standard procedures for VTE prevention and management. The patient' s attending physician formulated an individualized VTE prevention and treatment plan, including the choice of anticoagulant type, dose, frequency, and treatment duration. Before discharge, patients were required to complete the Chinese version of the 8-item Morisky Medication Adherence Scale (8-item Morisky Medication Adherence Scale, MMAS-8) and upload the anticoagulation prescription issued by the physician to mVTEA.

Before discharge, medical staff provided patients with standardized training on the use of mVTEA. After discharge, the mVTEA system began sending anticoagulant medication reminders according to the prescription, and reminded patients to record and provide feedback in mVTEA on their medication use on the day of dosing or in the preceding several days, in accordance with the training instructions. In addition, the system provided weekly feedback on adherence data to help medical staff and patients jointly review changes in the patient' s medication adherence and provide a basis for subsequent anticoagulation decisions. Medical staff conducted follow-up assessment 90 d after discharge. Follow-up methods included telephone follow-up, outpatient visits, or rehospitalization.

1.3 Chinese Version of the MMAS-8

In this study, the Chinese version of the MMAS-8 was used to quantitatively evaluate patients' adherence to anticoagulant medication. For items 1–7, the response options were "yes" or "no." For item 5, a response of "yes" was scored as 1 and "no" as 0; for the remaining items, a response of "no" was scored as 1 and "yes" as 0. Item 8 used a 5-point Likert response format, with codes (0–4) standardized by division by 4 to calculate the total score. The total MMAS-

8 score ranges from 0 to 8; a score of 8 indicates good adherence, 6–7 indicates moderate adherence, and <6 indicates poor adherence[^13]. The Chinese version of the MMAS-8 has good psychometric properties, with high internal consistency (Cronbach' s α=0.817) and excellent test-retest reliability (intraclass correlation coefficient =0.947) [^13], as shown in Figure 1.

Although the MMAS-8 has not yet been formally validated in the VTE population, because it is simple, feasible, and facilitates comparison across chronic diseases, the scale remains widely used in studies of medication adherence[^13-^16]. In this study, the MMAS-8 was used as a preliminary measurement tool to describe patients' baseline medication adherence, allowing standardized and comparable assessment of medication adherence among participants, and helping identify barriers before initiating mVTEA-supported management.

1.4 mVTEA-Assisted Patient-Centered VTE Management Model and Pathway

When designing mVTEA, the research team considered that long-term VTE management is multifaceted and requires individualized assessment and relatively detailed treatment strategies for patients. Therefore, an ABCDEF protocol for comprehensive VTE management was proposed to supplement mVTEA-assisted patient-centered management, thereby minimizing the risks of VTE and its complications while ensuring patient safety and quality of life: appropriate anticoagulation management (A) ; bleeding-risk management (B) ; complication monitoring (C) ; digital health management (D) ; exercise and rehabilitation (E) ; and facilitation of the management of risk factors and comorbidities (F) [^17], as shown in Figures 2 and 3.

mVTEA was designed with interfaces for both patients and physicians. The core functions of the patient interface include 4 modules: thrombosis-risk assessment, bleeding-risk assessment, anticoagulation management, and home rehabilitation reports.

1.4.1 Thrombosis- and Bleeding-Risk Module

The thrombosis- and bleeding-risk module provides dynamic monitoring of patients'thrombosis and bleeding risks. When a patient reports symptoms, adverse events, or uploads relevant examination results, risk assessment is automatically initiated. In addition, patients can complete a thrombosis-risk self-assessment scale. Based on individualized risk profiles, the mVTEA patient interface generates personalized VTE prevention and treatment recommendations. These risk-assessment results are also transmitted to the mVTEA physician interface so that thrombosis specialists can further evaluate and provide feedback.

1.4.2 Anticoagulation Management Module

The anticoagulation management module is structured into 4 key components: anticoagulant drugs currently in use, anticoagulation-risk monitoring, anticoagulation-quality monitoring, and medication adherence. For anticoagulation-risk and quality monitoring, patients can upload test results related to coagulation, liver function, or kidney function. These results are synchronized with the physician interface, and thrombosis specialists may conduct additional assessment and intervention as needed. The medication-adherence function allows patients to record their anticoagulant use through a digital "check-in" system and tracks and displays their medication history.

