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Impact of a Standardized Prevention and Treatment System on Venous Thromboembolism Management: An Interrupted Time Series Analysis

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Abstract

Background Despite clinical guidelines, significant gaps persist in the standardized implementation of assessment and prophylactic measures. To address this complex medical challenge, we evaluated the impact of a standardised prevention and treatment system for VTE that integrates management frameworks, standardised processes, information technology (IT) support and staff training.

Methods We analyzed monitoring data on the rate of standardized prevention of VTE and clinical outcome indicators for hospitalized patients between January 2021 and December 2023. Using the hospital's full implementation of the VTE prevention and control information system and standardised prevention and treatment framework in April 2022 as the intervention point, divided into pre-intervention (January 2021 to March 2022) and post-intervention (April 2022 to December 2023). An interrupted time series (ITS) analysis with segmented regression models was employed to evaluate the intervention's impact on standardized VTE prevention rates.

Results The VTE risk assessment rate increased from 44.83% to 85.26%, and VTE prophylaxis implementation rate increased from 48.25% to 85.01% after intervention. ITS analysis indicated that the intervention produced a significant immediate effect, with the VTE risk assessment rate rising instantly by 23.228% ($\beta=23.228$, $t=10.036$, $P<0.001$), and the VTE prophylaxis implementation rate increased immediately by 20.998% ($\beta=20.998$, $t=8.353$, $P<0.001$); both metrics maintained a steady upward trend following the intervention. In terms of clinical outcomes, the incidence of DVT decreased from 1.98% to 0.72%, and the incidence of PTE decreased from 0.63% to 0.14%; both reductions were statistically significant ($P<0.001$).

Conclusion Constructing and implementing a standardized VTE prevention and treatment system significantly improved the rate of standardized prevention of VTE,

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reduced the incidence of in-hospital VTE adverse events, and enhanced the quality of medical care.

Key words Interrupted Time Series; Venous Thromboembolism; Prevention and Treatment System; Standardized Prevention Rate

Introduction

Venous thromboembolism (VTE), which encompasses Deep vein thrombosis (DVT) and Pulmonary Thromboembolism (PTE), is a common thromboembolic disease. As one of the major risk factors for in-hospital unexpected mortality and perioperative death [1,2], it poses a serious threat to patient safety and imposes a substantial burden on healthcare systems. Studies indicate that without any prophylactic measures, the incidence of VTE among hospitalized medical and surgical patients can be as high as 10% to 40% [3]. In response to this major public health and healthcare quality challenge, the National Health Commission of China consecutively listed "improving the rate of standardized prevention of VTE" as one of the top ten national medical quality and safety improvement goals from 2021 to 2024 [4-7], underscoring its critical importance in hospital quality management.

Despite national promotion and exploratory efforts by many domestic medical institutions to establish in-hospital VTE prevention and management systems, significant challenges persist in practice. These primarily include insufficient awareness among healthcare professionals, lack of systematic and information technology-driven quality control mechanisms, non-standardized prevention strategies, and suboptimal implementation of preventive measures [8-10]. Substantial evidence demonstrates that systematic VTE risk screening of inpatients, coupled with the timely and standardised implementation of preventive measures for those at moderate-to-high risk can significantly reduce hospital-acquired VTE [11,12]. However, how to scientifically and sustainably improve the rate of standardized prevention of VTE and quantitatively evaluate the long-term effectiveness of a comprehensive intervention system—integrates management frameworks, standardised processes, IT support and staff training—remains a pertinent research question in the field of healthcare quality improvement. Interrupted time series (ITS) analysis [13,14] is a robust methodological approach for evaluating public health interventions, it is capable of distinguishing between immediate level changes and long-term trend changes following an intervention, thereby providing a rigorous assessment of its effect.

Therefore, this study employed ITS analysis method to evaluate the impact of a standardized VTE prevention and management system implemented at a Grade A

tertiary hospital since April 2022 (the implementing unit was recognized as an exemplary national thrombosis prevention center in July 2023). By analyzing the trends in process and outcome data over two years before and after the intervention, this study aims to provide scientific evidence for quantifying the effectiveness of comprehensive VTE prevention and treatment strategies and to offer an empirical reference for other medical institutions seeking to establish or optimize their own VTE prevention and management systems.

