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A Study on the Management of Sedation and Analgesia in ICU Patients Based on Fault Tree Analysis and the eCASH Concept

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Abstract: *Objective*: To investigate the efficacy of combining fault tree analysis with the eCASH (early Comfort using Analgesia, Sedation, and delirium monitoring) concept in the management of sedation and analgesia for ICU patients. *Methods*: A total of 90 patients admitted to the ICU of a certain hospital between January and December 2025 who required sedation and analgesia were selected as subjects. Using a random number table, they were divided into a control group and an observation group, comprising 45 patients each. The control group received conventional sedation and analgesia nursing management, whilst the observation group was managed using fault tree theory combined with the eCASH concept. Indicators such as RASS scores for sedation levels, pain intensity (NRS and FPS-R scores), and PSQI scores for sleep quality were compared between the two groups before and after intervention. *Results*: Compared with pre-intervention levels, RASS, NRS, FPS-R and PSQI scores were significantly reduced in both groups; however, the observation group showed lower scores than the control group, with statistically significant differences ($p < 0.05$). *Conclusion*: The application of fault tree theory combined with the eCASH concept in the management of sedation and analgesia for ICU patients can effectively standardise the management process and improve the efficacy of sedation and analgesia, and is worthy of clinical promotion and application.

Keywords: Fault tree analysis; eCASH concept; ICU; Sedation and analgesia; Nursing management; Prognosis

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1. Introduction

Sedation and analgesia management is a critical component of intensive care unit (ICU) treatment, directly influencing patient comfort, safety, and clinical outcomes. Inadequate management may lead to delirium, prolonged mechanical ventilation, increased length of stay, and impaired recovery. The eCASH (early Comfort using Analgesia, Sedation, and delirium monitoring) concept emphasizes early, patient-centered comfort with minimal sedation, while fault tree analysis offers a systematic, logic-based approach to identifying and mitigating risks in complex

clinical processes. However, the combined application of these two strategies in ICU sedation and analgesia management remains underexplored. This study aims to evaluate the efficacy of integrating fault tree analysis with the eCASH concept in improving sedation and analgesia outcomes among ICU patients.

2. Materials and methods

2.1. General information

A total of 90 patients admitted to the ICU of a certain hospital between January and December 2025 were selected as subjects. Using a random number table, the 90 patients were divided into a control group and an observation group, comprising 45 patients each. In the control group, there were 25 males and 20 females; ages ranged from 22 to 78 years, with a mean age of (56.32 ± 10.25) years; disease types included 15 cases of severe trauma, 12 cases of severe pneumonia, 10 cases of postoperative monitoring, and 8 other cases. In the observation group, there were 24 males and 21 females; aged 23–79 years, with a mean age of (57.14 ± 10.31) years; disease types: severe trauma (14 cases), severe pneumonia (13 cases), postoperative care (9 cases), and other conditions (9 cases). Comparison of general characteristics, including gender, age and disease type, between the two groups revealed no statistically significant differences ($p > 0.05$), indicating comparability.

2.1.1. Inclusion criteria

(1) Length of stay in the ICU ≥ 72 hours, requiring sedation and analgesia;
(2) Age ≥ 18 years and ≤ 80 years;
(3) Alert and oriented, or able to cooperate with relevant assessments following sedation (non-verbal assessment tools were used for those unable to cooperate);
(4) Informed consent from the patient and their family, with voluntary participation in the study;
(5) No history of severe hepatic or renal insufficiency, coagulation disorders, psychiatric disorders, or allergy to sedative-analgesic drugs.

2.1.2. Exclusion criteria

(1) Length of stay in the ICU < 72 hours
(2) Age < 18 or > 80 years;
(3) Presence of severe cognitive impairment or psychiatric disorders rendering the patient unable to cooperate with assessments;
(4) History of allergy to sedative-analgesic drugs, severe hepatic or renal failure, or coagulation disorders;
(5) Transfer to another hospital, withdrawal from the study, or death during the study period.

2.2. Methods

Patients in both groups received standard ICU care, including basic treatments such as antimicrobial therapy, fluid resuscitation, nutritional support and organ function protection. Appropriate sedative-analgesic medications were selected according to the patient's clinical condition, with dosages dynamically adjusted based on the achieved level of sedation and analgesia.

