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Original Article

Application of a feedforward control-based intervention for preventing hypothermia in trauma patients in a pre-hospital emergency setting

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Abstract: Objective: To investigate the efficacy of a feedforward control-based intervention strategy for preventing hypothermia among trauma patients during pre-hospital emergency care. Methods: We conducted a retrospective analysis comparing trauma patients treated before and after implementing the intervention, with 40 cases in each group. All patients received emergency care from the Fuzhou Emergency Center on the scene. Multivariate analysis was used to explore the risk factors for hypothermia. The effective rate, incidence of adverse reactions, quality of body temperature management, medical staff's knowledge, attitudes, and behaviors regarding mild hypothermia prevention, coagulation function, treatment time at various stages, prognosis score, and treatment situation were compared between the two groups. Results: The adverse reactions, intervention methods, and degree of cognitive improvement were influencing factors for hypothermia. The effective rate (92.50%) in the feedforward control group was higher than that in the non-feedforward control group (65.00%), with a lower incidence of adverse reactions (2.50%). The temperature management quality score of the feedforward control group (6.23±0.62) was higher. The feedforward control group achieved a higher quality score for temperature management (6.23±0.62) and exhibited a greater understanding of hypothermia prevention among trauma patients ($P<0.05$). Compared to the non-feedforward control group, the feedforward control group showed improved coagulation function, better performance in treatment time at each node, and higher prognosis scores. Conclusion: The intervention model based on feedforward control can effectively improve the standard of pre-hospital emergency care and prevent the incidence of hypothermia in trauma patients.

Keywords: Feedforward control, intervention mode, pre-hospital emergency, hypothermia, preventive care

Introduction

Trauma is a global public health problem, with both mortality and morbidity rates rising annually [1]. Post-traumatic hypothermia is one of the serious complications in the treatment of trauma patients, with an incidence of 12%-66% [2]. After trauma, the prognosis of patients with hypothermia is generally poor. Prompt prevention of the loss of heat is the key to avoid hypothermia, acidosis, and coagulation dysfunction, the "fatal triad", in trauma patients [3]. Pre-hospital emergency treatment, an indispensable part of the emergency medical system, is characterized by an interdisciplinary, high-risk nature and susceptibility to various constraints, such as environment, condition, psychology, public opinion, technology, and social support [4]. Feedforward control, also known as pre-control, refers to a method that predicts the consequences of management activities and takes preventive measures in advance, thereby precluding potential discrepancies. This approach has found application across diverse sectors [5-8]. Hypothermia is the most easily solved factor in the 'fatal triad' of trauma, and it is amenable to direct intervention using pre-hospital first aid. The European Guidelines for the Management of Severe Trauma Bleeding [9] have recommended early rewarming of trauma patients. However, there are few studies on the use of feedforward con-

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trol to prevent the occurrence of hypothermia in trauma patients. This study introduces a feedforward control-based intervention model tailored for pre-hospital trauma care, aiming to evaluate its effectiveness in practice.

Material and methods

Patient screening and intervention measures

This retrospective study was approved by the Ethics committee of Fuzhou Emergency Center. According to the timeline of feedforward control application in Fuzhou Emergency Center, patients who received treatment from January 2022 to October 2022 were selected as the non-feedforward control group, and patients who received treatment from November 2022 to August 2023 were set as the feedforward control group. Their clinical data were retrieved from the electronic medical record system. The selected trauma patients all received emergency care at the scene that was provided by Fuzhou Emergency Center.

Inclusion criteria: (1) Patient with acute trauma; (2) Patients aged between 18-75; (3) The transport time from site of accident to hospital was less than 24 h; (4) Patients who underwent specific intervention and were evaluated after treatment.

Exclusion criteria: (1) Patients diagnosed with clinical death on arrival at the emergency care center; (2) Patients who received treatment by another hospital before arriving at our emergency trauma center; (3) Patients with a history of severe liver, kidney, or lung dysfunction, hypothyroidism, or coagulation abnormalities; (4) Patients with previous malignant tumors, chronic inflammatory or autoimmune diseases; (5) Patients with prior acute cerebrovascular disease or psychiatric illness; (6) Patients previously treated with radiotherapy, chemotherapy, and renal replacement therapy; (7) Patients with incomplete urgent medical data.