Materials and Methods

Study Design and Data Sources

This study employed an interrupted time series (ITS) design to assess the trends in healthcare quality indicators before and after the implementation of a standardized VTE prevention and management system. Data were extracted from the electronic medical records and quality monitoring systems of hospitalized patients at a Grade A tertiary hospital in China, covering the period from January 2021 to December 2023. This hospital formally launched a dedicated VTE prevention and control information system in April 2022, concurrently rolling out a systematic, standardized VTE prevention and treatment strategy. Consequently, the time series was divided into two phases: the pre-intervention phase (January 2021 to March 2022) and the post-intervention phase (April 2022 to December 2023).

Intervention

The implemented standardized VTE prevention and management system was a multifaceted, full-cycle intervention strategy, comprising the following core components: (1) System Establishment and Quality Management: A hospital-wide standardized VTE prevention and management system was established, guided by the "Chain-Leader System" work plan for the entire VTE diagnosis and treatment process. This system involved mapping and implementing closed-loop management for all key elements in the VTE prevention, diagnosis, and treatment pathway. Continuous monitoring of related healthcare quality control indicators was conducted, combining both process and outcome quality management. (2) Process Standardization and Multidisciplinary Collaboration: In-hospital protocols for VTE risk assessment, diagnosis, treatment, and prophylaxis implementation were refined. A two-level (hospital and department) emergency response plan, green channel, and emergency handling procedures for VTE were established. A multidisciplinary team (MDT) was formed for complex cases, conducting regular drills for continuous process improvement. (3) Information Platform Development: A specialized intelligent VTE prevention and management system was developed and deployed. This system

integrated electronic versions of VTE-related assessment tools (e.g., Caprini score, Padua score), bleeding risk assessment scales, and prophylaxis options. It featured automated monitoring, reminders, and feedback functions at critical time points, enabling a streamlined, informatized closed-loop management of VTE prevention. (4) Training and Health Education: A systematic training and education program on VTE prevention knowledge was instituted. Education was delivered simultaneously to healthcare professionals, patients, and their families through various channels, including in-hospital training sessions, health education manuals, and pamphlets. Furthermore, regular analysis and dissemination of typical in-hospital VTE cases were conducted to reinforce risk awareness among all staff.

Outcome Measures

In alignment with the National Medical Quality and Safety Improvement Goals [4-7], the "the rate of standardized prevention of VTE" was selected as the primary improvement target. This was operationalized using two core process indicators:

(1) VTE Risk Assessment Rate: This was calculated as (Number of discharged patients who received VTE risk assessment / Total number of discharged patients) $\times$ 100%. This indicator reflects the penetration of VTE risk screening among hospitalized patients.

(2) VTE Prophylaxis Implementation Rate: This was calculated as (Number of at-risk discharged patients who received VTE prophylaxis / Number of discharged patients assessed as being at moderate or high risk for VTE) $\times$ 100%. This indicator measures adherence to implementing preventive measures in identified at-risk patients.

Interrupted Time Series Analysis

An Interrupted Time Series (ITS) analysis was employed to evaluate the effect of the intervention. This quasi-experimental method assesses the impact of an intervention by comparing changes in both the level and trend of an outcome before and after its implementation.

Monthly data on the VTE risk assessment rate and prophylaxis implementation rate were collected over 36 months, from January 2021 to December 2023. The intervention start date (April 2022) served as the interruption point. A segmented linear regression model was fitted using the ordinary least squares method (The detailed settings of the independent variables in the ITS analysis are shown in Table 1), specified as follows:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \varepsilon$$

Y : represents the monthly VTE risk assessment rate or prophylaxis implementation rate at time t .

X_1 : represents the continuous variable time (in months), numbered sequentially from 1 to 36.

X_2 : represents the intervention (0 for pre-intervention period, 1 for post-intervention period).

X_3 : represents the interaction term between time and the intervention phase. Its value is 0 during the pre-intervention period and counts from 1 to 21 in the post-intervention period.

β_0 : represents the baseline level of the outcome at the start of the series.

β_1 : represents the average pre-intervention trend (slope).

β_2 : represents the immediate level change following the intervention.

β_3 : represents the change in the trend (slope) after the intervention compared to the pre-intervention period, representing the sustained effect of the intervention.

$(\beta_1 + \beta_3)$: represents the average post-intervention trend.

ε : represents the error term.