2.2.1. Control group

Received routine nursing care and sedation and analgesia management. The designated nurse in charge provided health education and sedation and analgesia interventions during the patient's hospital stay and prior to discharge. Based on their clinical experience, the nurse assessed the effectiveness of sedation and analgesia using standard evaluation methods and adjusted drug doses as required; simultaneously, basic nursing care such as oral care, skin care, and turning and back-patting was carried out in accordance with standard ICU nursing procedures, with attention paid to the patient's sleep patterns and the provision of sleep-aid measures where necessary.

2.2.2. Observation group

Managed using a combination of fault tree analysis and the eCASH framework, with the specific implementation steps as follows:

(1) Formation of a dedicated management team

A dedicated management team was established comprising the Head of the ICU, the Head Nurse, Senior Nurses, Charge Nurses and Clinical Pharmacists. A one-week specialized training programmed was conducted, covering the fundamentals of fault tree analysis, the core principles of the eCASH framework, the use of sedation and analgesia assessment tools, relevant guidelines and standards, and management procedures.

(2) Investigation and analysis of existing issues

The dedicated management team conducted a comprehensive review of all patient sedation and analgesia assessment forms, nursing records, medical records and medical orders. Referencing relevant guidelines such as the 'Chinese Guidelines for Analgesia and Sedation in Adult ICUs (2021 Edition)' and the 'Expert Consensus on Pain Assessment and Analgesic Treatment for Critically Ill Patients', they drafted the 'Questionnaire on Sedation-Related Issues for ICU Nurses' and administered it to all charge nurses in the ICU [1]. The questionnaire covered four dimensions, self-assessment of sedation efficacy, medication monitoring capabilities, accuracy of sedation assessment, and standardization of sedation care—comprising a total of 25 items. A 5-point Likert scale (1–5, where 1 indicates 'completely non-proficient' and 5 indicates 'completely proficient') was employed to comprehensively identify issues in the management of sedation and analgesia within the ICU.

(3) Analysis of root causes based on fault tree theory

Taking 'adverse events in ICU sedation and analgesia management' as the top event (including inappropriate sedation, poor pain control, and the occurrence of delirium), and combining this with the results of the preliminary survey, this study identified the direct and indirect causes of the top event and constructed a fault tree for ICU sedation and analgesia management (**Figure 1**). Direct causes included: inaccurate nursing assessments, non-standardized sedation and analgesia management objectives and processes, and inadequate implementation of sedation and analgesia nursing measures; indirect causes included: lack of standardized assessment tools, incorrect assessment frequency, inaccurate assessment methods, inconsistent management objectives, non-standardized management processes, inadequate implementation of bundled care measures, and inadequate medication management.