According to the inclusion and exclusion criteria, a total of 44 patients with non-feedforward control intervention and 40 patients with feedforward control intervention were collected. After further refinement based on the patients' ages and genders, the numbers were adjusted to ensure 40 patients in each intervention group. **Figure 1** shows the flow chart of the study.

The non-feedforward control group received standard hypothermia prevention measures for trauma patients, including routine procedures such as removing wet clothes, providing clean garments and pants when possible, applying localized covering to keep warm, and direct infusion without heating measures.

Building upon the practices in the non-feedforward control group, the feedforward control group was itreated with additional measures [10, 11]. (1) Team Formation for Feedforward Control Method Exploration: A dedicated team including a head nurse alongside ten medical staff members was established. Together with doctors, the head nurse incorporated the principles of feedforward control into the development of tailored prevention plans and actions, which encompass improving the standard operation process of body temperature monitoring, standardizing the recording and interpretation of body temperature readings, and strengthening the training and evaluation of nursing staff. Efforts were made to ensure timely implementation of temperature intervention strategies by the nursing team. (2) Analysis and Improvement of Pre-Hospital First Aid Records: An exhaustive review of past pre-hospital first aid records was conducted to identify and address factors contributing to ineffective temperature management, such as patient factors, disease factors, environmental factors, medical rescue factors, and medical equipment factors. By applying feedforward control principles, the problems existing in the system, routine, and process were addressed, and corresponding prevention plans and measures were formulated to guide and supervise the nursing staff's adherence, aiming to mitigate instances of ineffective temperature management. (3) On-Site Patient Assessment and Tailored Hypothermia Prevention: Upon arrival at the scene, medical staff quickly evaluated the severity and status of trauma patients. Those at a high risk of spontaneous hypothermia were screened according to body temperature, with a threshold of 36°C. Depending on the season, on-site rescue time and rescue measures, appropriate prevention measures were implemented, including but not limited to the rapid removal of wet and contaminated clothing, and covering the patient with blankets and quilts to avoid limb exposure. At the same time, the temperature in the ambulance was kept constant at about 28°C, and the infusion was