Table 1 Detailed settings of independent variables in ITS analysis

monitoring time	X_1	X_2	X_3	monitoring time	X_1	X_2	X_3
2021.01	1	0	0	2022.04	16	1	1
2021.02	2	0	0	2022.05	17	1	2
2021.03	3	0	0	2022.06	18	1	3
2021.04	4	0	0	2022.07	19	1	4
2021.05	5	0	0	2022.08	20	1	5
2021.06	6	0	0	2022.09	21	1	6
2021.07	7	0	0	2022.10	22	1	7
2021.08	8	0	0	2022.11	23	1	8
2021.09	9	0	0	2022.12	24	1	9
2021.10	10	0	0	2023.01	25	1	10
2021.11	11	0	0	2023.02	26	1	11
2021.12	12	0	0	2023.03	27	1	12
2022.01	13	0	0	2023.04	28	1	13
2022.02	14	0	0	2023.05	29	1	14
2022.03	15	0	0	2023.06	30	1	15
				2023.07	31	1	16
				2023.08	32	1	17
				2023.09	33	1	18
				2023.10	34	1	19
				2023.11	35	1	20
				2023.12	36	1	21

The Durbin-Watson (DW) statistic was applied to evaluate the presence of first-order autocorrelation in the time series. If significant autocorrelation was detected, the Cochrane-Orcutt iterative procedure was used to correct the original

model. The ordinary least squares method was employed to fit the regression models, and the goodness-of-fit was assessed using the coefficient of determination (R^2) and the adjusted R^2 .

Statistical Analysis

Statistical analyses were performed using R software (version 4.3.3). Categorical data are presented as frequencies and percentages. Comparisons between groups were conducted using the Chi-square test. A two-sided P -value < 0.05 was considered statistically significant.

Results

Analysis of Changes in VTE Risk Assessment rate

Comparison of Assessment Indicators Before and After Implementation of the Standardized VTE Prevention and Management System

During the monitoring period, 163,424 patient discharges were observed in the pre-intervention phase, of which 73,263 received VTE risk assessment, yielding an assessment rate of 44.83%. In the post-intervention phase, 218,862 discharges were observed, with 186,591 patients receiving VTE risk assessment, corresponding to a significantly higher assessment rate of 85.26%. This represents an absolute increase of 40.43% compared to the pre-intervention rate, and the difference was statistically significant ($P < 0.001$). The rates of assessment within 24 hours of admission and bleeding risk assessment also showed significant improvement in the post-intervention period compared to the pre-intervention period ($P < 0.001$) (Table 2).

Table 2 Comparison results of relevant assessment indicators before and after the intervention

Group	VTE risk assessment rate, n(%)	Assessment rate within 24 hours of admission, n(%)	Bleeding assessment rate, n(%)
pre-intervention (n=163424)	73263(44.83%)	68278(41.78%)	63180(38.66%)
post-intervention (n=218862)	186591(85.26%)	185639(84.82%)	184676(84.38%)
χ^2	70234.745	77709.884	85780.831
P	<0.001	<0.001	<0.001

Analysis of Trend Changes in VTE Risk Assessment Rate

Calculate the monthly VTE risk assessment rate during the monitoring period (Table 3).

Table 3 Monitoring results of VTE risk assessment rate

Pre-intervention monitoring time	Number of discharged patients who received VTE risk assessment	Total number of discharged patients	VTE risk assessment rate(%)	post-intervention monitoring time	Number of discharged patients who received VTE risk assessment	Total number of discharged patients	VTE risk assessment rate(%)
2021.01	3905	10716	36.44	2022.04	7893	10028	78.71
2021.02	3325	8732	38.08	2022.05	8721	10674	81.70
2021.03	3956	11535	34.30	2022.06	9196	10972	83.81
2021.04	4439	11773	37.70	2022.07	9645	12130	79.51
2021.05	4893	11190	43.73	2022.08	8842	10902	81.10
2021.06	4947	10949	45.18	2022.09	6545	8388	78.03
2021.07	4863	12735	38.19	2022.10	7585	9624	78.81
2021.08	5012	11845	42.31	2022.11	7105	8952	79.37
2021.09	5184	10783	48.08	2022.12	6876	8240	83.45
2021.10	5689	10670	53.32	2023.01	7791	9598	81.17
2021.11	6002	12083	49.67	2023.02	8806	10098	87.21
2021.12	6025	10872	55.42	2023.03	9854	10980	89.74
2022.01	5412	11539	46.90	2023.04	9533	10736	88.79
2022.02	3883	7451	52.11	2023.05	9565	10846	88.19
2022.03	5728	10551	54.29	2023.06	9171	10404	88.15
Total pre-intervention	73263	163424	44.83	2023.07	10678	11899	89.74
				2023.08	10598	11724	90.40
				2023.09	9367	10393	90.13
				2023.10	8976	10268	87.42
				2023.11	9968	11005	90.58
				2023.12	9876	11001	89.77
				Total post-intervention	186591	218862	85.26