1.4.3 Home Rehabilitation Report Module

The home rehabilitation report module summarizes the patient' s home rehabilitation plan, including the duration of anticoagulation treatment, previous anticoagulant use, detailed adherence records, and recommendations for VTE prevention and management. The report is automatically generated weekly and monthly to support continuous monitoring and assistance.

Text visible within Figure 1

- Medication adherence (Chinese revised version of the MMAS-8 scale)
  - Self-assessed by the patient; there are 8 questions in total, and the patient selects one answer for each item.
  - For items 1-7, the alternative answers are "yes" and "no" ; an answer of "no" is scored as 1 point and "yes" as 0 points, with item 5 reverse-scored.
  - For item 8, the alternative answers are "never," "occasionally," "sometimes," "often," and "all the time," scored as 1, 0.75, 0.5, 0.25, and 0 points, respectively.
  - The full score of the scale is 8 points. A score <6 indicates low adherence; a score $ $6 but <8 indicates moderate adherence; and a score of 8 indicates high adherence.

Morisky Medication Adherence Scale

This table is used to evaluate your medication adherence. Please place a "√" before the corresponding option according to your actual situation.

1. Do you sometimes forget to take your medication?
   Yes No
2. In the past two weeks, have you missed taking your medication?
   Yes No
3. Have you ever increased, reduced, or stopped taking medication on your own because you felt unwell after taking it, without telling your doctor?
   Yes No

4. When you left home or traveled, did you ever forget to bring your medication?
   Yes No
5. Did you take all the medication you were supposed to take yesterday?
   Yes No
6. When you thought your condition had been controlled, did you ever stop taking medication?
   Yes No
7. Do you think it is troublesome to adhere to the medication regimen according to the treatment plan?
   Yes No
8. Is it difficult for you to remember to take all of your medications?
   Never Occasionally Sometimes Often All the time

Note: MMAS-8 = 8-item Morisky Medication Adherence Scale.

Figure 1 The questionnaire interface and user instructions of the Chinese version of the MMAS-8 medication adherence scale used in mVTEA.

Note: VTE = venous thromboembolism; mVTEA = mobile health VTE management software.

Figure 2 The patient-side management interface of mVTEA

Figure 2 The patient-side management interface of mVTEA

In addition, the mVTEA application provides daily medication reminders. At the end of each week, the application feeds back the number of days on which anticoagulant medication was taken as prescribed. When the assessment of thrombosis or bleeding risk changes, the application also issues reminders and monitors the quality of anticoagulant therapy. The specific monitoring indicators are platelet count, albumin, activated partial thromboplastin time, and glomerular filtration rate. Patients can access their own electronic health records at any time. Figure 3 shows the pathway by which mVTEA assists patients in self-management.

mVTEA enables a visual connection between the physician side and the patient side through the physician–patient communication module. When necessary, thrombosis specialists can provide patients with health education through the mVTEA physician–patient communication module, including motivational interviewing, or conduct online consultations. This module supports communication by text, images, and voice. If needed, outpatient appointments can also be arranged through mVTEA.

1.5 Patient medical data privacy and security

To ensure privacy and security when medical data are transmitted from the hospital to the patient application, the mVTEA application adopts a QR code-based secure transmission algorithm that combines Avro and byte pair encoding technology (QR Code-based Security Transmission algorithm using Avro and Byte Pair Encoding, QRST-AB)[18]. This algorithm processes a de-identified dataset that contains key information in structured JavaScript Object Notation (JSON) format, including medical records, laboratory tests, and imaging results, while excluding all direct personal identity information, thereby ensuring that the transmitted data themselves cannot be associated with a specific individual. The byte pair encoding framework integrates the ChaCha20 stream cipher for encryption and uses a mechanism based on the BLAKE3 cryptographic hash function for identity authentication, verifying the user' s QR-code content through a digital fingerprint. Data are transmitted via offline QR codes, thereby eliminating the risk of network exposure. System security is further strengthened through a proprietary Avro serialization architecture and byte pair encoding tokenizer. These core components are synchronized between the encoder and decoder through a secure offline channel, making it impossible for third parties to understand the data structure and content, and thereby jointly ensuring comprehensive data protection.