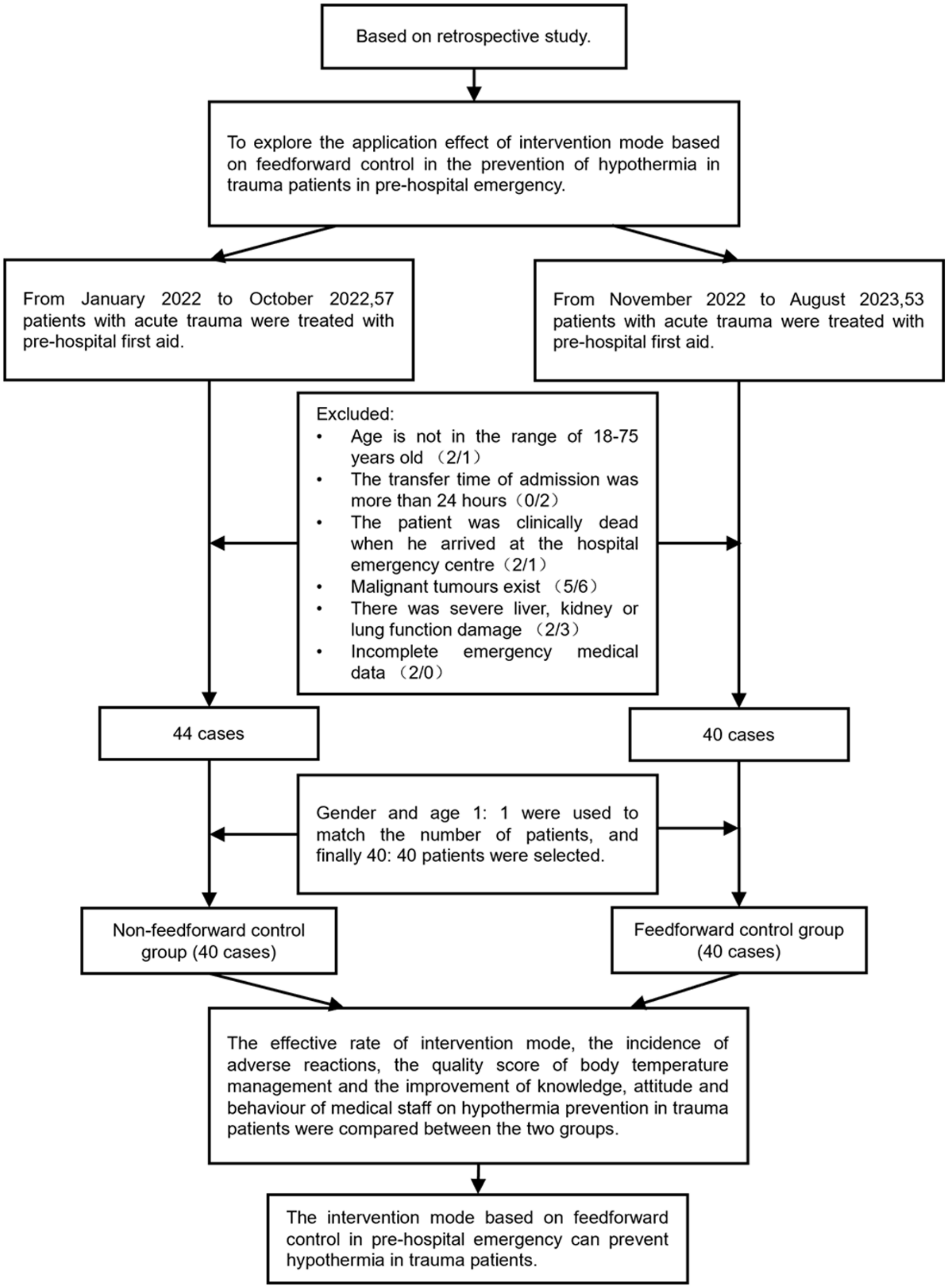

Figure 1. Flow chart providing the procedures of this study.

heated. At the same time, the patient's signs and body temperature changes were continuously monitored to prevent core hypothermia. The implementation of this model spanned from the arrival of medical staff at the scene through to hospital admission.

Clinical data collection

The data were extracted from the electronic medical record system of the hospital, and the working mode of cross double check was adopted to avoid errors in the data extraction process.

(1) Clinical baseline data were collected, including gender, age, shock index, heart rate, traumatic factors, whether the clothes were moist before emergency treatment, whether warm measures were given during emergency treatment, and whether infusion was given. (2) According to the collected data, the percentage of patients with normal body temperature at arrival and the occurrences of adverse reactions (including chills, agitation, nausea and vomiting, etc.) were calculated. The percentage of normal body temperature = the number of patients with normal body temperature (body temperature 36°C)/the total number of trauma patients × 100%; adverse reaction rate = number of adverse reactions/total number of trauma patients × 100%. (3) The coagulation function of patients after admission were collected, including prothrombin time (PT), thrombin time (TT), and activated partial thromboplastin time (APTT). (4) The data on duration of emergency department stay, average time for symptom improvement, average hospitalization time, and pre-discharge prognosis score of the two groups were collected. (5) The improvement in knowledge, attitude and behavior of medical staff on hypothermia prevention was evaluated. Based on the theory of knowledge-attitude-practice [12], a self-designed questionnaire was designed and administered following training and assessment of medical staff. The questionnaire includes three parts: knowledge of hypothermia prevention (20 items covering risk factors, preventive measures, and complications, with each correct answer scored as 2 points, for a total score range of 0-40), attitudes towards hypothermia prevention (6 items, with a scoring range from 1 for complete disagreement to 5 for complete agreement, total score range 6-30), and behaviors related to hypothermia prevention (6 items, with scores ranging from 1 for inability to perform to 5 for full implementation, total score range 6-30). The reliability of the questionnaire was 0.823, and the Cronbach's α coefficient was 0.873. (6) Treatment satisfaction was compared between the two groups. Patient satisfaction with the treatment was surveyed before discharge, using a custom scale: satisfied (≥85 points), average (75-84 points), and dissatisfied (≤75 points). Satisfaction = (total number of cases - dissatisfied cases)/total number of cases × 100%.