The Durbin-Watson value for the autocorrelation analysis of the VTE risk assessment rate was 1.957 ($P = 0.256$), suggesting that there was no autocorrelation in the series. The final fitted ITS model was:

$$Y = 33.542 + 1.422 \times X_1 + 23.228 \times X_2 - 0.791 \times X_3 + \varepsilon$$

The model demonstrated excellent goodness-of-fit, with an R^2 of 0.971 and an adjusted R^2 of 0.969. The results showed that during the pre-intervention period, the VTE risk assessment rate had a slow upward trend, increasing by an average of 1.422% per month ($t=5.948$, $P<0.001$). Following the intervention, a significant immediate level change was observed, with the rate increasing by 23.228% ($t=10.036$, $P<0.001$).

Furthermore, a significant change in the post-intervention trend occurred, indicated by a slope change of -0.791 ($t=-2.881$, $P=0.007$). Consequently, the average monthly change in the post-intervention period was calculated as 0.631% (1.422% - 0.791%), indicating that the VTE risk assessment rate maintained a sustained upward trend after the implementation of the standardized system (Table 4 and Figure 1).

Table 4 ITS analysis results of VTE risk assessment rate

DW	P	R ²	Adjusted R ²	Variable	β	SE	t	P
2.022	0.102	0.990	0.985	Constant	32.654	3.634	8.986	<0.001
				term				
				X_1	1.422	0.239	5.948	<0.001
				X_2	23.228	2.314	10.036	<0.001
				X_3	-0.791	0.275	-2.881	0.007

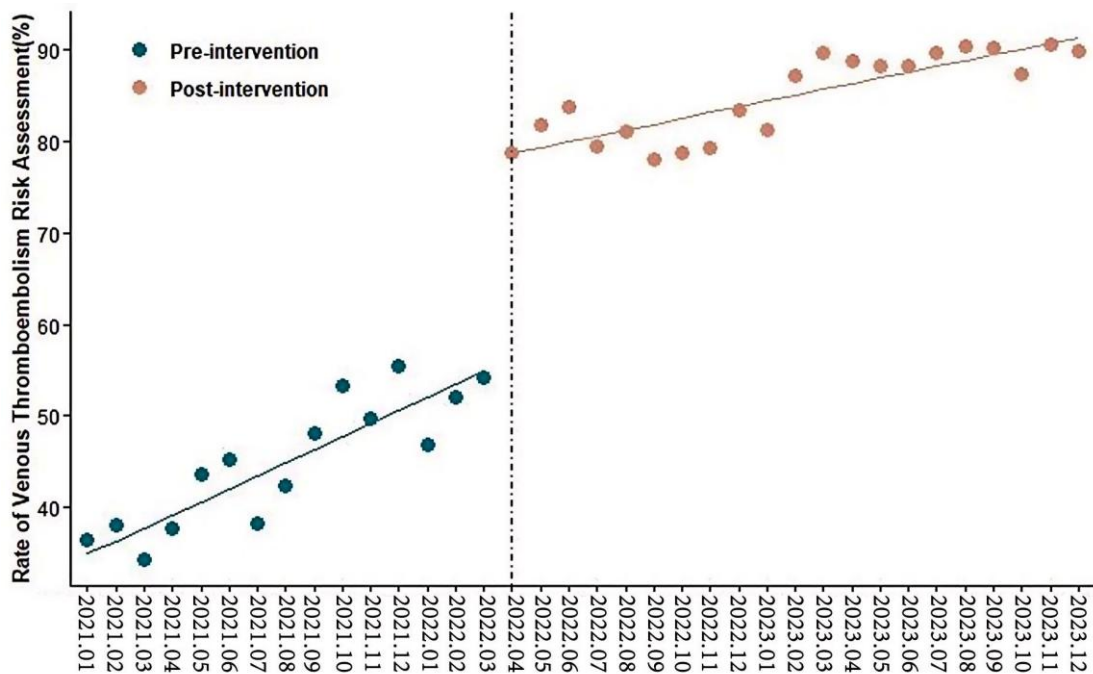


Fig. 1 Trends in VTE risk assessment rates

Analysis of Changes in VTE Prophylaxis Implementation Rate

Comparison of Prophylaxis Indicators Before and After Implementation of the Standardized VTE Prevention and Management System