1.6 Study outcomes

1.6.1 Primary endpoint The primary endpoint is the proportion of patients with good adherence to the prescribed anticoagulant regimen at the 90-day post-discharge follow-up. Good adherence is defined as a score of 8 on the Chinese version of the MMAS-8 adherence scale after follow-up, together with complete consistency between the patient' s self-reported medication use—verified through pharmacy refill records and remaining medication packaging—and the prescribed regimen in terms of medication type, dose, and frequency. If no deviation is found, the patient is classified as having "good adherence" ; if the score is $ $6 and <8, the patient is classified as having "moderate adherence." If the score is <6, the patient is classified as having "poor adherence."

1.6.2 Secondary endpoints The secondary endpoints include: (1) the rate of change before and after good adherence; (2) the check-in rate for interactive anticoagulant treatment reminders conducted through mVTEA, calculated as the ratio of the number of completed check-ins for prescribed anticoagulant doses to the total number of prescribed doses; (3) clinical safety and efficacy outcomes, including VTE events, major bleeding events as defined according to the standards of the International Society on Thrombosis and Haemostasis, VTE-related hospitalization, VTE-related rehospitalization, and all-cause death. Admission for newly developed VTE will be recorded as VTE-related hospitalization, whereas rehospitalization due to VTE recurrence, progression, or complications caused by VTE treatment will be classified as VTE-related re-

hospitalization. All-cause death refers to death from any cause occurring during the study period.

1.7 Data collection

Patients' demographic and clinical information will be extracted from the hospital information system (HIS). Patients' medication adherence at recruitment will be assessed using the Chinese version of the MMAS-8 scale. At the 90-day post-discharge follow-up, the primary measure of anticoagulant adherence will be comprehensively determined through the following methods: (1) structured telephone follow-up; (2) the Chinese version of the MMAS-8 scale completed by patient self-report; (3) outpatient follow-up; and (4) medication records and medication feedback from the patient in the mVTEA application.

In addition to the above methods, the researchers will also record the current medication regimen,

Flowchart text in Figure 3

Start → Anticoagulation management → Whether medication is taken → Drug type

- Medication check-ins, latest laboratory/examination results, and feedback on related adverse events
- Daily medication reminders

Drug type branches into:

- Warfarin anticoagulation management
  - Risk monitoring
  - Quality control
  - Medication adherence
- DOAC anticoagulation management
  - Risk monitoring
  - Renal function
  - Liver function
  - Medication adherence

→ Recommend to medical staff the corresponding guideline-compliant drug type and dose → Patient

Patient decision branches into:

- Adjust drug type and dose according to the recommendation → Maintain and improve medication adherence
- Maintain the current status → Maintain and improve medication adherence

Note: DOAC = direct oral anticoagulant.

Figure 3 The workflow of mVTEA-assisted patient self-management

Verify discrepancies from the discharge prescription, record missed doses, and confirm continuation of the treatment course. When possible, adherence was objectively verified through pharmacy refill records or remaining medication packaging.

Secondary endpoints were also collected during these follow-up assessments. Clinical safety events were recorded according to patient reports and verified against the medical records. In addition, the interactive check-in rate in mVTEA was automatically recorded to assess patients' engagement with the application.

1.8 Statistical Methods

Based on the research team' s previous small-scale pilot study, the proportion of patients with good medication adherence before software intervention was estimated to be 31%

. It was estimated that the improvement rate in patients' medication adherence under the mVTEA intervention could reach 30%. With $\alpha = 0.05$ (two-sided) and a power of $1 - \beta = 0.80$, the minimum sample size calculated using PASS software was 219. Assuming a loss-to-follow-up rate of up to 20%, the final required number of recruited patients was calculated to be 274.