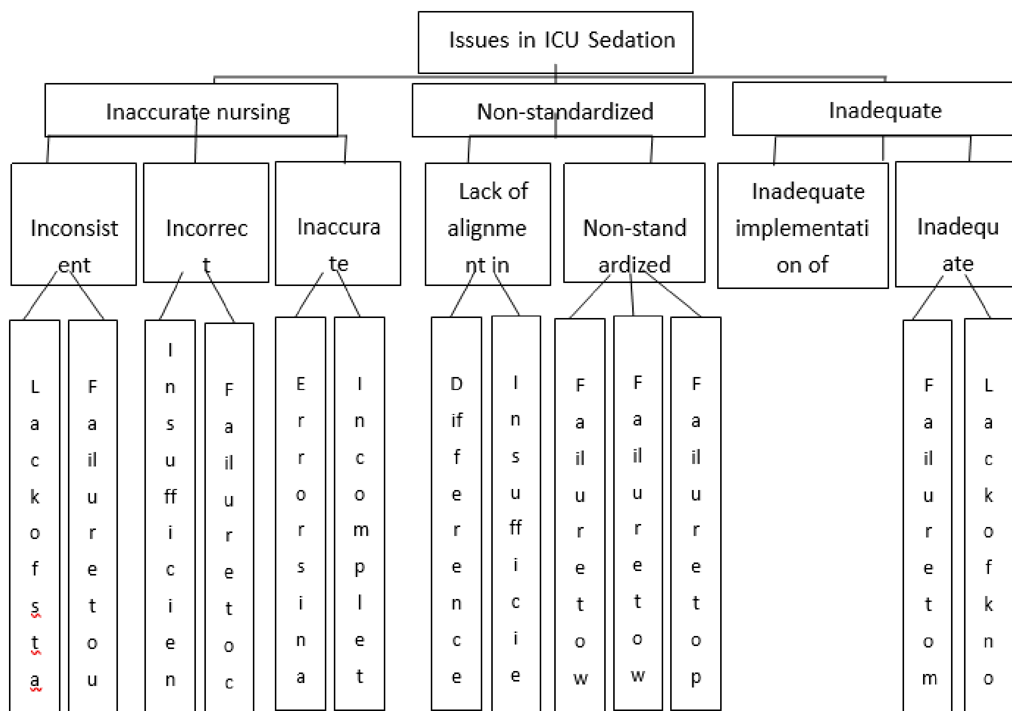

Figure 1. Fault tree for sedation and analgesia management in the ICU.

(4) Formulation and implementation of management strategies based on the eCASH concept

Through fault tree analysis, the logical relationships between events at various levels were clarified, and weaknesses in management were identified. Guided by these findings and in conjunction with the core requirements of the eCASH concept—'early comfort, individualized sedation and analgesia, enhanced delirium monitoring, and promotion of early patient mobilization'—targeted ICU sedation and analgesia management strategies were formulated and implemented, as detailed below: ① Standardized assessment tools and methods: All nursing staff shall use standardized assessment tools. Sedation levels shall be assessed using the Richmond Agitation-Sedation Scale (RASS); pain levels shall be assessed using the Numeric Rating Scale (NRS) and the Chinese Revised Adult Nonverbal Pain Scale (NVPS-R).Assessments are conducted at fixed intervals of once every 1–2 hours; for patients with unstable conditions or inadequate sedation and analgesia, the assessment interval is reduced to once every 30 minutes to 1 hour. ② Implementation of precise sedation and analgesia monitoring and intervention: Strictly adhering to the precise sedation targets of the eCASH concept, with 'optimal light sedation' (RASS score 0–2) as the core objective, and developing individualized sedation and analgesia plans based on the patient's specific condition. Clinical pharmacists guide nurses in the appropriate selection of sedative-analgesic drugs and initial dosages based on the patient's age, weight, disease severity, and hepatic and renal function; if the patient's NRS score is > 4, FPS-R score is > 3, or RASS score is >2 (insufficient sedation), promptly increase the dosage of sedative-analgesic drugs; If a patient's RASS score is < -3 (excessive sedation), promptly reduce the drug dose (by no more than 1–2 ml per hour per reduction) until the desired control target is achieved. For patients whose scores remain below the standard after multiple dose adjustments, conduct a comprehensive assessment to rule out irreversible factors such as severe infection or organ failure, and report to the doctor for investigation of the cause and targeted management. □ Strengthen

training and assessment on sedation and analgesia: In response to the issue of ‘insufficient professional competence among nurses’ identified by the fault tree analysis, develop a systematic training plan. Led by the clinical team and teaching supervisors, conduct regular training on theoretical knowledge and practical skills related to sedation and analgesia. Content should include: the pharmacological effects of sedative and analgesic drugs, methods of administration, management of adverse reactions, correct use of assessment tools, core concepts of the eCASH framework, and relevant guidelines and standards [2]. Following the training, assessments of theoretical knowledge and practical skills will be conducted. Only those who pass the assessment will be permitted to participate in sedation and analgesia nursing duties; those who fail will be suspended from work and required to undergo further intensive training, followed by a re-assessment, until they pass. ④ Optimizing sedation and analgesia nursing interventions: Comprehensive sedation and analgesia nursing interventions are implemented in accordance with the ‘comfort-oriented care’ requirements of the eCASH concept. Basic care: Perform warm sponge baths twice daily, oral care twice daily, and repositioning with back tapping (once every two hours) to keep the skin clean and dry, and prevent complications such as pressure ulcers and oral infections; Sleep care: Dim the lights in the ward and draw the curtains at set times to simulate a normal circadian rhythm, helping patients develop regular sleep patterns; Communication care: For patients unable to express themselves verbally, special identification cards are created to guide patients in communicating their wishes through gestures or the cards, ensuring their needs are met promptly. ⑤ Establish a quality tracking and continuous improvement mechanism: Drawing on the eCASH framework and the results of fault tree analysis, develop the ‘Intensive Care Unit Precision Sedation Quality Tracking Form’. Analyze the causes of issues identified in the checklist, formulate improvement measures, specify deadlines and assign responsibility. Following the implementation of these measures, conduct follow-up inspections to establish a closed-loop management cycle of ‘investigation–analysis–improvement–follow-up’.