Body temperature management quality score table

The implementation quality of feedforward control mode was evaluated by using a temperature management quality score table, a routine evaluation program of our center. The table is a self-made form, which is completed by the medical staff who performed first aid upon the patient's arrival. It comprises a total of 8 items, including the body temperature during first aid (1 point at 36°C, 0 point otherwise), presence of wet clothes upon arrival, maintenance of ambulance temperature at 28°C, use of quilts for heat preservation, whether the infusion was heated, adherence to temperature measurement methods and frequency, and occurrence of adverse reactions. 'Yes' - 1 point, 'no' - 0 points, with a total score ranges 0-8 points. The Cronbach's α coefficient of the questionnaire was 0.824.

Statistical methods

SPSS 23.0 statistical software was used for statistical analysis. The counted data were expressed as number (n) and percentage (%), and the comparison between groups was performed by χ^2 test. Measured data were expressed as mean ($\overline{x}$) and standard deviation(s), and the t-test was used for comparison between groups. Multivariate logistic regression analysis was performed to assess whether the patient's body temperature was normal at admission as a dependent variable, hoping to confirm whether the included indicators were independent risk factors for the main outcome. A difference was considered significant at $P<0.05$.

Results

Baseline data of patients

In the non-feedforward control group, there were 21 males (52.50%) and 19 females (47.50%), with an average age of (40.58±12.49)

Table 1. Comparison of general data between two groups of patients

Clinical baseline data	Feedforward control group (n = 40)	Non-feedforward control group (n = 40)	χ^2/t	*P*
Sex [n (%)]			0.202	0.653
Male	23 (57.50)	21 (52.50)		
Female	17 (42.50)	19 (47.50)		
Age ($\overline{x}$±s, years)	43.33±10.15	40.58±12.49	1.081	0.283
Shock index ($\overline{x}$±s, point)	0.84±0.26	0.91±0.34	1.034	0.304
Heart rate ($\overline{x}$±s, beats/min)	92.63±29.89	104.28±26.18	1.854	0.067
Traumatic factors [n (%)]			2.039	0.361
High falling injury	8 (20.00)	13 (32.50)		
Traffic accident injury	29 (72.50)	23 (57.50)		
Others	3 (7.50)	4 (10.00)		
With wet clothes upon arrival [n (%)]			0.228	0.633
Yes	26 (65.00)	28 (70.00)		
No	14 (35.00)	12 (30.00)		
Measures to keep warm [n (%)]			0.139	0.709
Yes	35 (87.50)	37 (92.50)		
No	5 (12.50)	3 (7.50)		
Transfusion [n (%)]			0.052	0.820
Yes	23 (57.50)	24 (60.00)		
No	17 (42.50)	16 (40.00)		

Table 2. Multivariable regression analysis

Variable	*B*	*SE*	*Wald*	*P*	*OR*	*95% CI*
Adverse reaction	-2.457	0.980	6.291	0.012	0.086	0.013-0.584
Group	-6.747	3.171	4.527	0.033	0.001	0.000-0.588
Cognitive improvement of medical staff	0.319	0.123	6.754	0.009	1.376	1.082-1.751
Constant	-15.474	6.375	5.891	0.015	<0.001	-

years old (range 21-70). The shock index was (0.91±0.34) in the non-feedforward control group, and there were 23 cases (57.50%) of traffic accidents, 13 cases (32.50%) of falling injuries, and 4 cases (10.00%) of other injuries. In the feedforward control group, there were 23 males (57.50%) and 17 females (42.50%), with an average age of (43.33±10.15) years old (range 21-70). The shock index was (0.84±0.26) in the feedforward control group, and there were 29 cases (72.50%) of traffic accidents, 8 cases (20.00%) of falling injuries, and 3 cases (7.50%) of other injuries. There was no significant difference in general data between the two groups (all *P*>0.05), indicating that the two groups were comparable (**Table 1**).

Multivariate logistic regression analysis

Multivariate logistic regression analysis was performed as to whether the patient's body temperature was normal at admission (yes = 1, no = 0) as the dependent variable and the classified data were assigned: adverse reactions (yes = 1, no = 0), group (feedforward control group = 1, non-feedforward control group = 0); continuous variables: cognitive improvement of medical staff were recorded as actual values. The results showed that the occurrence of adverse reactions, intervention mode, and cognitive improvement of medical staff were influencing factors of hypothermia in pre-hospital first aid (all *P*<0.05) (**Table 2**).