Data were analyzed using SPSS 27.0 statistical software. Measurement data were first tested for normality. Measurement data conforming to a normal distribution were expressed as $(\bar{x} \pm s)$; comparisons among multiple groups were performed using one-way analysis of variance, and pre- and post-intervention comparisons were performed using the paired t-test. Data not conforming to a normal distribution were expressed as $M(P_{25}, P_{75})$, and pre- and post-intervention comparisons were performed using the Wilcoxon signed-rank test. Count data were expressed as frequencies and percentages. Comparisons of paired binary categorical data before and after intervention were performed using the McNemar test, and comparisons of ordered multicategorical data were performed using the Wilcoxon signed-rank test. For all test levels, post hoc pairwise comparisons were performed after Bonferroni correction to determine specific differences between groups. All tests were two-sided, with a test level of $\alpha = 0.05$; $P < 0.05$ was considered statistically significant.

2 Results

2.1 Baseline Characteristics of Patients

The patient recruitment process is shown in Figure 4. A total of 274 patients with VTE were recruited in this study, including 239 patients (87.2%) diagnosed with DVT and 35 patients (12.8%) diagnosed with PE. The mean age of the patients was (62.54 ± 15.28) years, and 122 patients (44.5%) were female, as shown in Table 1.

2.2 Baseline Medication Adherence Scores of Patients

According to the scores from the Chinese version of the MMAS-8 scale completed by patients themselves at recruitment, 69 patients (25.2%) self-repor···

2025 年 5—8 月就诊的患者共 6 665 例
Total of 6,665 patients seen from May to August 2025

↓

Exclusions:
(1) 354 patients aged <18 years at admission
(2) 5,136 patients who had not been diagnosed with VTE, or whose Padua score (<4 points) or Caprini score (<2 points) indicated low risk
(3) 245 patients with a planned duration of anticoagulant use <90 days

↓

Patients aged >18 years with VTE: 930 cases

↓

Exclusions:
(1) 204 patients with neurological disorders or inability to understand the study process
(2) 256 patients unable to use smart devices such as smartphones or tablet computers
(3) 196 patients who refused to register for mVTEA and did not sign informed consent

↓

Number of documents obtained after full-text reading ($n = 19$)

↓

At recruitment, completed the Chinese version of the MMAS-8 medication adherence questionnaire and registered for mVTEA

↓

Medication adherence good: 69 patients | Medication adherence moderate: 114 patients | Medication adherence poor: 91 patients

↓

274 patients completed follow-up

↓

Medication adherence good: 101 patients | Medication adherence moderate: 101 patients | Medication adherence poor: 72 patients

Figure 4 Flowchart of patient inclusion process

Table 1 Baseline Information of Patients ($n = 274$)

Indicator	Value
Age ($\bar{x} \pm s$, years)	62.54 ± 15.28
Sex [cases (%)]	
Male	152 (55.5)
Female	122 (44.5)
VTE type [cases (%)]	
DVT	239 (87.2)
PE	35 (12.8)
Comorbidities [cases (%)]	
Hypertension	115 (42.0)
Cancer	55 (20.0)
Diabetes mellitus	164 (60.0)
Stroke	55 (20.0)
Atrial fibrillation	19 (0.7)
Coronary heart disease	55 (20.0)
Other	74 (27.0)

Note: VTE = venous thromboembolism; DVT = deep venous thrombosis; PE = pulmonary embolism.

were reported to have good medication adherence, while the remaining 205 patients (76.2%) had moderate or poor medication adherence. The factors contributing to low medication adherence among all patients were concentrated in item 1, "sometimes forget to take medication," and item 7, "feeling that adhering to the treatment plan is troublesome," with mean scores of (0.58 ± 0.47) points and (0.58 ± 0.50) points, respectively; see Table 2. Comparisons of item scores on the Chinese version of the MMAS-8 among patients in different adherence categories showed statistically significant differences for all items ($P < 0.05$); see Table 3.

During the 90-day follow-up after discharge, no patients were lost to follow-up, and the follow-up rate was 100%. A total of 219 patients (80.0%) participated in software check-ins. During follow-up, no patients reported secondary adverse outcomes such as thrombosis or bleeding.