During the monitoring period, 33,195 patient discharges assessed as being at moderate or high risk for VTE were observed in the pre-intervention phase, of which 16,016 received VTE prophylaxis, resulting in a prophylaxis implementation rate of 48.25%. In the post-intervention phase, 97,907 at-risk discharges were observed, with 83,231 patients receiving prophylaxis, corresponding to a significantly higher rate of

85.01%. This represents an absolute increase of 36.76% compared to the pre-intervention period, and the difference was statistically significant ($P < 0.001$). The rates of pharmacological prophylaxis, mechanical prophylaxis, and combined prophylaxis all showed significant improvement in the post-intervention period compared to the pre-intervention period ($P < 0.001$) (Table 5).

Table 5 Comparison results of relevant Prophylaxis indicators before and after the intervention

Group	VTE prophylaxis implementation rate, n(%)	Pharmacological prophylaxis rate, n(%)	Mechanical prophylaxis rate, n(%)	Combined prophylaxis rate, n(%)
pre-intervention (n=33195)	16016 (48.25%)	9291 (27.99%)	12704 (38.27%)	7383 (22.24%)
post-intervention (n=97907)	83231 (85.01%)	41434 (42.32%)	52899 (54.03%)	35364 (36.12%)
χ^2	18213.769	2146.201	2462.611	2172.981
P	<0.001	<0.001	<0.001	<0.001

Analysis of Trend Changes in VTE Prophylaxis Implementation Rate

Calculate the monthly VTE prophylaxis implementation rate during the monitoring period (Table 6).

Table 6 Monitoring results of VTE prophylaxis implementation rate

Pre-intervention monitoring time	Total				Total		
	Number of	number of			Number of	number of	
	discharged	patient	VTE		discharged	patient	VTE
	patients	discharges	prophylaxis	post-	patients	discharges	prophylaxis
	who	assessed as	implementa	intervention	who	assessed as	implementa
	received	being at	-tion	monitoring	received	being at	-tion
	VTE	moderate or	rate(%)	time	VTE	moderate or	rate(%)
	prophylaxis	high risk for			prophylaxis	high risk for	
		VTE				VTE	
2021.01	1052	2183	48.19	2022.04	2869	4102	69.94
2021.02	931	1856	50.16	2022.05	2953	4078	72.41
2021.03	983	2085	47.15	2022.06	3118	4376	71.25
2021.04	1186	2248	52.76	2022.07	3289	4701	69.96
2021.05	1149	2356	48.77	2022.08	3505	4596	76.26
2021.06	1077	2193	49.11	2022.09	2897	3946	73.42
2021.07	1075	2079	51.71	2022.10	3296	4313	76.42
2021.08	1056	2241	47.12	2022.11	3325	4306	77.22
2021.09	1087	2145	50.68	2022.12	3354	4076	82.29
2021.10	1074	2371	45.30	2023.01	4067	4730	85.98
2021.11	1146	2653	43.20	2023.02	4075	4861	83.83

2021.12	1182	2539	46.55	2023.03	4873	5480	88.92
2022.01	1042	2248	46.35	2023.04	4706	5107	92.15
2022.02	854	1684	50.71	2023.05	4784	5066	94.43
2022.03	1122	2314	48.49	2023.06	4621	4875	94.79
Total pre-intervention	16016	33195	48.25	2023.07	4859	5176	93.88
				2023.08	4771	5139	92.84
				2023.09	4436	4718	94.02
				2023.10	4273	4579	93.32
				2023.11	4567	4826	94.63
				2023.12	4593	4856	94.58
				Total post- intervention	83231	97907	85.01

The Durbin-Watson value for the autocorrelation analysis of the VTE prophylaxis implementation rate was 2.139 ($P = 0.476$), suggesting that there was no autocorrelation in the series. The final fitted ITS model was:

$$Y = 50.477 - 0.216 \times X_1 + 20.998 \times X_2 + 1.666 \times X_3 + \varepsilon$$

The model demonstrated excellent goodness-of-fit, with an R^2 of 0.951 and an adjusted R^2 of 0.946. The results showed that during the pre-intervention period, the monthly VTE prophylaxis implementation rate exhibited no significant trend, with an average monthly change of -0.216% ($t = -0.709$, $P = 0.483$). Following the intervention, a significant immediate level change was observed, with the rate increasing by 20.998% ($t = 8.353$, $P < 0.001$). Concurrently, a significant change in the post-intervention trend occurred, indicated by a slope change of 1.666 ($t = 4.642$, $P < 0.001$). Consequently, the average monthly change in the post-intervention period was 1.45% (-0.216% + 1.666%), demonstrating that the VTE prophylaxis implementation rate maintained a stable upward trend after the implementation of the standardized system (Table 7 and Figure 2).