Comparison of the percentage of patients with normal body temperature between the two groups

The feedforward control group exhibited a higher percentage of patients with normal body temperature upon hospital arrival (92.50%, 37/40), compared to the non-feedforward con-

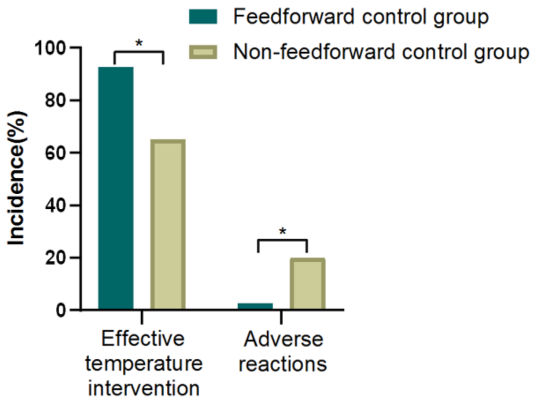

Figure 2. Comparison of effective rate of temperature intervention and incidence of adverse reactions between the two groups of patients. *$P<0.05$.

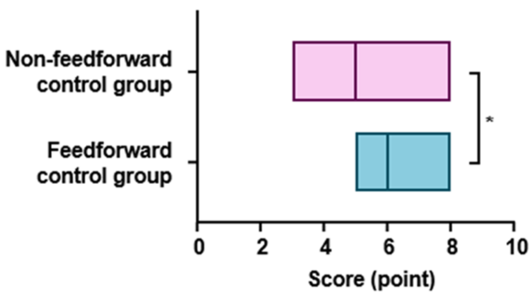

Figure 3. Quality scores of body temperature management were compared between the two groups. *$P<0.05$.

trol group (65.00%, 26/40) ($P = 0.003$). Also, the total incidence of adverse reactions in the feedforward control group was lower than that of the non-feedforward control group (2.50% vs. 20.00%, $P = 0.039$) (**Figure 2**).

Comparison of temperature management quality scores between the two groups of patients

The temperature management quality score in the non-feedforward control group was (5.15±1.03), which was significantly lower than (6.23±0.62) in the feedforward control group ($P<0.001$), as shown in **Figure 3**.

Comparison of medical staff's cognition of preventing hypothermia between the two groups

Through the implementation of the feedforward control intervention, the medical staff's knowledge, attitudes, and behaviors towards preventing hypothermia were significantly im-

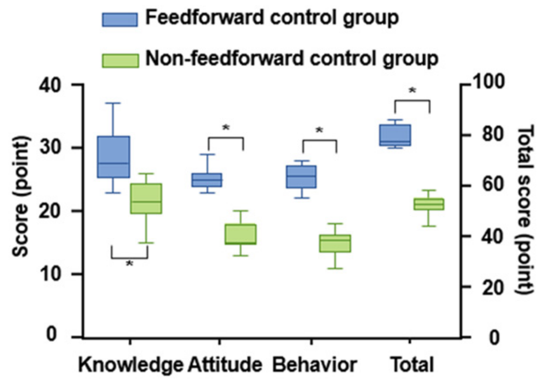

Figure 4. A self-made scale was used to compare medical staff's knowledge, attitudes, and behaviors toward hypothermia between the two groups. *$P<0.05$.

proved. The total score for these components in the feedforward control group was (79.10±4.33) points, which was greatly higher than the score (52.40±3.89) in the non-feedforward control group ($P<0.001$), as shown in **Figure 4**.

Comparison of coagulation function between the two groups

The coagulation function indexes upon admission were compared between the two groups. The PT, TT, and APTT of the feedforward control group were (14.79±1.28) s, (19.53±2.01) s and (37.94±3.62) s, respectively, which were significantly shorter than (15.64±1.09) s, (23.38±2.24) s, and (40.35±2.73) s of the non-feedforward control group (all $P<0.01$), as shown in **Table 3**.

Comparison of prognosis between the two groups

Following the body temperature management intervention, the feedforward control group experienced significantly shorter average duration of emergency department stay [(36.80±12.14) min vs. (60.73±4.46) min], average time for symptom improvement [(6.15±2.03) d vs. (10.23±2.09) d], and the average hospitalization time [(8.10±1.93) d vs. (12.68±4.57) d], than the non-feedforward control group (all $P<0.001$). The prognosis score of the feedforward control group prior to discharge was (3.55±1.08), which was higher than (2.10±0.67) for the non-feedforward control group ($P<0.05$), as shown in **Table 4**.