2.3 Analysis of Changes in Medication Adherence Scores after mVTEA Intervention

The results showed that after the mVTEA intervention, 101 patients (36.7%) had good medication adherence, with an increase rate of 46.4%; 46 patients (16.8%) had an improved medication adherence category compared with baseline; 144 patients (52.6%) had no change in medication adherence category from baseline; and 5 patients (1.8%) decreased from moderate medication adherence

to poor medication adherence. The difference in changes was statistically significant ($\chi^2 = 44.45$,

Table 2 The overall mean score of each item on the Chinese version of the MMAS-8 adherence scale

MMAS-8 item	Score ($\bar{x} \pm s$, points)
1. Do you sometimes forget to take your medication?	0.58 ± 0.47
2. In the past two weeks, have you ever missed taking your medication?	0.82 ± 0.38
3. Have you ever, because you felt unwell after taking medication, increased, reduced, or stopped taking the medication on your own without informing your doctor?	0.82 ± 0.38
4. When you left home or traveled, have you ever forgotten to bring your medication?	0.87 ± 0.34
5. Did you take all the medications you were supposed to take yesterday?	0.96 ± 0.19
6. When you believed that your condition had been controlled, have you ever stopped taking your medication?	0.89 ± 0.31
7. Do you think it is troublesome to adhere to taking medication according to the treatment plan?	0.58 ± 0.50
8. For you, is it difficult to remember to take all your medications?	0.85 ± 0.21
Total score	6.46 ± 1.49

Note: MMAS-8 = 8-item Morisky Medication Adherence Scale.

Table 3 Item scores of the Chinese version of the MMAS-8 medication adherence scale across different adherence categories ($\bar{x} \pm s$, points)

MMAS-8 item	Good adherence ($n = 69$)	Moderate adherence ($n = 114$)	Poor adherence ($n = 91$)	F value	P value
Item 1	1.00 ± 0.00	0.77 ± 0.42	0.26 ± 0.44	85.068	<0.001
Item 2	1.00 ± 0.00	0.96 ± 0.21	0.52 ± 0.50	62.717	<0.001
Item 3	1.00 ± 0.00	0.89 ± 0.31	0.59 ± 0.50	31.269	<0.001
Item 4	1.00 ± 0.00	0.93 ± 0.26	0.69 ± 0.46	22.464	<0.001
Item 5	1.00 ± 0.00	0.97 ± 0.16	0.92 ± 0.27	3.646	0.021
Item 6	1.00 ± 0.00	1.00 ± 0.00	0.68 ± 0.47	42.330	<0.001
Item 7	1.00 ± 0.00	0.57 ± 0.50	0.29 ± 0.45	58.440	<0.001
Item 8	1.00 ± 0.00	0.89 ± 0.14	0.69 ± 0.24	72.841	<0.001

($P < 0.001$), see Table 4.

The changes in the mean scores of each item of the Chinese version of the MMAS-8 adherence scale before and after mVTEA intervention showed that, after the intervention, the total score, Item 1, and Item 7 were higher than before the intervention, and the differences were statistically significant ($P < 0.05$). For Items 2-6 and Item 8, the differences before and after the intervention were not statistically significant ($P > 0.05$), as shown in Table 5 and Table 6.

Table 4 Analysis of the significant differences in the overall effect of mVTEA intervention on patient adherence

Before intervention	After intervention: Good ($n = 101$)	After intervention: Moderate ($n = 101$)	After intervention: Poor ($n = 72$)	Total
Good ($n = 69$)	69	0	0	69
Moderate ($n = 114$)	32	77	5	114
Poor ($n = 91$)	0	24	67	91
Total	101	101	72	274

Table 5 Changes in the mean scores of each item on the Chinese version of the MMAS-8 adherence scale before and after mVTEA intervention ($\bar{x} \pm s$, points, $n = 274$)

MMAS-8 score	Before intervention	After intervention	t_{paired} value	P value
Item 1	0.58 ± 0.47	0.73 ± 0.45	2.340	0.020