Table 7 ITS analysis results of VTE prophylaxis implementation rate

DW	P	R ²	Adjusted R ²	Variable	β	SE	t	P
2.139	0.476	0.951	0.946	Constant	50.477	3.119	16.184	<0.001
				term				
				X_1	-0.216	0.304	-0.709	0.483
				X_2	20.998	2.514	8.353	<0.001
				X_3	1.666	0.359	4.642	<0.001

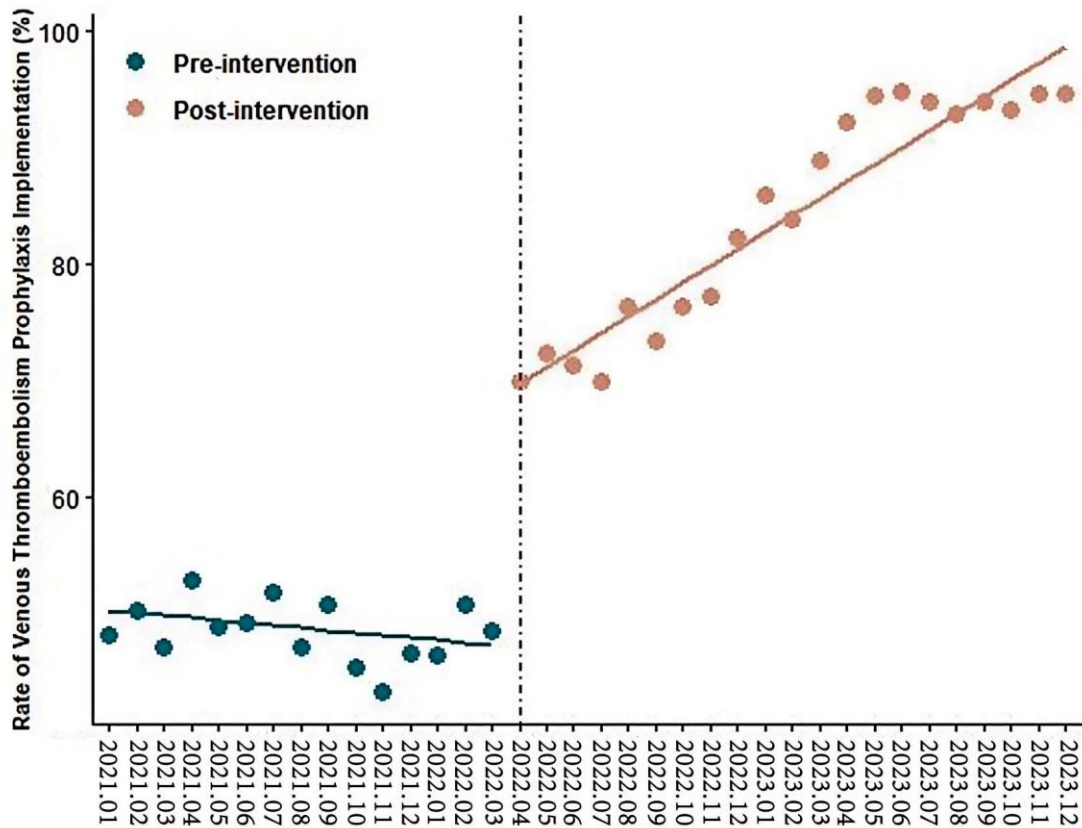


Fig. 2 Trends in VTE prophylaxis implementation rates

Comparison of Venous Thromboembolism Incidence Before and After Implementation of the Standardized VTE Prevention and Management System

Regarding clinical outcomes, the incidence of deep vein thrombosis (DVT) decreased from 1.98% (3,236/163,424) in the pre-intervention period to 0.72% (1,576/218,862) in the post-intervention period. Similarly, the incidence of Pulmonary Thromboembolism (PTE) decreased from 0.63% (1,030/163,424) to 0.14% (306/218,862). All these reductions were statistically significant ($P < 0.001$)(Table 8).