2.3. Observation indicators

(1) Level of sedation

The RASS score was used to assess the level of sedation in both groups of patients prior to management and 7 days after management. The RASS score ranges from -5 to +4; a higher score indicates a shallower level of sedation. Specifically, -5 indicates unresponsiveness, -4 indicates deep sedation, -3 indicates moderate sedation, -2 to 0 indicates light sedation (optimal sedation state), and +1 to +4 indicates agitation.

(2) Pain intensity

The Numeric Rating Scale (NRS) and the revise

Facial Pain Scale-Revised (FPS-R) to assess pain levels in both groups of patients before treatment and 7 days after treatment. The NRS score ranges from 0 to 10, where 0 indicates no pain, 1–3 indicates mild pain, 4–6 indicates moderate pain, and 7–10 indicates severe pain; a higher score indicates more intense pain. The FPS-R score is assessed using six facial expression symbols, with a score range of 0–10; a higher score indicates more intense pain.

(3) Sleep quality

The Pittsburgh Sleep Quality Index (PSQI) was used to assess sleep quality in both groups before management and 7 days after management. This scale comprises five dimensions: sleep quality, time to sleep, sleep duration, sleep efficiency, and sleep disturbances. Each dimension is scored on a scale of 0–3, with a

total score ranging from 0 to 15; a lower score indicates better sleep quality.

2.4. Statistical analysis

Data analysis was performed using SPSS 26.0 statistical software. Continuous variables are expressed as mean ± standard deviation ($\bar{x}$ ± s). Paired *t*-tests were used for comparisons within groups, and independent samples t-tests were used for comparisons between groups. Categorical variables are expressed as frequency (percentage) [n (%)], and chi-square (χ^2) tests were used for comparisons between groups. A *p*-value of < 0.05 was considered statistically significant.

3. Results

3.1. Comparison of RASS scores between the two groups

Compared with pre-intervention levels, RASS scores in both groups decreased significantly, with the observation group scoring lower than the control group, and the difference was statistically significant ($p < 0.05$). See **Table 1**.

Table 1. Comparison of RASS scores between the two groups before and after intervention ($\bar{x}$ ± s, points)

Group	Before intervention	After intervention	t	p
Control group (n = 45)	2.54 ± 0.62	1.22 ± 0.48	11.293	< 0.001
Observation group (n = 45)	2.52 ± 0.59	0.71 ± 0.23	19.174	< 0.001
t	0.157	6.428		
p	0.876	< 0.001		

3.2. Comparison of sleep quality scores between the two groups

Following scientific nursing management, all sleep quality scores in the observation group were significantly lower than those in the control group, with the differences being statistically significant ($p < 0.05$), as shown in **Table 2**.

Table 2. Comparison of sleep quality scores between the two groups ($\bar{x}$ ± s, points)

Group	Sleep quality	Time to fall asleep	Sleep duration	Sleep efficiency	Sleep disorders
Control group (n = 45)	1.45 ± 0.49	1.24 ± 0.37	1.26 ± 0.35	1.34 ± 0.35	1.42 ± 0.53
Observation group (n = 45)	1.03 ± 0.37	0.82 ± 0.19	0.64 ± 0.22	1.03 ± 0.31	1.01 ± 0.35
t	4.589	6.774	10.061	4.448	4.330
p	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

3.3. Comparison of pain status between the two groups before and after management

Prior to management, there was no statistically significant difference in NRS and FPS-R scores between the two groups ($p > 0.05$); following systematic management, NRS and FPS-R scores decreased significantly in both groups, with the observation group showing lower scores than the control group, and the difference was statistically significant ($p < 0.05$), as shown in **Table 3**.