Table 3. Comparison of coagulation function between the two groups (s, $\bar{x}$±s)

Group	PT	TT	APTT
Feedforward control group (n = 40)	14.78±1.27	19.53±2.01	37.93±3.61
Non-feedforward control group (n = 40)	15.63±1.08	23.38±2.24	40.35±2.73
t	3.225	8.091	3.382
P	0.002	<0.001	0.001

Note: The coagulation index in the table is prothrombin time (PT), thrombin time (TT), and activated partial thromboplastin time (APTT).

Table 4. Comparison of prognosis between the two groups ($\bar{x}$±s)

Index	Feedforward control group (n = 40)	Non-feedforward control group (n = 40)	*t*	*P*
Emergency department stay (min)	36.80±12.14	60.73±4.46	11.702	<0.001
Symptom improvement time (d)	6.15±2.03	10.23±2.09	8.856	<0.001
Hospitalization time (d)	8.10±1.93	12.68±4.57	5.839	<0.001
Prognosis score (point)	3.55±1.08	2.10±0.67	7.216	<0.001

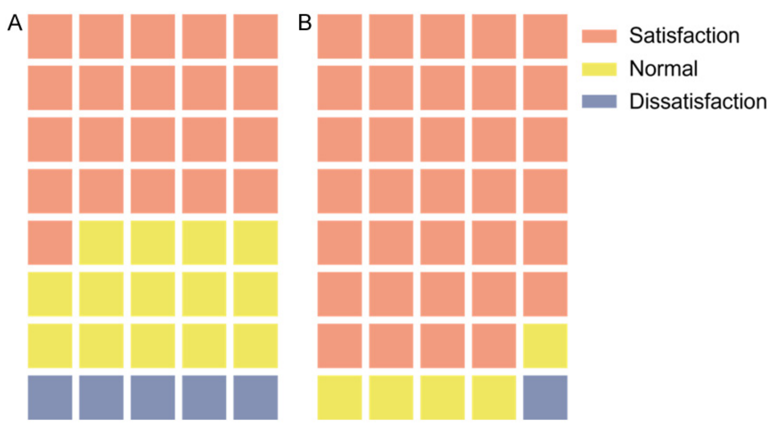

Figure 5. Comparison of treatment satisfaction between two groups of patients. (A) Non-feedforward control group, and (B) Feedforward control group. The colors indicate the degree of satisfaction of patients.

Comparison of treatment satisfaction between the two groups

The patient's satisfaction with treatment was evaluated before discharge. In the non-feedforward control group, 21 cases were satisfied, 14 cases were general, 5 cases were dissatisfied, with a total satisfaction rate of 87.50%. In the feedforward control group, 34 cases were satisfied, 5 cases were general, 1 case was dissatisfied, with a total satisfaction rate of 97.50%. The treatment satisfaction in the feedforward control group was significantly higher than that of the non-feedforward control group (χ^2 = 10.452, *P* = 0.005), as shown in **Figure 5**.

Discussion

Hypothermia is prevalent and serious complication after trauma, characterized by a core body temperature below 35°C. This condition can disrupt the body's endogenous functions, leading to a progressive decline in body temperature, affecting coagulation and immune function, thereby increasing the likelihood of poor prognosis in trauma patients [13]. Traditionally, the primary focus of medical staff in ambulances was to stabilize the patient's injury to the greatest extent possible, with interventions for hypothermia typically initiated only after its onset. Based on the concept of feedforward control, senior nurses and doctors proactively identify the factors contributing to hypothermia and formulate corresponding operation procedures for training and assessment. This proactive approach enables medical workers to intervene before the occurrence of hypothermia, thereby reducing the incidence of hypothermia and improving the patient prognosis. The feedforward control mode analyses the influencing factors by predicting future risks, and formulates corresponding preventive measures based on these factors, including environmental changes and body reactions, to prevent the occurrence of post-traumatic hypothermia effectively. Therefore, how to improve the symptoms of hypothermia and reduce the incidence of hypothermia-related adverse events through effective nursing intervention is the focus of current research.