Table 8 Comparison results of relevant venous thromboembolism incidence indicators before and after the intervention

Group	DVT incidence rate, n(%)	PTE incidence rate, n(%)
pre-intervention (n=163424)	3236 (1.98%)	1030 (0.63%)
post-intervention (n=218862)	1576 (0.72%)	306 (0.14%)
χ^2	1195.167	646.229
P	<0.001	<0.001

Discussion

This study employed Interrupted Time Series (ITS) analysis to evaluate the effectiveness of a comprehensive, hospital-wide standardized venous thromboembolism (VTE) prevention and management system. The results demonstrated that following the implementation of the system, both the VTE risk assessment rate and the VTE prophylaxis implementation rate among moderate-to-high-risk patients exhibited a significant immediate increase and a sustained positive growth trend. Concurrently, key clinical and process indicators, including the 24-hour admission assessment rate, bleeding risk assessment rate, and the rates of pharmacological, mechanical, and combined prophylaxis, showed significant improvement post-intervention. Moreover, the incidences of Deep vein thrombosis (DVT) and Pulmonary Thromboembolism (PTE) were significantly reduced. These findings indicate that the systematic intervention effectively enhanced adherence to VTE prevention protocols, ultimately translating into tangible patient benefits. The following discussion addresses the key elements contributing to the successful implementation of this system.

Establishing a Standardized VTE Prevention and Management System as the Foundation for improving the rate of standardized prevention of VTE

The accreditation requirements for tertiary hospitals mandate standardized assessment, identification, prevention, diagnosis, and management for patients at moderate-to-high risk of VTE. Establishing a systematic and standardized VTE prevention and management system is therefore fundamental to addressing this complex medical challenge [15]. Drawing on the "Chain-Leader System" management concept [16, 17], this study developed and implemented specific work plans, establishing a standardized hospital-wide VTE prevention and management system. This system involved a "chain-style" mapping and clarification of responsibilities for all elements within the full cycle of VTE prevention, diagnosis, treatment, follow-up, and adverse event reporting, thereby resolving issues of process disconnection and unclear accountability. More importantly, a standardized quality control and evaluation indicator system for healthcare professionals was established [18]. This system implemented a dual supervisory mechanism combining "process quality" (focused on conformance checks) and "outcome quality" (centered on indicator monitoring), supported by regular departmental audits and feedback to drive continuous improvement of VTE diagnosis and treatment processes. The results of this study showed that the VTE risk assessment rate increased from 44.83% to 85.26%, and the VTE prophylaxis implementation rate increased from 48.25% to 85.01% post-intervention. This confirms that establishing a structured VTE

prevention and management system, standardizing strategies, and strengthening quality management and control can effectively enhance the rate of standardized prevention of VTE, promoting homogeneity and standardization in hospital VTE management. This aligns with previous research concluding that a structured quality improvement framework is a key driver for improving VTE prophylaxis rates [19-21].

Standardized Clinical Pathways and Multidisciplinary Collaboration Ensure Accurate Implementation

Studies indicate that even with guideline availability, a significant gap persists between recommended and actual VTE prophylaxis practices in clinical settings [22]. The core of our hospital's standardized system lies in translating guidelines into actionable, standardized pathways. This was achieved by developing integrated physician-nurse protocols and practical handbooks, revising and optimizing electronic risk assessment forms and workflows, establishing green channels and emergency response plans, and deeply integrating a Multidisciplinary Team (MDT) into the decision-making process for complex cases [23, 24]. This ensured continuity and standardization from risk identification to prophylaxis execution. The ITS analysis revealed an immediate level increase of 23.228% in the VTE risk assessment rate and 20.998% in the prophylaxis implementation rate post-intervention, both followed by a sustained upward monthly trend. This demonstrates that standardized in-hospital VTE prevention pathways and strategies provide clear operational guidance for clinical practice, effectively bridging the "know-do" gap between guidelines and real-world application[25], thereby enhancing VTE prevention outcomes.