Table 3. Comparison of pain status between the two groups of patients ($\overline{x} \pm s$, points)

Group	NRS				FPS-R			
	Before management	Before management	t	p	Before management	After management	t	p
Control group (n = 45)	5.32 ± 1.39	4.11 ± 1.14	4.515	< 0.001	5.41 ± 1.37	3.42 ± 1.25	7.198	< 0.001
Observation group (n = 45)	5.28 ± 1.35	3.05 ± 1.04	8.778	< 0.001	5.39 ± 1.42	2.05 ± 1.03	12.772	< 0.001
t	1.139	1.609			0.068	5.674		
p	0.890	< 0.001			0.946	< 0.001		

4. Discussion

Many ICU patients require sedation and analgesia due to severe trauma, critical infections, or major surgery; however, current routine clinical management of sedation and analgesia largely relies on nurses' clinical experience. This approach suffers from issues such as inconsistent assessment criteria, non-standardized procedures, and inadequate interventions, resulting in suboptimal outcomes [3]. Therefore, exploring a scientific and efficient management model for sedation and analgesia in the ICU, optimizing management processes, and improving management quality holds significant clinical importance.

Fault tree analysis is a systematic safety analysis method. By establishing logical relationships between top-level events (adverse events) and causal events at various levels, it clearly identifies the root causes of adverse events and weaknesses in management, thereby providing a scientific basis for formulating targeted improvement measures. The eCASH concept is a novel approach to sedation and analgesia management for critically ill patients proposed in recent years. Its core principles are 'early comfort, individualized sedation and analgesia, enhanced delirium monitoring, and promotion of early patient mobilization'. It emphasizes a patient-centered approach, aiming to achieve optimized sedation and analgesia management through precise assessment, individualized intervention and continuous monitoring, thereby reducing the incidence of adverse events [4]. This study attempts to integrate fault tree analysis with the eCASH concept to achieve a closed-loop management system comprising "precise problem identification–systematic root cause analysis–scientific strategy formulation–continuous quality improvement". The aim is to address the shortcomings of conventional management models and enhance the scientific rigor and standardization of sedation and analgesia management in the ICU.

The results showed that following the implementation of the management strategy, the RASS, NRS, FPS-R and PSQI scores of patients in the observation group were significantly lower than those in the control group, with statistically significant differences ($p < 0.05$). This indicates that the combination of fault tree theory and the eCASH concept can effectively improve the efficacy of sedation and analgesia in ICU patients, alleviate pain and enhance sleep quality. The reasons for this are as follows:

(1) Problem analysis based on fault tree theory enables the precise identification of core issues in ICU sedation and analgesia management, such as 'inaccurate assessment, non-standardized procedures, and inadequate nursing measures', providing clear guidance for the formulation of management strategies and avoiding blind intervention;

(2) The standardization of sedation and analgesia assessment tools and methods effectively improves the accuracy and timeliness of assessment results, providing a reliable basis for the precise adjustment of sedation and analgesic drug doses [5];

(3) The development of individualized sedation and analgesia plans in accordance with the eCASH concept enables dynamic adjustment of drug dosages with the aim of achieving optimal light sedation, thereby preventing both oversedation and undersedation and significantly enhancing the safety and efficacy of sedation and analgesia treatment.

5. Conclusion

In summary, the management of sedation and analgesia in ICU patients based on a combination of fault tree theory and the eCASH concept has yielded favorable results. It effectively standardizes the management process, improves the accuracy of sedation and analgesia assessments and the compliance rate with procedural standards, optimizes the effects of sedation and analgesia, alleviates patient pain, improves sleep quality, and enhances patient prognosis. It is therefore worthy of widespread clinical application.

Disclosure statement

The authors declare no conflict of interest.

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