MMAS-8 score	Before intervention	After intervention	t_{paired} value	P value
Item 2	0.82 ± 0.38	0.84 ± 0.36	0.884	0.377
Item 3	0.82 ± 0.38	0.84 ± 0.36	0.787	0.432
Item 4	0.87 ± 0.34	0.88 ± 0.33	0.294	0.769
Item 5	0.96 ± 0.19	0.96 ± 0.19	0.000	1.000
Item 6	0.89 ± 0.31	0.89 ± 0.31	0.000	1.000
Item 7	0.58 ± 0.50	0.66 ± 0.48	2.282	0.023
Item 8	0.85 ± 0.21	0.86 ± 0.21	0.686	0.423
Total score	6.46 ± 1.49	6.66 ± 1.55	3.303	<0.001

Table 6 Analysis of the significance of score changes across different dimensions of the adherence scale after mVTEA intervention

MMAS-8 item	Before intervention	After intervention = 1	After intervention = 0	χ^2 value	P value
Item 1	Before intervention = 1	157 (57.3%)	24 (8.8%)	51.126	0.03*
Item 1	Before intervention = 0	43 (15.7%)	50 (18.2%)	51.126	0.03*
Item 2	Before intervention = 1	205 (74.8%)	20 (7.3%)	44.031	0.23
Item 2	Before intervention = 0	26 (9.5%)	23 (8.4%)	44.031	0.23
Item 3	Before intervention = 1	199 (72.6%)	26 (9.5%)	16.282	0.51
Item 3	Before intervention = 0	32 (11.7%)	17 (6.2%)	16.282	0.51
Item 4	Before intervention = 1	216 (78.8%)	22 (8.0%)	16.696	0.88
Item 4	Before intervention = 0	24 (8.8%)	12 (4.4%)	16.696	0.88

MMAS-8 item	Before intervention	After intervention = 1	After intervention = 0	χ^2 value	P value
Item 5	Before intervention = 1	255 (93.1%)	9 (3.3%)	1.190	1.00
Item 5	Before intervention = 0	9 (3.3%)	1 (0.4%)	1.190	1.00
Item 6	Before intervention = 1	227 (82.8%)	18 (6.6%)	25.630	1.00
Item 6	Before intervention = 0	18 (6.6%)	11 (4.0%)	25.630	1.00
Item 7	Before intervention = 1	131 (47.8%)	29 (10.6%)	44.679	0.03*
Item 7	Before intervention = 0	49 (17.9%)	65 (23.7%)	44.679	0.03*
Item 8	Before intervention = 1	122 (44.5%)	32 (11.7%)	54.887	0.30
Item 8	Before intervention = 0	42 (15.3%)	78 (28.5%)	54.887	0.30

Note: *$P < 0.05$; for Item 8, when patients indicated that remembering to take all medications was not difficult, the score was categorized as "1"; all other answers were uniformly categorized as "0".

3 Discussion

This study evaluated the effectiveness and application value of mVTEA, a patient-centered mobile health intervention, in supporting anticoagulation management for patients with VTE or populations at moderate to high risk. The results of this study preliminarily demonstrate that mobile health technology has a certain positive role in improving out-of-hospital adherence to anticoagulant medication among patients with VTE, particularly in improving problems such as missed doses and the burden of medication management. At 90 days after discharge, the study observed a 46.4% increase in the proportion of patients with good adherence; meanwhile, the participation rate for the in-app check-in function was 80%, which can, to some extent, serve as evidence reflecting the effect of the mVTEA intervention.

Multiple factors may have contributed to the relatively favorable improvement in adherence observed in this study. First, in addition to retaining the traditional medication reminder function in mVTEA, the research team also required patients to check in through the software, thereby intervening in patients' own behavior and enhancing their awareness of medication use. Second, the management pathway and design concept of mVTEA also differ from those of traditional medication-management software. Unlike passive reminders, mVTEA provides individualized feedback through a conversational interface and interactive modules, enabling patients to participate actively in self-management. This real-time interaction may strengthen disease awareness and improve perceptions of the necessity of treatment, thereby forming a positive feedback loop that promotes strict adherence. Therefore, the 46.4% improvement rate in adherence may be the result of synergy between favorable baseline characteristics and the strong behavioral support provided by the technology.