An Informatized Intelligent VTE Prevention Platform as the Core Engine for Closed-Loop Management

Informatization and intelligentization of VTE management can make prevention efforts more convenient, scientific, standardized, and consistent, significantly improving work efficiency [26]. In this study, VTE-related assessment tools (e.g., risk assessment, bleeding risk assessment) and clinical probability scales (e.g., Wells score) were embedded into the hospital's Electronic Health Record system, creating an intelligent decision support and reminder system. This system automatically identifies assessment points, prompts clinicians, and pushes relevant forms for completion. Based on assessment results, it recommends appropriate prophylaxis measures. This not only ensures the mandatory, timely, and standardized nature of assessments but also significantly reduces omissions in prophylaxis. Furthermore, patient VTE information is dynamically and synchronously displayed on the medical record interface, electronic bedside cards, and nursing whiteboards, enabling full-process informatized management. This closed-loop, technology-enabled intervention is a key

mechanism explaining the stable and optimized upward trends in VTE risk assessment and prophylaxis implementation rates observed in this study. This finding is consistent with conclusions from researchers such as Nikolaos Tsaftaridis, Christopher J. Tignanelli, and White Nicole M [27-29], indicating that clinical decision support systems can effectively and sustainably improve rates of standardized VTE prophylaxis.

Sustained Education and a Culture of Safety as the Enduring Driver for Maintaining Prevention Effectiveness

Healthcare professionals are pivotal to VTE prevention. Insufficient awareness and knowledge among staff are key contributors to low VTE assessment rates [30, 31]. To address this, our hospital established a structured education and training management system. We implemented multi-level training programs, including onboarding for new staff, specialized training for clinicians and nurses, intensive sessions for high-risk departments, and patient education. Concurrently, education was disseminated through various channels such as VTE health management manuals, thrombosis prevention pamphlets, instructional videos on compression stockings, expert lectures, joint physician-nurse guidance, and free clinics. This multi-pronged approach aimed to build a hospital-wide VTE prevention culture by enhancing knowledge, skills, and awareness among all stakeholders—doctors, nurses, and patients—thereby comprehensively strengthening the institution's VTE prevention capabilities.

Limitations of the study

This study has several limitations. First, as a single-center study, the generalizability of its findings requires validation across healthcare institutions of different levels and regions. Second, while the ITS design strongly suggests causality, it cannot entirely rule out the influence of historical confounding factors. Third, the study primarily evaluated selected process measures and clinical outcomes, it did not conduct an in-depth analysis of prophylaxis-related adverse events (e.g., major bleeding) or health economic outcomes. Future research should employ more complex designs (e.g., stepped-wedge cluster randomized trials) in multi-center settings to comprehensively evaluate the clinical effectiveness, safety, and cost-effectiveness of such integrated systems, thereby providing a more robust evidence base for decision-making.

Conclusion

Aligned with the VTE Tertiary Hospital Center Construction Standards and Scoring Rubric (2022 edition)[32] and China's thrombosis prevention benchmarks,

this study constructed a systematic, standardized in-hospital VTE prevention and management system. Using a rigorous ITS design, it provided empirical evidence for the effectiveness of this comprehensive intervention. The results indicate that a multi-dimensional strategy integrating management frameworks, standardised processes, IT support and staff training can sustainably improve key indicators such as VTE risk assessment and prophylaxis implementation rates. This offers valuable experience for other medical institutions, particularly those aiming to establish high-level thrombosis prevention centers.

Abbreviations

VTE	Venous thromboembolism
DVT	Deep vein thrombosis
PTE	Pulmonary Thromboembolism
ITS	Interrupted time series
MDT	Multidisciplinary team
DW	Durbin-Watson

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Author contributions

Minhui Luo: Conceptualization, Methodology, Formal analysis, Writing - original draft, Writing - review & editing, Funding acquisition. Qi Xu and Junping Luo: Methodology, Formal analysis, Writing - original draft, Writing - review & editing. Li Zou: Investigation, Formal analysis. Yuanfei Liu: Formal analysis, Writing - review & editing, Supervision, Project administration. Jinfeng Zhang: Investigation, Writing - review & editing, Supervision, Project administration.

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Data availability

The datasets generated and analyzed during the current study can be obtained from the corresponding author upon justified request.

Declarations

Ethics approval and consent to participate

This retrospective, quality improvement study was conducted using anonymized data. In accordance with the guidelines of the Ethics Center of Ganzhou People's Hospital and pursuant to Article 32 of the "Ethical Review Measures for Life Sciences and Medical Research Involving Humans" (National Health Commission, No. 4, 2023), research utilizing anonymized information data is exempt from ethical review. Since all patient data were fully de-identified and aggregated prior to analysis, the requirement for obtaining individual informed consent was waived. The study was conducted in accordance with the ethical standards of the institutional review body and the principles of the Declaration of Helsinki.

Consent for publication

Not applicable.

Competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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