Trauma mainly refers to the damage of body tissues and organs caused by external forces. It is usually accompanied by coagulation dysfunction, infection, shock and other symptoms. These complications can lead to a decrease in circulating blood volume and hypoxia of tissue cells, eventually resulting in tissue and organ dysfunction, and necessitating prompt treatment measures [14]. While conventional emergency care offers targeted interventions based on the immediate needs of patients, its effectiveness can sometimes be hampered by a lack of predictability and specificity. Inadequate attention to maintaining body warmth can lead to continuous temperature decline in patients, increasing the risk of adverse events [15, 16]. Persistent hypothermia will increase blood viscosity and slow down the patient's blood flow rate, resulting in coagulation dysfunction. It can also cause multiple organ dysfunction and shock, even death in trauma patients [17-19]. Therefore, maintaining a stable temperature is fundamental to preserving the body's metabolic and physiological functions. Hypothermia can be directly intervened in the pre-hospital emergency setting, and it is also the easiest factor to solve in the 'fatal triad' [20]. The results of this study showed that the effective rate of temperature management in the feedforward control group (92.50%) was higher than that of the non-feedforward control group (65.00%), and the incidence of adverse reactions (2.50%) was lower than that in the non-feedforward control group (20.00%), indicating that the intervention mode based on feedforward control can improve the professional ability of medical staff through comprehensive training. This approach significantly reduces the incidence of hypothermia and its associated adverse events.

Traumatized patients in pre-hospital emergency settings are mostly suffering falling injuries, car accidents, or other causes. As the amount of bleeding increases, the core body temperature of patient gradually decreases. Chills can increase the body's oxygen consumption and lead to an augmented CO_2 concentration, ultimately adding to cardiac strain [21]. An open wound, combined with a lack of warming measures during transport, can accelerate heat loss, diminishing coagulation function, increasing bleeding, and further reducing the body's heat production function. These factorselevate the incidence of spontaneous hypothermia [22, 23]. Our findings reveal that the patients who received the feedforward control intervention mode had improved coagulation function compared to those with conventional intervention, laying a good foundation for subsequent treatment.

The results of this study showed that the body temperature management quality score of feedforward control group was higher than that of the non-feedforward control group [(35.35±3.60) vs. (33.40±3.77)]. After the training in hypothermia prevention, the medical staff's knowledge, attitudes and behaviors regarding hypothermia management significantly improved, as reflected by their higher questionnaire scores compared to those untrained. Through the unified standard of training and guidance, the professional quality of medical personnel was improved, leading to increased vigilance toward traumatic hypothermia and improved implementation of hypothermia management protocols. The head nurse organized the emergency personnel to learn the relevant knowledge of hypothermia after trauma so that the personnel could quickly assess the severity of trauma upon arrival at the scene, identify patients at high risk of hypothermia, and mitigate the ischemia and hypoxia of brain and limbs, thus preventing temperature drop. In the process of transport and first aid, medical staff continuously monitored the patient's temperature change and carefully avoided single limb temperature rise, which may affect peripheral blood vessel dilation, core hypothermia, or shock [24]. In our study, the emergency department stay, symptom improvement time and hospitalization time of patients receiving feedforward control intervention mode were all shorter than those receiving ordinary intervention mode, while their pre-discharge prognosis score and treatment satisfaction were higher. Therefore, the implementation of specialized training and assessment, alongside comprehensive warm intervention measures for hypothermia was shown to be beneficial to the prognosis of patients and has significantly improved their satisfaction with treatment.

In summary, the intervention based on feedforward control can better improve the efficiency of temperature management, temperature management quality, and coagulation function, and reduce the occurrence of adverse reactions. It provides a reference for the standard formulation of hypothermia prevention in trauma patients for the future. However, there are also some limitations in this study. The duration of pre-hospital rescue is uncertain, and observation and intervention are short for most of the time. There are many factors that affect the body temperature of trauma patients, and the measurement tools and sites may affect the results to a certain extent. In future studies, we will track the intervention time, unify the temperature measurement tools and sites, and address the identified issues in the implementation process at the same time, to provide empirical evidence for medical staff to prevent hypothermia in the pre-hospital setting.

Disclosure of conflict of interest

None.

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