Furthermore, the 80% check-in rate underscores the value of patient-centered design in overcoming common barriers such as forgetfulness. In addition, the association between app engagement and positive medication beliefs suggests that mVTEA can serve as an auxiliary tool to strengthen awareness of the necessity of treatment. By combining digital risk assessment with patient engagement, the mVTEA model can adapt to healthcare systems with limited outpatient resources by reducing the burden of routine follow-up.

Current findings provide growing evidence supporting the role of mobile health interventions in cardiovascular disease management. Previous studies have repeatedly demonstrated that smartphone applications have significant effects in improving medication adherence. Specifically, CAO et al.[20] and JIANG et al.[21] reported that the Alfalfa application significantly improved anticoagulation management and reduced adverse events during warfarin therapy. These findings were corroborated by TALBOOM-KAMP et al.[22], whose team established the safety and reliability of an e-health platform for self-management of oral anticoagulation. Compared with previous studies, this study focuses on a more heterogeneous VTE population receiving various anticoagulant treatments, while also incorporating a dedicated VTE protocol, including individualized risk assessment and direct physician–patient interaction.

Previous mAFA trials have already demonstrated the efficacy of an integrated mobile health approach combined with the ABC management pathway in atrial fibrillation, showing improvements in treatment adherence and clinical outcomes[11,23]. This study applies this patient-

a patient-centered integrated model suited to the specific clinical context of VTE management. In addition, the findings of this study are consistent with the existing literature, which has documented the potential of mobile health to enhance patient engagement and overcome barriers to access to care, as reflected in the high participation rates observed in mobile-based cardiac rehabilitation programs [24-25]. These findings underscore the need for large-scale randomized controlled trials to evaluate whether the observed improvement in adherence can

be translated into reductions in VTE recurrence and bleeding complications—important clinical outcomes that remain insufficiently explored in current mobile health research.

This study has several limitations. First, the single-arm design and lack of a control group preclude causal inference regarding the intervention effect. Second, although the 46.4% rate of improvement to good adherence reached and exceeded the expected estimate, it should be interpreted with caution. Adherence was assessed mainly through self-report and medication records; these methods are susceptible to recall bias and social desirability bias, and a Hawthorne effect may also have been present. Future large-scale randomized controlled trials should incorporate objective measures (such as pharmacy refill data) and extend follow-up to assess sustainability. Third, although the Chinese version of the MMAS-8 medication adherence scale is widely used, its specific validation among patients with VTE is limited, and such scales are susceptible to bias; therefore, caution is warranted when interpreting factors influencing medication adherence. Finally, excluding patients without smartphones or with low digital literacy introduces selection bias and may overestimate adherence. Those excluded are often older adults with multiple comorbidities—precisely the groups that may benefit most from adherence support. Therefore, the applicability of these findings to the broader VTE population is limited. Future versions of mVTEA must address this gap, possibly through a simplified interface, family-assistance modules, or a hybrid digital-and-analog model, to ensure equitable access.

This study demonstrates the effectiveness of mVTEA in assisting patients with VTE in individualized out-of-hospital anticoagulation management, and shows that it can effectively intervene to help patients improve and maintain adherence to anticoagulant medication. The results indicate that mobile health technology can, to a certain extent, improve out-of-hospital adherence to anticoagulant medication among patients with VTE, with particularly positive effects on problems such as missed doses and the burden of medication management, suggesting its positive application value in out-of-hospital anticoagulation self-management for patients with VTE.

Author contributions: Zhang Zheqi was responsible for patient recruitment, patient follow-up, data collection, data organization and statistical analysis, and manuscript writing; Jin Shengkang was responsible for implementation and revision of the research protocol, statistical analysis and revision, and revision of the manuscript content; Ouyang Jing provided guidance during study initiation and design, supported study implementation and organization of patient recruitment, and provided suggestions for manuscript revision; Liu Binbin was responsible for patient recruitment, patient follow-up, and data collection and organization; Guo Yutao proposed the research idea, proposed and designed the research protocol, revised the final version of the manuscript, and takes responsibility for the manuscript.

The authors declare no conflicts of interest.

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